Towards Estimating the Social and Environmental Costs of Transportation in Canada

A report for Transport Canada

by

Anming Zhang (Project Director), Anthony E. Boardman,
David Gillen and W.G. Waters II

In collaboration with Diane Forbes, Heng Ju, Alice Owen,
Markus von Wartburg, Steve Yong, and Andrew Yuen

Centre for Transportation Studies
Sauder School of Business
The University of British Columbia
2053 Main Mall
Vancouver BC V6T 1Z2
Canada

August 2004
Revision November 2004
Revision to Sections 6.5, 6.7, 7.6 March 2005

Towards Estimating the Social and Environmental Costs of Transportation in Canada

A report for Transport Canada

Authors:

Anming Zhang (Project Director), Anthony E. Boardman,
David Gillen and W.G. Waters II

In collaboration with Diane Forbes, Heng Ju, Alice Owen, Markus von Wartburg, Steve Yong, and Andrew Yuen.

Specific chapters were authored primarily by:
Chapter 1 – W.G.Waters II, David Gillen, Alice Owen and Anming Zhang
Chapter 2 – Markus von Wartburg and W.G. Waters II
Chapter 3 – Anthony E. Boardman and Steve Yong
Chapter 4 – Diane Forbes and Anthony E. Boardman
Chapter 5 – David Gillen
Chapter 6 – Anming Zhang and Andrew Yuen
Chapter 7 – Heng Ju, Andrew Yuen and Anming Zhang

Additional research assistance was supplied by Li Chen, Kate Foreman, Carl Ruest, Victor Ortiz, Qing Wu, and Li Yu.

Centre for Transportation Studies
Sauder School of Business
The University of British Columbia
2053 Main Mall
Vancouver BC V6T 1Z2
Canada
Phone (604) 822-4510
Fax (604) 822-4977

August 2004
Revision November 2004
Revision to Sections 6.5, 6.7, 7.6 March 2005

Table of Contents

List of Tables

List of Figures

Abbreviations

AAR: Association of American Railroads
AIS: Abbreviated Injury Scale
APO: Office of Aviation Policy and Plans
AQVM: Air Quality Valuation Model
ASC: Average Social Costs
AU$: Australian Dollar
BC: British Columbia
BLS: Bureau of Labour Statistics
BTRE: Bureau of Transport and Regional Economics (Australia)
CA: Conjoint Analysis
CAAA: Clean Air Act Amendments
CASM: Cost per Available Seat Mile
CAD: Canadian Dollar (CAD, C$, and $C all used in the text)
CBA: Cost Benefit Analysis
CDS: Crashworthiness Data System
CE: Choice Experiments
CFC: Chlorofluorocarbon
CO: Carbon Monoxide
COI: Cost of Injuries
CPI: Consumer Price Index
CVM: Contingent Valuation Method
CV: Compensating Variation
DALY: Disability Adjusted Life Years
DOT: Department of Transportation (US), Department of Transport (UK)
ECU: European Currency Unit
ECMT: European Conference of Ministers of Transport
EPA: Environmental Protection Agency, USA
ERF: Exposure Response Functions
EU: European Union
EV: Equivalent Variation
FAA: Federal Aviation Administration
FARS: Fatal Analysis Reporting System
FF: French Franc (currency)
FUND: Climate Framework for Uncertainty, Negotiation and Distribution
FHWA: Federal Highway Administration
GDP: Gross Domestic Product
GNP: Gross National Product
GES: General Estimates System
GHG: Greenhouse Gas
GRT: Gross Registered Tonnage
HA: Highly Annoyed
HC: Human Capital
HCFC: Hydro Chlorofluorocarbon

HP: Hedonic Pricing
ICAO: International Civil Aviation Organization
IPCC: Intergovernmental Panel on Climate Change
MAE: Multiple Account Evaluation
MAIS: Maximum Abbreviated Injury Scale
NAAQO: National Ambient Air Quality Objectives
NASS: National Accident Sampling System
NHIS: National Health Interview Survey
NHTSA: National Highway Traffic Safety Administration
NTSB: National Transportation Safety Board
NDI: Noise Depreciation Index
NEF: Noise Exposure Forecast
NIOSH: National Institute for Occupational Safety and Health
NPV: Net Present Value
NPTS: Nationwide Personal Transportation Study
NOK: Norway Kroner (currency)
NOx: Nitrogen Oxides
NSW: New South Wales
NZ$: New Zealand Dollar
ODS: Ozone Depleting Substance
ODP: Ozone Depletion Potential
OF: Open Framework
OLS: Ordinary Least Squares
OST: Office of the Secretary of Transportation (US)
PM: Particulate Matter
PPP: Purchasing Power Parity
QALY: Quality-Adjusted Life Year
QOL: Quality of Life
RAD: Restricted Activity Day
RCNPT: Royal Commission on National Passenger Transportation
RP: Revealed Preference
S.A.A.Q.: Société de l'assurance automobile du Québec
SCBA: Social Cost Benefit Analysis
SEK: Sweden Kronor (currency)
SIC: Standard Industry Classification
SO_x: Sulphur Oxides
SP: Stated Preference
SRTP: Social Rate of Time Preference
TSB: Transportation Safety Board
TRRL Transport and Road Research Laboratory (UK)
UCD: University of California, Davis
UK£: United Kingdom Pound Sterling (currency)
VATT: Value of Air Travel Time
VBTT: Value of Business Travel Time
VMT: Vehicle-Mile Traveled
VSI: Value of Statistical Injury

VSL: Value of Statistical Life
VOLY: Value of Life Year
VOT: Value of Time
VOR: Value of Reliability
VTTS: Valuation of Travel Time Savings
VFTTS: Valuation of Freight Travel Time Savings
WTA: Willingness to Accept
WTP: Willingness to Pay

Executive Summary

Towards Estimating the Social and Environmental Costs of Transportation in Canada

A Report for Transport Canada

by

Anming Zhang (Project Director), Anthony E. Boardman, David Gillen and W.G. Waters II

In collaboration with
Diane Forbes, Heng Ju, Alice Owen, Markus von Wartburg, Steve Yong, and Andrew Yuen.

This report explores the main methods of estimating social and environmental costs of transportation. This is an input to Transport Canada's ongoing effort to estimate the full costs of various transportation modes, i.e., both the full costs provided and borne by transportation users, and the social or external costs imposed on society at large.

There are many cost components of the full social costs of transportation. A substantial portion of these cost components are recognized and borne by transportation users, such as the costs of vehicles and their operation. Some costs are subjective but still recognized and borne by users, such as the time and effort expended by automobile drivers. Some costs are imposed on society at large, such as the costs of air pollution and contributions to global warming. Some costs are borne partly by users and partly by society, such as the costs of motor vehicle crashes.

This report is confined to the externality costs. Based on evidence and experience elsewhere, this report develops externality cost estimates, in 2002 Canadian dollars, across a range of inter and intra urban transportation modes, both passenger and freight.

Externalities are costs or benefits arising from an economic activity that affect somebody other than the people engaged in the economic activity and are not reflected fully in prices. An externality induces a divergence between social cost and private cost. The concern is that market participants only consider the personal benefits and costs in making their decisions; but if externalities are present, then market outcomes (the aggregate of individual decisions) will not be socially optimal.

An investigation of the full costs of transportation can be done for two separate but overlapping purposes. One is a desire to measure the full costs (including environmental costs) of modes to compare them with the proportion of total costs that are borne by users. This reveals the implicit level of subsidy and how it differs across modes. For this purpose an average cost concept is adequate; the average cost estimate is multiplied by total output to arrive at a total cost estimate. Note that it is possible that some portion of the average cost estimate would be recognized and borne by the users while some proportion would be borne by society at large.

A second purpose of measuring the full social costs of transport is to identify what policy actions such as pricing or regulatory policy would bring about a more efficient use of transportation and mix of transport modes. For this a marginal cost concept is required, i.e., the incremental externality cost associated with the current level of transport output (which will differ among localities, e.g., such as the degree of road congestion in a community). Note that if the marginal costs are rising – which is often thought to characterize transportation externalities – then it would be incorrect to multiply the marginal cost times total output to estimate the total costs. That would be an overestimate. Much of the literature overlooks this subtlety in estimating total costs of pollution or other externalities. The relationship between average and marginal externality costs are well recognized for road congestion, but the distinction is less clear for other externality categories.

In addition to developing estimates of the unit costs (average or marginal) of major externality categories, the review sought to identify what portion of potential externality costs were borne by transportation users. This is clear-cut for some categories such as congestion delays which are borne entirely by users, and any climate change effects which would be borne by the world at large rather than by transport users. But what is internalized or external is less clear for accident costs for example.

Five externality categories are examined in this report:

Chapter 2: congestion and the value of travel time;

Chapters 3 and 4: the valuation of life and accident costs;

Chapter 5: noise costs;

Chapter 6: the costs of air pollution; and

Chapter 7: the costs of greenhouse gases.

There are some additional externality categories that were less important and not reviewed. These include: water pollution; vibration damage to structures adjacent to transportation facilities; visual intrusion, i.e., transport facilities or operation may interfere with people's ability to enjoy their surroundings and scenery; 'barrier effects' such as the social and community disruption caused by transport facilities; security risks, i.e., risks posed to the public at large from possible terrorist acts; and situations where market prices in other sectors do not reflect the underlying marginal costs and transport activities could exacerbate these economic distortions, i.e., 'second-best' issues.

Each of the chapters are summarised below.

Chapter 1: Introductory Chapter

Chapter 2: Congestion Externalities and the Value of Travel Time Savings

Some of the most significant social costs of many transport operations are those associated with congestion. This is a classic example of externalities: users recognize that travel times and costs are higher under congestion, but individuals only recognize the costs they themselves incur and do not recognize the delay costs they impose on others. The full marginal social cost of a decision to operate on a congested system is greater than the costs recognized by an individual operator. It is an intra-sectoral externality in that the total costs of delay are borne collectively by transport users and not imposed directly on the rest of society, but it is an externality nonetheless.

To measure the costs of congestion involves two components:

1. measuring the amount of delays borne individually and collectively by transportation users; and
2. estimating the value users place on these delays, i.e., the valuation of time delays or time savings.

We address the latter first.

The valuation of travel time savings

Both theoretical argument and empirical evidence confirm that people do place a value on time delays or time savings, usually referred to as the value of travel time savings (VTTS). There is extensive literature on VTTS, primarily from road transport. The latter literature dominates our review but we include what materials we can find on VTTS for other modes and for freight transport.

Early conceptual literature linked VTTS to wage rates via the tradeoff between leisure time and working. But the relevant concept for VTTS is the valuation of time (delays) for specific activities, such as commuting to work or time required for delivery of freight. The conceptual literature is reviewed and summarized briefly because the main emphasis is on reviewing empirical estimates of VTTS.

Empirical estimates of VTTS are in two primary categories: (1) revealed preference (RP) studies that infer time tradeoff valuations from behavioural choices, such as choice of faster or slower routes at different costs, or choice of travel modes involving differences in price; and (2) stated preference (SP) or questionnaire-based methods that get people to indicate their preferences between time savings and other attributes including the price of travel. Some recent studies have been able to combine both methods for the same population.

There have been a number of thorough literature reviews that are drawn on for this review. We summarise the state of the literature circa 1990s from these previous reviews, and then examine more recent contributions. There are some significant improvements in valuation methods and refinements in understanding factors that underlie VTTS.

One caveat to note is that the literature on VTTS has been dominated by developing estimates for investment appraisal of transport projects. An improved road or transport facility will benefit all users. It does not matter too much if those users have different VTTS, an average VTTS is adequate to estimate total time saving benefits. But in focusing on divergences between private and social costs and the prospect of pricing/taxation to correct these divergences, it matters if there is a skewed distribution of VTTS (e.g., if a few have high VTTS balancing a larger number with low VTTS), or if large and small time savings are valued the same. Regrettably, the existing literature has not looked closely at the underlying distribution of VTTS and other valuation attributes. Congestion pricing requires more information about users' VTTS than is adequate for investment appraisal.

A summary of VTTS findings are as follows:

An overall average or base VTTS would be 50% of the average wage rate. However, assuming a constant value of time is not appropriate unless one has to rely on the thinnest data on the composition of traffic. We propose the following segmentation and adjustments to the value of travel time savings:

- No distinction based on trip purpose for non-work related journeys should be made and travel time savings on leisure and commuting trips should both be valued at 50% of the average wage rate.
- Travel time savings on business trips should be valued at the gross wage plus labor related overheads.
- The value of travel time savings varies with income and income elasticity of 0.75 reflects the current state of the evidence. Additionally, VTTS varies with distance and a positive distance elasticity of 0.3 is appropriate. Income and distance are the two most important sources of variation across studies, regions and modes.
- No adjustment across different modes apart from accounting for differences in socio-economic characteristics of travelers (e.g. income, trip-purpose) or of the trip (distance, wait times).
- Small travel time savings should be valued the same per unit as for large travel time savings, and travel savings and travel losses should be valued symmetrically (although where one is predicting behavioural responses to changes in prices or other public policies, it may be necessary to examine more carefully transport users' reaction to small time savings or delays).
- Travel time savings in congested traffic should be valued at twice the rate in uncongested traffic.

- A weighting factor of two for walking time and two-and-a-half for waiting time relative to in-vehicle time is consistent with recent evidence.
- Recent evidence has shown that travel time reliability is a substantial part of travel time savings. Without any further knowledge on how reliability varies with the level of congestion on the road it is impossible to make any recommendations although our belief is that incorporating reliability is crucial.
- Special attention should be paid to the fact that all VTTS values and all proposed adjustments are averages. There is some evidence that the VTTS-distribution over the population is right-skewed (a few people have very high values while the majority has quite low values). While this might not matter much for investment appraisal, behavioral changes to the imposition of a congestion toll will depend on the VTTS-distribution and the impact on traffic volumes of road pricing may be larger than would be predicted using a constant VTTS.

The evidence on the valuation of freight travel time savings (VFTTS) is sparse and of wider variance than estimates of passenger VTTS. VFTTS will vary with the type of goods shipped and other characteristics such as urgency of shipment. But the variety of goods with different attributes is immense. There is growing evidence that the most important aspect of freight travel time is not the reduction in travel time per se, but the increased reliability of delivery/schedule time. Studies show that the values for reliability and schedule delay exceed the values for freight time savings possibly multiple times. Reasonable estimates of the mean VFTTS for road transport mode would range from $45-$200 per shipment. If it is possible to control for the variability of travel times, appropriate mean values of freight travel time per se are at the lower end of the range. Developing improved estimates of VFTTS should be a research priority.

Estimating Congestion Delays

The pattern of congestion delays is traditionally shown as a relationship between travel times and traffic volumes relative to capacity of the facility. This is illustrated in the standard diagrams to illustrate the concept of congestion pricing. In Figure E1 (Figure 2.10.1.4 in Chapter 2), automobile users recognize the rising unit costs they face as traffic volumes increase, labeled MPC for marginal private costs. For this illustration, we assume all cars and drivers have the same operating costs and VTTS, respectively, shown as generalized cost (time and money costs combined). MPC is also the average social cost, i.e., the cost recognized and borne by all users. But incremental users not only increase their own costs of driving, they cause the costs of others to increase too. This is indicated by the marginal social costs MSC, which can be calculated by the elasticity or rate of rise of the MPC as traffic volumes increase (the MSC is the unit rise in MPC or ASC multiplied by traffic volume).

The demand for travel (expressed as generalized price, i.e., time and money costs combined) is shown. As is well known, allowing people to choose whether or not to drive results in traffic volume V1, where privately perceived cost MPC is equated to demand. MSC is greater than MPC, that is, the marginal social costs beyond V2 exceed the collective valuation of the road indicated by the area beneath the demand curve. Correcting the externality via a congestion tax equal to the divergence between MPC and MSC results in the optimal level of congestion at volume V2. Figure E1 is complicated if the VTTS is heterogeneous, but the modeling of congestion is relatively straight-forward.

However, many believe that congestion is more complex than the standard speed-flow figure above. In networks, congestion often arises as bottlenecks and dynamic queuing. This approach to congestion modeling is reviewed. If this characterization of congestion is more relevant than the standard speed-flow relationships, the implication is that the marginal impacts of additional vehicles is more complicated than in Figure E1. The incremental delay depends on the location and timing of when vehicles enter and leave the network, and the overall level of congestion prevailing at any point and moment of time. In order to estimate both the marginal and total costs of congestion, it is necessary to develop models of congestion representative of diverse network sizes and configurations. This is an important topic for research. Congestion pricing is more difficult to formulate accurately than has been commonly suggested.

Measuring the social costs of congestion

Part of Transport Canada's aim is to be able to identify what portion of costs are borne by users and what portion are borne by society at large. Congestion delays do not fit this schematic well because the total delay costs are borne by users, but externalities are still involved intra-sectorally. We are unsure of how to measure the social costs of congestion in these circumstances.

The traditional way to measure total congestion costs is to compare the observed costs including congestion relative to free-flow conditions. In Figure E1, this would be measured by MPC (= ASC) at volume V1 (indicated as OA) compared to the minimum MPC (indicated by OF), times V1, or area ABDF. This is a valid calculation but it is misleading, because the alternative is not zero congestion but some lower level.

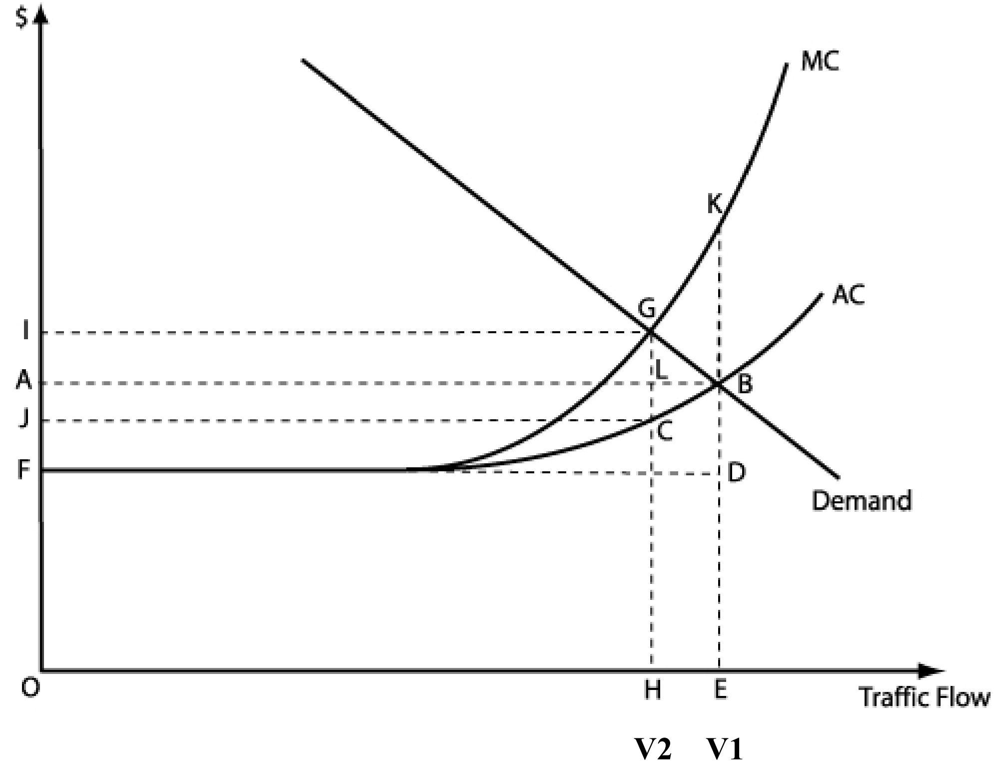


Figure E1: The Costs of Congestion
(generalised price and cost, i.e., time expressed in monetary equivalents)

Another approach would be to calculate the extra costs of congestion relative to the optimal level of congestion, i.e., the level that would accompany pricing at MSC or volume V2. This can be calculated as the difference between the two measures of total costs (ABEO – JCHO), or by the area beneath the MSC curve HGKE. Also note that the position and shape of MPC and MSC reflect the level of road investment. The area HGKE would be less than the traditional calculation of total congestion costs.

But the incremental congestion costs HGKE overlook that there are some economic benefits associated with the increased congestion, indicated by the area beneath the demand curve HGBE. The net cost of inefficient congestion as measured by economic concepts would be the deadweight loss triangle GKB, a measure of loss far below what most people think is the measure of congestion costs.

In sum, despite the fact that the total delay costs are borne by transportation users, there is an externality cost to society at large although it is borne by users as non-optimally high congestion costs. This is measured by the standard welfare economics measure of deadweight loss, GKB in Figure E1, as noted, a figure much smaller than most would calculate as the measure of congestion costs.

Chapter 3: The Value of Statistical Life

Accident or crash costs are a regrettable part of transportation operations. We seek to minimize their occurrence, but accidents cannot be eliminated completely. The loss of human life is the largest cost component of accident costs, and also the ultimate cost of air pollutants. Because resources are finite, it is necessary to arrive at measures of society's willingness to forego other output in order to reduce the loss of life. This is termed "the value of a statistical life" (VSL). Because the literature is so extensive, this topic warranted its own chapter. The conclusions from this chapter are then used for examining those externalities that pose risks to life.

Valuing life is a contentious subject. The value of a statistical life (VSL) is one of the most frequently researched topics in policy analysis and has been the subject of a number of recent reviews and meta-analyses. Despite this research, recent estimates still vary widely from 2002 C$ 1 million to 2002 C$ 33 million.

Early methods to estimate the value of life were based on a person's foregone earnings. Earnings provide a measure of the value of a person's lost output, but it does not reflect an individual's willingness to pay to reduce his or her own death. Nor does it distinguish between the deaths of identifiable individuals and statistical deaths. A safety improvement to a highway, for example, does not lead to the saving of the lives of a few individuals who can be identified *ex ante*, but rather to the reduction in the risk of death (or injury) to all users of the highway. In order to value the benefit of proposed safety improvements, analysts should ascertain how much people are willing to pay for reductions in their risk of death that are of the same order of magnitude as the reduced risk that would result from the proposed safety improvements. The VSL is calculated as:

$$V(\text{life}) = \text{WTP}/\text{reduction in risk}$$

Three important conceptual issues/problems are associated with estimating the VSL*:*

1. Studies measure the WTP for small changes in the probability of living (or dying) and extrapolate to impute a valuation per life.
2. The VSL depends on the level of risk—the higher the risk, the higher the VSL. Since some models of transportation are safer than others (e.g. air is safer than road, per mile), a strong case can be made that the VSL on some (safer) modes would be less than the VSL on other modes.
3. Safety is a normal good. Consequently, the VSL in a rich country is higher than in a poor country. Furthermore, one can argue that there are within-country differences in the VSL based on income. However, ethical and practical reasons may make governments reluctant to assign different VSL to different groups, regions and projects. One implication of the positive income elasticity of demand for safety is that the VSL calculated based on the WTP in one country should be adjusted for income differences before it is applied to

another country. *In particular, estimates of the VSL obtained from the US should be adjusted downwards before they are applied to Canada.*

Most recent estimates of the VSL are based on one of three methods: wage-risk studies, consumer purchase studies, or contingent valuation method (CVM) studies. The first two methods are based on revealed preferences, while the latter is based on stated preferences. There are many methodological concerns with all of these estimation methods.

Problems with wage-risk studies are:

1. Workers may not have full information and may be subject to cognitive biases.
2. There may be an omitted variables problem. Studies assume that all relevant variables are controlled for in the regression. This includes non-fatality risk, other job quality characteristics, individual characteristics and labour market characteristics.
3. There may be a measurement error problem. An extreme version of this argument is that fatality rates are random so that it is impossible to measure the relationship between wages and risk.
4. Workers may not have the option of selecting the wage-risk combination that maximises their utility.
5. Low occupational risk levels may lead to truncation bias.
6. Risk-averse individuals may be under-represented.

Consumer market studies suffer from all of these problems. The fourth problem is the worst. While most individuals typically face a variety of options in the labour market, consumers have only two choices – they either buy the product or they do not.

CVM estimates are based on surveys and suffer from all of the problems with surveys including sample selection bias, non-response bias and interviewer bias. Problems specific to CVM include hypotheticality problems (respondents do not understand the alternatives), order bias, framing bias, embedding bias, and strategic bias.

Despite their limitations, economists prefer revealed preference methods to survey methods. Thus, they tend to prefer labour market studies and consumer purchase studies to CVM. Indeed, in the past 10 years there have been far more labour market studies than CVM studies.

A VSL for use in policy analyses in Canada was derived in two ways. First we conducted a comprehensive review of recent VSL studies, which are summarized in Tables 3.1 through 3.5 at the end of chapter 3. We then computed an estimate and a range of the VSL based on the information in these studies most pertinent to Canada. Second, we obtained a "best" estimate for the U.S. based primarily on US data and then adjusted this estimate to reflect lower average incomes in Canada. Both methods yielded similar point estimates and ranges (CHK).

The first method was based primarily on studies that had significant Canadian content. These were Krupnick et al. (2002), Mrozek and Taylor (2002), Boardman et al. (2001), Miller (2000), Chestnut et al. (1999), Dionne and Lanoie (2004) and Viscusi and Aldy's (2003). Collectively, these studies suggest the VSL in Canada ranges between 2002 C$ 1.0 million and 2002 C$ 7.5 million. The $1.0 million - $7.5 million range is too large for practical purposes. *In our opinion, we believe that a reasonable point estimate of the VSL for policy purposes in Canada is 2002 C$ 4.25 million. This figure is at the mid point of the $1.0 million to $7.5 million range*. It is between the estimates recommended by Chestnut et al. (1999) and Dionne and Lanoie (2004) and it fits within Viscusi and Aldy's (2003) range.

The $4.25 million figure is more than twice the figure currently used by Transport Canada ($1.76 million). However, it is slightly lower than figures used by Environment Canada ($4.46 million) and Health Canada ($4.47 million). It is slightly higher than the US Office of the Secretary of Transportation (OST, 2002), which recommends 2002 C$ 3.63 million.

The second method begins with best estimates for the US and then adjusts for income differences. Drawing exclusively on US studies suggests the VSL in the US is in the range of 2002 C$ 1.5 million – 2002 C$ 8.5 million. As above, we select a point estimate at the mid-point of this range, specifically 2002 C$ 5.0 million. Using an income elasticity that ranges between 0.5 and 1.0 implies that the best point estimate of the VSL in Canada is between 2002 C$ 4.25 million and 2002 C$ 4.63 million. These point estimates are very close to, but slightly higher, than the 2002 C$ 4.25 million figure suggested above. Adjusting the range for Canadian incomes suggest that the VSL in Canada ranges between 2002 C$ 1.3 million and 2002 C$ 7.9 million. This range is very similar to the 2002 C$ 1.0 million – 2002 C$ 7.5 million suggested above, and serves to confirm the previous results.

We have focused on an "average" VSL for use in Canada. Considerable evidence suggests that the VSL varies according to individual characteristics (income/wealth, age and culture) and transportation mode (risk level and degree of control) or policy dimension characteristics. The question arises whether the "average" VSL should be adjusted for such factors. Traditional economic theory indicates that one should make such adjustments to improve the efficient allocation of resources. However, ethical, political and pragmatic arguments can be put forward to suggest that one should not. (Note that using the average VSL is implicitly adjusting to nullify the influence of income or other factors).

In our view, some legitimate reasons for the use of a single VSL are:

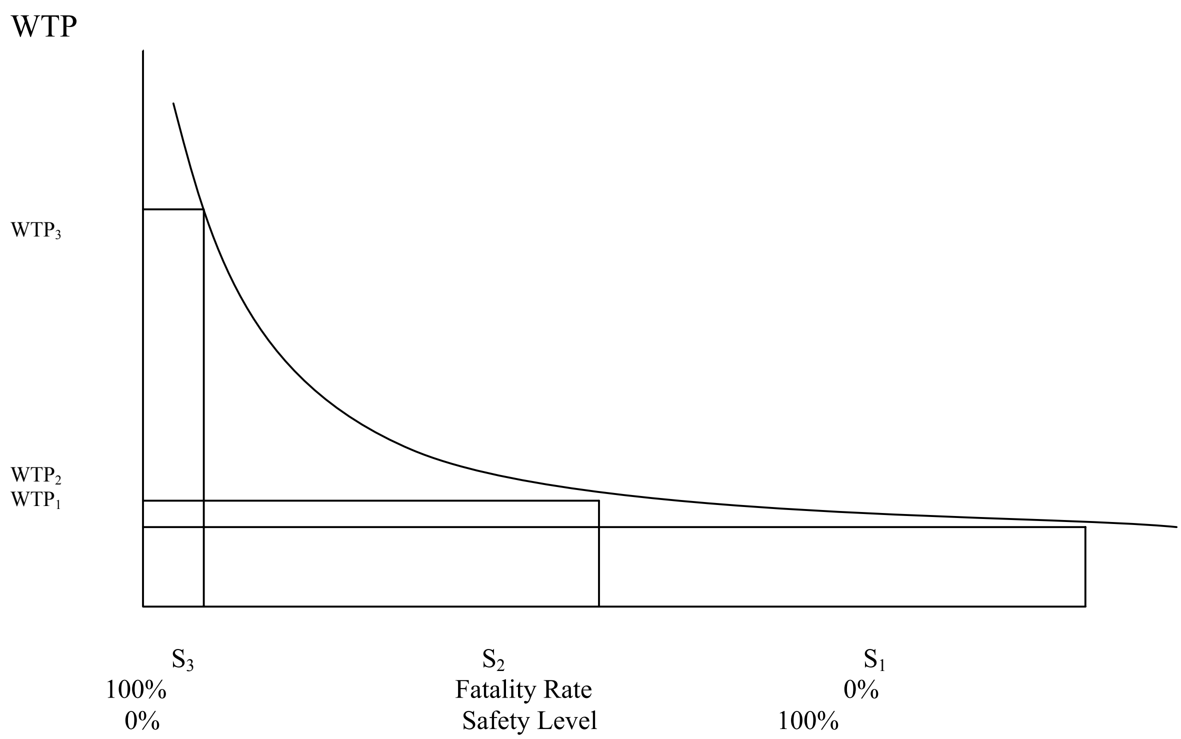
1. A single number has the virtue of consistency across policy applications.

2. A single number is simple and reduces the cost of analysis. Thus, it might lead to more analysis and ultimately to more efficient allocation of resources.
3. Attaching different VSLs to different groups within a society based on income would be interpreted by most as a form of distributionally-weighted cost-benefit analysis (Boardman et al., 2001) (although using the average VSL may already imply an implicit income adjustment). This leads to normative propositions that are beyond the scope of this paper.
4. In order to use VSLs that differ across individuals or modes we need to be more certain of the accuracy and appropriateness of the magnitudes of the differences—the functional form(s).

Nonetheless, there are arguments for using different VSLs for people with different ages and different incomes, and for different modes of transportation due to different risk levels and differences in the degree of control.

Adjusting for age and income is not appropriate in the transportation area. Adjusting for the risk of different modes makes analytical sense but we do not have good estimates of the functional form of Figure E2 (Figure 3.2 in Chapter 3).

Figure E2: Hypothetical (Convex) Relationship Between the Willingness to Pay for Increased Safety and the Level of Safety (and Fatality Risk)



In practice, graphs such as Figure E3 (Figure 3.4 from Chapter 3), are not very precise and may not even include the "relevant range."

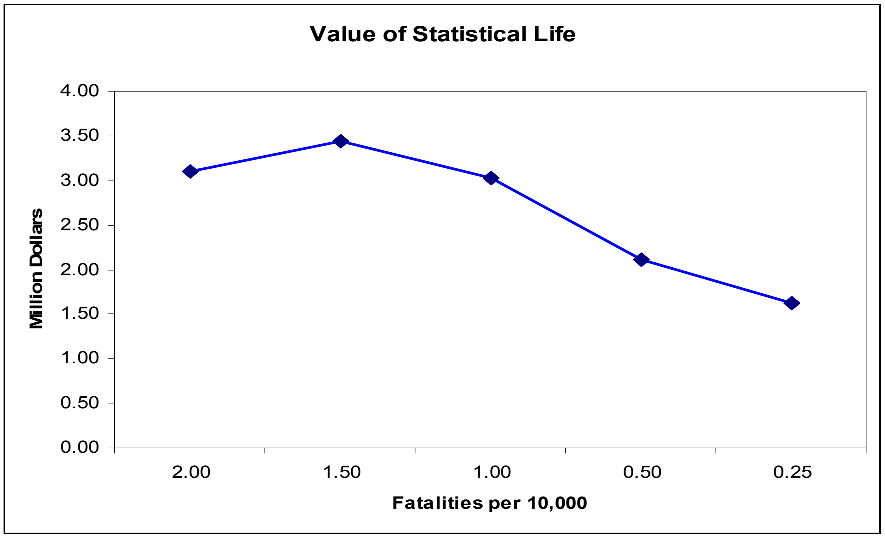


Figure E3: Mrozek and Taylor's (2002) Estimates of the Relationship between the VSL and the Risk level

Furthermore, individual assessments of the risks can be very poor. Under the circumstances and valuing simplicity, it does not seem reasonable to adjust the VSL across modes or across broad applications. In our opinion all departments in government should use the same VSL for public investment decisions or broad policies. However, note that if one were recommending pricing policies (or regulations) to internalize externalities imposed on society, it would be necessary to recognize how the VSL and injury risks differ among individuals and groups. Behavioural responses to policy changes will reflect underlying differences in valuations and applying a single VSL or cost of accident in these circumstances would not be a reliable predictor of outcomes.

Chapter 4: Cost of Accidents

A common method used to compute the cost of an accident is to sum the various components: the direct costs, indirect costs, and intangible costs. Direct costs pertain to property damage and other accident costs, medical costs, including rehabilitation and counseling, and administrative costs (household help and insurance administration). Indirect costs include productivity losses, other associated work related costs, and costs imposed on family members. These include absenteeism and worker substitution costs for both the injured and their family members, productivity losses through reduced participation and ability/throughput, and tax losses. Intangible costs include loss of quality of life and pain and suffering.

Productivity losses are usually measured by the human capital approach (e.g., lost wages). Intangible costs are measured from wage risk studies, jury awards, time trade off measures, consumer market studies or contingent valuation methods.

The total cost of an accident should be comprehensive and cover both the private costs to individuals and those costs that accrue to society at large. It should include both ex ante costs (including prevention) and *ex post* costs (including clean-up).

Despite its use in common practice, the method described above ignores the cost of slowing down to reduce the probability of an accident. Consistent with other studies, this cost is not included in our analysis of the cost of accidents. However, it is important to recognize that it is included implicitly in the value of travel time. While we are underestimating the total cost of an accident, this cost would be included in estimates of the value of travel time savings.

To capture all of the costs of an accident is in and of itself expensive and time consuming. In practice, many studies of accident costs have only focused on some components. We try to be comprehensive with the exception noted above concerning travel time costs.

Our recommended estimate of the cost of an accident draws largely on Miller (1993). These cost estimates are comprehensive in their scope of costs covered and take due consideration of potential double counting. Given the extensive time required to recreate these costs from entirely Canadian data sources, these estimates are likely to be more accurate than costs derived through another method. However, there are some misgivings concerning Miller's method of measuring the WTP to avoid an accident with a particular severity of injury based on a somewhat arbitrary proportion of the VSL.

We have made some adjustments to Miller's data considering the current situation in Canada. Specifically, for motor vehicle crashes, we:

- Adjust the medical cost component for severe injuries (approximately 14% of the total cost of an accident), recognizing that Canadian health care expenditures are 56% of those in the US).
- Adjust the total cost of an accident, recognizing that incomes in Canada are 85% of those in the US (adjusted for purchasing power).
- Adjust by a factor to reflect the stated VSL of $ 4.25 million from Chapter 3.

Despite these adjustments, it is possible that medical costs and legal costs are still over-estimated.

For other modes of transportation, we aggregate the various components. We use Miller's estimates after the above adjustments as the base cost of a severe injury C$ 330,875 and C$ 4.25 million as an estimate of the VSL from Chapter 3, and then add other costs.

The recommended estimates of the cost of accidents are:

Urban/ Interurban Vehicle:	$142.76/1000 km
Urban/ Interurban Bus:	$446.02/1000 km
Freight Vehicle/Truck	$152.57/1000 km
Interurban/ Freight Rail	$5.73 million / million main-track train-miles
Ferry (Interurban)	$158.67 / trip
Freight / Work related Marine	$822.00 / trip
Interurban Air	$ 2.89 million / 100,000 hrs flight
Freight Air	$13.15 million / 100,000 hrs flight

There is a relatively high degree of uncertainty in these estimates. Sensitivity analysis is presented in Appendix 4A.

The estimate for rail accidents costs of 2002 $C 5.73 million per million main-track train-miles incorporates both passenger and freight rail traffic accidents. We could not distinguish between passenger and freight rail transport accident costs due to lack of data. Care should be taken to use this number only once in aggregating costs, otherwise it could be double counted: once for passengers and once for freight.

The cost of accidents incorporates several components. Some of them are private and are borne by the user of transportation and some of them are not and are borne by society. Costs not borne by the user are referred to as externalities or as uncompensated externalities. Estimates of the costs of such externalities range from 0.59% (Delucchi, 2000) to 2.5% (ECMT, 1998) of GDP. Delucchi's estimate considers that a large portion of the costs of accidents is born by the users of motor vehicles through insurance premiums, and does not consider them to be externalities. The ECMT figure is adopted at a level that is greater than the total social cost of accidents.

Measuring externalities is not a simple task and has only begun to be evaluated in depth in the past few years. UNITE (2003) considers the external cost of accidents separately from the effect that congestion has on the rate of accidents when examining the marginal external cost of accidents. The question of external versus internal costs considers the degree to which the user of transportation considers the relevant risks to all participants in the transportation system. The congestion effect suggests that number of accidents increases at a decreasing rate as traffic volume increases and that risk is therefore decreasing.

Some estimates of average external costs of passenger vehicle accidents have been made in the European Union. Externalities due to motor vehicle traffic accidents is the largest for all modes of transportation examined, creating approximately 2002 $C 51.32 per 1000 passenger kilometers (p-km) traveled. Bus transportation is the next largest contributor of external costs due to accident creating roughly 2002 $C 4.40 per 1000 p-km. For freight vehicle transportation every 1000 tonne-km traveled creates roughly 2002 $C 17.60. Note the difference between vehicle and passenger and tonne kilometer traveled.

From our estimates one can compute the average cost per accident, if the accident rate is known. Implicitly, the cost of the average accident is computed by multiplying the average impact for each component by a cost of that component. In our opinion these costs are marginal costs – they reflect the opportunity cost of the resources. Whether this cost pertains to an individual's loss of productivity or police or hospital services, these costs are marginal costs (for the average individual or hospital). Thus, we have estimated the average marginal cost. Little is known about the shapes of the accident cost curves. However, costs are likely to vary little between one accident and another, whether it is the first or the last, at least not in a particular region. It is possible that accident costs vary from one region to another with low-accident rate regions suffering higher per accident costs due to lack of economies of scale. However, within a region, the marginal cost is unlikely to change much with changing frequency of accidents, assuming reasonably optimal provision of hospital and emergency services and assuming that accident rates do not change quickly.

Of course, if there is a major accident (a disaster), then the marginal cost of some components are likely to be higher than those we have assumed. Indeed, if circumstances were to change (i.e. risk levels increase or decrease) then the marginal cost per accident and the average cost per accident may change. In some circumstances, levels of risk could be exogenous, perhaps varying with traffic volumes such as congestion or different across modes such as would be implied by the risk of terrorist act. Under these circumstances the cost of accidents then will definitely change.

Chapter 5: Noise Costs

Noise is unwanted sound and emanates from all modes of transportation. In order to place a price on noise (or the lack of quiet) two magnitudes must be established: the amount of noise and value which people place on it. The amount of noise is measured in decibels (dB) and can reflect the difference between ambient noise levels at a point in time or over a period of time. There is no market in which noise is bought and sold and therefore the value for noise must be established through secondary markets where noise is bundled with other market products such as housing. Alternatively, values can be established through stated preference experiments using tools such as contingent valuation or conjoint analysis.

Generally, sound measures are weighted to reflect what is perceived as "loudness." The most common weight, the A scale, gives the measure dB (A), where the number of decibels is weighted by sound at various frequencies to give equivalent loudness. Noise measured for a point in time are described as single event measures while those which are measured over time such as NEF (Noise Exposure Forecasts) reflect the amount of noise locations are exposed to over a day with nighttime noise carrying a higher weight than daytime noise. NEFs are used to create noise contours that define noise exposure of a given level over space.

The amount of noise generated by a vehicle/aircraft/unit interacting with its infrastructure and how much of this noise is received by people (noise exposure) is measured relative to some benchmark or 'normal' ambient or background noise levels. Factors that influence this include background flow, the size of the vehicles, their speed, materials of the pavement surface, overflight paths and weather. In addition, ground cover, obstruction, barriers, the grade of the road or slope of take-off, the grade of surrounding land, and presence of buildings influence the propagation of the noise over distance. The most important factors to consider are: what is ambient noise and what is the increment with the presence of a particular mode of transport?

There is an extensive literature on both noise measurement and noise valuation. Both are reviewed in depth in Chapter 5. Noise measurement has a lengthy history but there is relatively little debate on the technical measure of noise. Where there is debate is the use of generated noise taken from engineering data, for aircraft for example, and measured noise using noise monitoring systems. The former does not take account of the environmental factors that can affect received sound while the latter does. This means the engineering value will be a constant while the measured noise level will have, in some cases a high variance. If the goal is to establish a price for noise, markets require some stability in order that the price can convey the resource cost of the product or service being consumed. If noise values --hence prices -- vary by some amount the information content of prices is lost to some degree since consumers cannot trade-off prices and choice if the price is unknown before the purchase. Therefore, a noise map that measures noise exposure is needed to provide the data to develop such prices.

Like other externalities considered in full social costing there are two fundamental questions that enter the valuation and pricing decision. The first is the noise exposure based on average or marginal values and second, is the externality internal or external to the system? In some cases, congestion, for example, all users may internalize an externality in the system but not users outside of the system. In the situation of noise, users of the system internalize nothing while those outside the system bear all the noise costs. One might argue that those who are also road users absorb road noise or that road noise is also partly internalized because others 'accept' noise on an implied contract to be able to generate noise. This type of argument could be applied to a number of externalities. In the case of noise the argument is hard to make since there is no correspondence between noise generation and noise reception at some later date, nor is there a strong general correspondence between noise generation and noise damage at some future date. Noise damage from road, rail and transit use depends on where and when the noise is generated. This is true for air, auto, rail and truck while it may be less true for public transit. Therefore, the full costs of noise should be included in the calculations of full social costs because the noise externality is generated by the components of the transportation system but paid for (through a loss of consumer surplus) by agents outside the system; those beside the airport, the roadway and the rail tracks.

Is it the average or marginal value that is important for the basis of establishing price? Empirically, the vast majority of the literature measuring noise value is based on cumulative noise metrics. For noise from aviation, there would be no distinction between average and marginal since the noise metric is a cumulative noise measure where the additional or marginal flight is included in the metric. For other modes, rail, road (car, truck and bus) and water, the same argument would hold. The noise contour measured along a road or rail corridor would be based on NEFs where the marginal vehicle has been included in the measure. NEF rises very slightly with the amount of traffic (vehicles or aircraft, for example) but rises significantly with the level of noise (dB). Therefore, the cost per unit of noise, as reflected in the noise depreciation index is relatively constant across a spectrum of noise exposure levels.

There are two valuation literatures, the empirical hedonic valuation measures and the experimental stated preference measures. Both literatures contain studies from all modes, from most developed countries in the world and for the past four decades. Therefore, there is a rich array of values from the studies from which to develop median or average noise valuation across time and location. These values are used to calculate overall noise costs each mode of transportation. Noise cost calculations measuring willingness to pay for quiet are based almost entirely on property value depreciation with more or less noise.

The review undertaken in this report found for aviation that a noise discount for housing **in the U.S.** was 0.5 to 0.6 percent per dB. Hence a property located in 55 dB would sell for 10-12 percent less if it were located in a 75 dB zone. However, in Canada, the discount seems to be higher, from 0.8 to 0.9 per cent per dB. For road traffic noise, for auto, truck and urban bus, noise discounts have been reported that range from 0.08% to 2.22%. A simple mean for these studies is a value of around 0.55, although one would want to use a range of 0.4 to 0.65 in any calculations. Two studies for rail, both stated preference found a noise depreciation of 10 percent but the value dissipated quickly for perpendicular distance from the rail track.

Noise costs are calculated for air, road (auto, truck and urban bus) and rail using the values of noise depreciation. The noise cost calculation depends on a number of assumptions including the level of noise exposure, number of operations or traffic density, density of population and number of homes affected and the median value of homes affected. For air the noise cost per operation is each flight adds 0.00011 dB to the annual noise levels at the houses surrounding airports; this means a 1 dB reduction in noise increases the present value of affected homes by 1 percent.

Rail: the average social costs [ASC] of noise per tonne kilometer is given by:

$$ASC= [0.0050 – 0.0015\ ln\ Q_t]/12$$

where Q_t is the number of trains per hour.

Highway-car: the noise cost is $0.0068/pkt, however this value is extremely sensitive to assumptions. Calculations for specific jurisdictions can be made using the model developed by Gillen et al. (1996) in which the average social cost (AC) for automobiles per vehicle km of travel (vkt) is:

$$AC_{HA} = f(D)^* f(H) * f(C) (- 0.018 + 0.0028 \ln (Q_h))$$

where Q_h is the traffic flow in vehicles per hour, and f(D) is housing density, f(H) is value of home and f(C) is the noise discount rate. The total costs of noise for automobile for a given jurisdiction can be calculated with information on the total vehicle-km of travel in a year.

Highway- truck and Bus: based on studies in North America and Europe the total noise cost calculation for truck would be based on a value of $.018/tkt times the total tonne–km for a given jurisdiction. For bus the total noise costs would be calculated as $0.0044 per passenger km, again using the same jurisdictions as for auto and truck.

Chapter 6: Air Pollution Costs

Air pollution refers to the direct effects of emissions from transportation on health and economic activity such as agricultural production. This chapter adopts the "dose response," or "damage function," approach to the estimation of full costs of emissions for each transportation mode. The analysis involves six specific tasks:

1. Identification of major air pollutants;
2. Establish dose-response functions linking emissions and damage effects, based mainly on epidemiology studies;
3. An air dispersion model is used to estimate the atmospheric concentration of the pollutant;
4. "Emission factors" of air pollutants are estimated for each transport mode;
5. The monetary value of the damage incurred is estimated drawing from economic studies, which place values on mortality and morbidity (e.g., short-term illness, chronic morbidity, productivity loss, and cancer);
6. The results from the epidemiological and engineering literature are merged with the results from the economic literature to arrive at our full-cost estimates for each transportation mode.

Whenever possible, attempts are made to use Canadian studies and employ Canadian figures.

Our cost estimates are given in the following table (in 2002 $C):

Interurban passenger transport (per passenger-km)	
Private vehicle	0.00088
Aircraft	0.00008
Bus	0.00100
Train	0.00471
Ferry	0.01091

Urban passenger transport (per passenger-km)	
Private vehicle	0.00842
Urban transit	0.00331
Freight transport (per tonne-km)	
Truck	0.00503
Rail	0.00173
Marine	0.00074
Aircraft	0.00003

Our estimates are towards the lower end of the ranges estimated in other studies.

Unfortunately, the literature on the full costs of transportation often is unclear on whether marginal or average costs are being estimated. We believe that our estimates are marginal costs, in the sense that they are estimated at the current levels of environmental conditions. As a result, these estimates will be useful for the purpose of identifying what policy actions such as pricing policy would bring about a more efficient use of transportation and mix of transport modes.

In making our estimation, we have made a number of assumptions regarding:

- value of mortality, or value of statistical life (VSL);
- value of morbidity;
- passenger occupancy rates per vehicle;
- emission factors.

Sensitivity analysis has been conducted with respect to these variables. The analysis shows that our cost estimates do not seem to be very sensitive to the valuation of mortality. Relative to other modes, the estimates of road transportation appear to be somewhat sensitive to the choice of VSL. This may be due to its high emission of PM_{10} which is crucial to the change in mortality. Further, the variations in the monetary value of morbidity do not seem to affect our base estimates very much, and that our estimates are much tighter in the morbidity case than the VSL case. In both cases, the costs for air transportation are insensitive to the values of mortality or morbidity. However, our cost estimates are roughly proportional, indirectly, to the occupancy rates assumed. For example, when the occupancy rate for urban private vehicle increases by 7.1%, from 1.4 to 1.5 passengers per vehicle, the cost estimate is reduced by 6.6%: from $0.00842 to $0.00786 per passenger-km. Similar results are observed for other modes, suggesting that our estimates are quite sensitive to the passenger occupancy rate.

While our estimates, as marginal costs, are applicable to small reductions in those levels, the question remains whether they are also applicable to large reduction, or complete elimination, of the damage. Further, it is not clear how to use these estimates to compile total national costs of transportation. These two questions hinge on the shape of the damage cost functions. In the literature, the underlying mathematical form for the cost function is almost never specified. In the context of air pollution, as elaborated in the chapter, there are several reasons to suspect that marginal externality costs increase with the volume of output, i.e., total externality costs are rising at an increasing rate. If indeed the marginal costs are rising, then we would overestimate the total costs if we multiply the marginal cost by total output. To obtain total externality costs, one must compute the area beneath a marginal cost curve or calculate an average externality cost associated with the observed level of output. While the relationship between average and marginal externality costs is well recognized for road congestion, this subtlety in estimating total costs of pollution is overlooked in the air pollution literature. We consider this as an important research area in the future.

Another future research question is whether and to what extent any of the current "total costs of air pollution" are actually borne by transport users, and hence are internalized, as distinct from borne by society as a whole. The discussions about congestion (Chapter 2) and safety (Chapters 3 and 4) categorise the non-monetary costs of delays and risks imposed by users on themselves are internal, while the costs imposed on other users and on non-users are external. Applying this criterion to pollution emissions, we suggest that the internalized part of the social cost might be small. On the other hand, the cost users impose on one another may be ambiguous; it is an externality but it is imposed on other users hence internalised by the user group. If the effects on other users were considered as being internalized rather than external, then the internalized part of the social cost is certainly non-trivial and, hence, the marginal social costs reported would overestimate the external costs. This would have further implications for the national "full cost" accounts, which should exclude the component of total costs that would be internalized by an environmental damage charge. Nevertheless, the magnitude of the adjustment is unclear and depends on the nature of environmental damage charges. Moreover, considerations of internal and external costs will of course have implications for the eventual analysis of damage charges. Given the extraordinarily complex issues involved, both conceptual and empirical, resolution of these issues is beyond the scope of the present chapter, but certainly is an important topic for further research.

Chapter 7: Greenhouse Gas Emissions

While still fraught with scientific uncertainty over the impacts of greenhouse gas (GHG) emissions, the cost of climate change has been under considerable scrutiny by policy makers concerned with, in particular, energy and transportation. In order to arrive at estimates of that element of the cost of transportation associated with the effects of GHG emissions, this Chapter initially describes the potential impacts of GHG emissions, specifically climate change effects. To move towards costing these impacts, how climate change effects can be quantified is explored. The global climate system is a very large system and there are decades of lag between emissions now and impacts that may take effect in the future. How these impacts can be forecast is examined, together with the particular economic and environmental modelling issues which arise in trying to assess the impact of those climate change effects. As any policy development associated with GHG emissions must operate within a substantial body of international regulation, economic aspects of GHG reduction agreements, regulations and policies are outlined. Reviewing the literature on forecast impacts, and considering what discounting is appropriate for future effects, mode by mode emission factors are presented, which are then converted into estimates of unit externality costs and damages to Canada.

While suggesting the cost estimates of GHG emissions, the Chapter also introduces the sources of uncertainty along with the estimation and possible treatments. Uncertainties arise from factors such as lack of knowledge of basic scientific relationships, linguistic imprecision, statistical variation, measurement error, variability, approximation, and subjective judgment. These problems are compounded by the global scale of climate change, and local scales of impacts, long time lags between forcing and response, low-frequency variability with characteristic times that are greater than the length of most instrumental records and the impossibility of before-the-fact experimental controls also come into play. Moreover, it is important to recognize that even good data and thoughtful analysis may be insufficient to dispel some aspects of uncertainty associated with the different standards of evidence. Two of the studies that are covered within Chapter 7, FUND 1.6 and FUND 2.0 (Tol 2000, 2002a, b) have explicitly tried to analyze the uncertainty related to the damage cost estimates. Uncertainty analysis is restricted to parametric uncertainty and tries to reflect the ranges found in the literature.

A cost benefit analysis of efficient GHG reduction policy is introduced, based on Nordhaus (1991). The efficient level of GHG reduction is shown to be the middle level of damages and for a discount rate that is 1% above the growth rate. This estimate corresponds to the middle damage estimate of US$7.33 ($11.67 at 2002 $C) per tonne of CO_2 equivalent. Equating the marginal damage with the marginal cost leads to an efficient level of control, which is 11% of GHG emissions. At the efficient control level, the total cost of reducing emissions is around US$3 billion ($4.78 billion at 2002 $C) per year while the total benefit is estimated to be around US$6 billion ($9.55 at 2002 $C) per year.

Global cooperation is a necessary step in GHG reduction and countering ozone depletion. Among several established international agreements, the Montreal Protocol deals mainly with the protection of the stratospheric ozone layer. It decrees that developed countries will phase out the consumption of HCFC by 2030, and developing countries will achieve the goal by 2040. The Kyoto Protocol is an international agreement that will commit industrialized countries to reduce emissions of the six greenhouse gases. The target amounts for each country are listed as a percentage of their base-year emissions (1990 for most countries). Canada's target is to reduce its GHG emissions to 6% below 1990 levels by the period between 2008 and 2012. Most European countries have a target of 8%.

The last section of this Chapter provides estimated unit costs of GHG emissions for various transportation modes. With regard to the emission factors (kg per passenger-km, per tonne-km, or per vehicle-km), a large range of emission factors has been reported for each transport mode in the existing studies, most of which have focused on EU countries.

However, substantial differences in emission rates might exist between Canada and EU countries, owing to different technologies in Canada and differences in operating conditions. We have used Canadian figures to derive our cost and damage estimates: we obtain the Canadian figures for passenger transportation from the Options Paper (Transportation Table 1999), and the Canadian figures for freight transportation from Transport Canada. We consider these federal estimates to be the best available, as they are based on a more thorough compilation of national vehicle-km, passenger-km and tonne-km data than any other studies have done. Our estimates of the unit costs of GHG emissions for Canada are given in the following table (in 2002 $C):

Interurban passenger transport (per passenger-km)	
Private vehicle	0.000599
Aircraft	0.000817
Bus	0.000142
Train	0.000670
Ferry	0.001553
Urban passenger transport (per passenger-km)	
Private vehicle	0.001172
Urban transit	0.000420
Freight transport (per tonne-km)	
Truck	0.000545
Rail	0.000109
Marine	0.000082
Aircraft	0.004360

We consider these unit costs to be a marginal cost concept, in the sense that they are estimated at the current levels of environmental conditions, but this could be debated. The unit costs are highly uncertain in magnitude, and are thought to be increasing at an unknown rate. If indeed these unit costs are the marginal costs which are rising, then we would overestimate the total costs if we multiply the marginal cost by total output. It is also important to comment on whether the "total costs of emissions" identified in the table are actually external costs. This question hinges on if any of the current costs are borne by transport users as distinct from borne by society as a whole. For GHG emissions, the fact that there are no direct effects of the emissions on human health or well-being may change the analysis, in that any climate-changing effects of GHG emissions are borne by the world at large rather than borne by individual users. As a result, it may be reasonable to dismiss any consideration of internalized components, and to consider the costs identified solely as external costs.

Chapter 1: Introduction

1.1 Background and Purpose of Study

This report is a first stage response to the Transport Canada discussion paper "Investigation of the Full Costs of Transportation" issued in September 2003. It explores the main methods of estimating social and environmental costs of transportation. Economists and researchers at the Centre for Transportation Studies (CTS) at the Sauder Business School in the University of British Columbia have carried out literature reviews on six major themes. These themes do not cover all potential costs of transportation, but they do pick up the major issues in considering the full costs of transportation and they also reflect where research has already been focused, allowing a substantial body of work to be reviewed.

Based on evidence and experience elsewhere, the report develops cost estimates, in Canadian dollars, across a range of inter and intra urban transportation modes, both passenger and freight. There have been very few previous attempts in Canada to estimate the full costs of transport modes, most notably research conducted for the Royal Commission on National Passenger Transportation (RCNPT) in the early 1990s and studies carried out in British Columbia at about the same time (Bein, 1995).

The full cost of transportation has been attracting increasing attention in research and policy internationally. Numerous studies have examined the issue (e.g., Greene, et al. 1997; Eyre et al. 1997, Levinson et al. 1998, Danielis and Chiabai 1998), but perhaps the most convincing sign of its significance is that interest has extended well beyond academic circles. Some national governments have commissioned estimates of the externality costs of transportation. Examples include, BeTa (the Benefits Table database) has been developed for the European Commission to provide a model for the estimation of the external costs of air pollution; and the addendum to the US 1997 Federal Highway Cost Allocation Study (HCAS), prepared by the U.S. Department of Transportation (US DOT), presents estimates of social and environmental costs of highway use and summarizes how these costs relate to other costs analyzed in the 1997 HCAS (US DOT 2000).

1.2 Structure of the report

This introductory chapter aims to set the context of this report, and provides a summary of the economic concepts which recur in more than one of the themes in later chapters.

The five major themes are covered in an order which leads the reader through categories of costs that increasingly are borne by society at large rather than by transportation users, starting with the costs of congestion where there are externalities affecting decisions but the full costs are borne by transportation users, through the costs of accidents and injuries which are largely but not completely recognized by users, to the costs of noise, air pollution and greenhouse gas emissions, where the costs are not recognised by individuals at all.

The discussion in each theme relates the issues uncovered from a thorough literature review. The policy background shaping research in the area is sketched where appropriate together with the different research themes that need to be examined in order to make a logical progression to modal marginal full-cost estimates. There is discussion of whether marginal or average costs are being estimated, and the implications of this. An extensive list of references is placed after each thematic chapter to make them more easily accessible.

Costs referred to throughout this report are in the currency of original studies, translated into 2002 Canadian dollars for the marginal cost estimates, unless stated otherwise.

1.3 Marginal Costs or Average Costs, Internal or External?

Several economic concepts occur repeatedly in consideration of the themes in the following chapters. One of the most important concepts in the subject of full transportation costs is "externality." Externalities are costs or benefits arising from an economic activity that affect somebody other than the people engaged in the economic activity and are not reflected fully in prices.[1] An externality induces a divergence between social cost and private cost. The concern is that market participants only consider the personal benefits and costs in making their decisions; but if externalities are present, then market outcomes (the aggregate of individual decisions) will not be socially optimal.

An investigation of the full costs of transportation can be done for two separate but overlapping purposes. One is a desire to measure the full costs (including environmental costs) of modes to compare them with the proportion of total costs that are borne by users. This reveals the implicit level of subsidy and how it differs across modes. For this purpose an average cost concept is adequate; the average cost estimate is multiplied by total output to arrive at a total cost estimate. Note that it is possible that some portion of the average cost estimate would be recognized and borne by the users while some proportion would be borne by society at large.

A second purpose of measuring the full social costs of transport is to identify what policy actions such as pricing policy (Pigouvian taxation) would bring about a more efficient use of transportation and mix of transport modes. For this a marginal cost concept is required, i.e., the incremental externality cost associated with the current level of transport output (which will differ among localities, e.g., the degree of road congestion in a community). Note that if the marginal costs are rising – which is often thought to

[1] Economist.com. Another definition, given in Button (1993), is "Externality exists when the activities of one group (either consumers or producers) affect the welfare of another group without any payment or compensation being made."

characterize transportation externalities – then it would be incorrect to multiply the marginal cost by total output to estimate the total costs. That would be an overestimate. We fear that many overlook this subtlety in estimating total costs of pollution or other externalities. To obtain total externality costs, one must compute the area beneath a marginal cost curve or calculate an average externality cost associated with the observed level of output. The relationship between average and marginal externality costs are well recognized for road congestion, but the distinction has been discussed less for other externality categories.

Unfortunately, the literature on the costs of externalities is often unclear on whether marginal or average costs are being estimated, nor does it necessarily sort out which components of unit costs are borne by transport users as opposed to being imposed on the community. Even if an externality cost is identified as marginal or average cost, the underlying mathematical form for the cost function is almost never specified. But without the mathematical function, it is not possible to convert between marginal and average costs. In some cases there may be no difference between average and marginal costs. In such a case the total externality cost curve would be a straight line, i.e. rising at a constant rate with output. But in most cases we think that marginal externality costs increase with the volume of output, i.e. total externality costs are rising at an increasing rate.

The various chapters comment on whether they provide marginal or average cost estimates, speculate on whether linear or non-linear relationships are likely, and attempt to identify what proportion of externality costs is actually borne by users as distinct from borne by society as a whole. Two externality categories are clearer on this. Congestion delays are borne entirely by users despite the presence of externalities, marginal costs are rising and in some cases it is possible to identify rigorously the relationship between average and marginal costs. At the other extreme, any climate changing effects of greenhouse gases (GHGs) are borne by the world at large rather than individual decision makers, the unit costs are highly uncertain in magnitude but are thought to be increasing at an unknown rate. The unit costs are thought to be a marginal cost concept but this could be debated.

1.4 Internalisation of Costs

A major consideration in the measurement of full costs of transport is whether or not users recognize and bear the costs of their actions. The efficiency concern of (negative) externalities is that there are costs resulting from transport users' decisions but the costs are imposed on others. If instead the costs are internalized, then markets can function efficiently and public policy intervention is not necessary.

The foregoing statement sounds compelling, but there is more to it. In the case of congestion, users of congested facilities impose delay costs on one another. The costs of delays are borne collectively by users, but there are still externality distortions at work. An accounting exercise tabulating who is bearing the costs is not a sufficient criterion for assessing efficiency and associated rationales for public policy. Internalisation of costs refers to decision makers recognizing and incorporating what were externalities into their decisions.

Another argument about internalization of external costs is the possibility that there is an implicit "contract" whereby individuals recognize mutual rights to impose costs on one another. Perhaps there is an implicit bargain among vehicle users to tolerate emissions (noise or otherwise) by others, in return for their reciprocal permission? If so, the externality may have been internalized. There are two flaws to this argument. The first is the number of underlying assumptions that would have to hold, including no change in technology so future noise recipients received the same noise per unit output as current recipients, a zero discount rate, a one to one correspondence between generators and recipients, and similar if not identical preference structures. An agent's willingness to trade present noise exposure, for example, for the future right to generate noise, seems to have the implicit assumption that the consumption bundle will not differ so the exchange rate is constant. There is also the problem of non-users. In the case of vehicle noise, those who bear the cost of the noise are not the same as those who generate it, unlike congestion.

A second and more fundamental flaw in the mutual recognition argument is that it overlooks an inadequacy of internalization of costs as a test for efficiency of resource use. Transport congestion costs are borne by users, but externalities are still present and causing distortions, i.e., the costs are borne by users but not "internalised." To use a familiar common property resource example: fishermen might realize the collective folly of over-fishing the stock, but it is rational for each individual fisherman to fish aggressively and the collective result is lower income streams from the resource. They are collectively bearing the cost of the reduced fishery, but there is more to it. The wealth of the nation and planet has been lowered. The fact that fishermen experience lower income does not indicate that efficiency is served.[2]

In sum, the concept of internalizing an external cost is not identical to determining who is bearing the cost. Who bears the average external costs might be used for an accounting exercise but – as in other economic decisions and analysis – the relevant concept is that of marginal costs, and average and marginal costs may often differ in dealing with transport externalities.

In the chapters below, we attempt to identify whether average or marginal costs are being measured, and comment where we can on who bears the costs and whether or not that implies internalization of costs for decision making among transport users.

1.5 Issues in Measuring Externality Costs

The cost of an externality is in general a function of two processes. The first relates the physical production of the externality to the amount of, in this case, transportation output.

[2] This flaw points to a second subtle consideration, which is partial versus general equilibrium models for developing Pigouvian taxes.

The second computes the economic cost per unit of externality. The amount of an externality produced by transportation is the result of the technology of the transportation, as well as the amount of defense and abatement measures undertaken.

There are several issues of general concern in the physical production of externalities. They are classified as: fungibility, geography, life cycle, technology, and point of view (macro or micro analysis). Each is addressed in turn below.

Fungibility: "Is the externality fungible?" In other words, does the externality, which is physically produced by the system under question, have to be eliminated or paid for, or can something substitute for it? For example, a car may produce X amount of carbon dioxide. If carbon dioxide were not fungible, then that X would need to be eliminated, or a tax assessed based on the damage that X causes. However, if it were fungible, then an equivalent amount X could be eliminated through some other means (for instance, by installing pollution control on a factory or by planting trees). The second option may be cheaper, and this may influence the economic effects of the pollution generated. While it may be important in some cases, our estimates of externality costs may not be able to recognize alternative means for adjusting for externalities. We limit ourselves to measuring the direct costs associated with the externalities.

Geography: "Over what area are the externalities considered?" "Is a cost generated by a project in BC which is borne by those outside BC relevant?" This is the issue of who is affected by the externality. This is particularly important in estimating environmental costs, many of which are global in nature. If we try to estimate damages (rather than the protection costs of defense, abatement, and mitigation), this becomes particularly slippery. However, if we can assume fungibility, and use the cost of mitigation techniques, the measurement problem becomes much simpler. Ideally, we would obtain estimates for both protection and damages in order to determine the tradeoffs. Although we cannot change any geographic assumptions that underlie existing studies, we have tried to check that no cost measures were excluded for jurisdictional reasons. In the case of climate change studies, it is explicit that costs are included regardless of political jurisdiction.

Life Cycle: In some respects we would like to view the life cycle of the transportation system. But it is difficult or even impossible to consider the life cycle of every input to the transportation system. The stages that may be considered include: Pre-production, construction, utilization, refurbishing, destruction, and disposal. Ignoring the life cycle of all inputs may create some difficulties. Electric power will produce pollution externalities at production. Thus, modes using electric power (rail, electric cars) would be at an advantage using this decision rule over modes that burn fuel during the transport process (airplanes, gasoline powered cars, diesel trains). This is true, though to a lesser extent, with other inputs as well. We have tried to identify the life cycle implications of various empirical studies, although this is not always possible.

Technology: The technology involved in transportation is constantly changing. The automobile fleet on the ground in 2000 will have very different characteristics to that in the year 1900 regarding the number of externalities produced. Hopefully, cars will be safer, cleaner, and quieter. Similar progress will no doubt be made in aircraft and trains. While the analysis will initially assume current technology, sensitivity tests should consider the effect that an improved fleet will have on minimizing externality production.

Macro vs. Micro Analysis: Estimates for externalities typically come in two forms: macro and micro levels of analysis. Macroscopic analysis uses national (or global) estimates of costs as a share of gross domestic product (GDP), e.g. Kanafani (1983), Quinet (1990), and Button (1994). The data for microscopic analysis is far more dispersed. It relies on numerous engineering and empirical cost-benefit and micro-economic studies. By and large, this study is macroscopic simply because of the geography and the data requirements. The macroscopic numbers will be used as benchmarks for comparison and estimates of data where not otherwise available. This will be true for both the physical production of externalities and their economic costs through damages borne or protection/attenuation measures. Once cost estimates are produced, they can be expanded to estimate the local, regional or provincial social costs of transport as a share of respective product (e.g. BC GDP), which can be compared with other national estimates.

1.6 Economic Valuation

As mentioned above, the costing of an externality in general involves two processes: first, measuring the physical production of the externality due to transportation output; and second, providing the economic valuation of the physical impacts. We now discuss some of the key concepts and methods involved in such valuation.

1.6.1 Opportunity Cost and Foundations of Valuation Methods

Opportunity cost is the fundamental building block of modern economic analysis. The true economic cost of one unit of some good X reflects the cost of opportunities foregone by devoting resources to its production. This cost measures the economic value of outputs, goods, and services that would have been possible to produce elsewhere with the resources used to produce the last unit of good X. The social opportunity cost of employing a resource for which there is no alternative economic use is thus zero, even if its price is positive, and opportunity cost will be different under conditions of full employment than under circumstances involving large quantities of visible or invisible unemployment. Moreover, opportunity cost applies only to small "marginal" changes from equilibrium in systems for which there are multiple equilibria. Likewise, the marginal benefit from consuming good X is the value of the last unit purchased, measured in terms of a real price that reflects the welfare that would have been enjoyed if the requisite expenditure had been devoted to consuming another good (or goods).

These concepts may appear circular, but that is an artifact of the circular nature of economic systems. Suppliers of some economic goods are consumers of others. The opportunity cost of a good to the producer and the marginal benefit to the consumer are equal when all of the following conditions are obtained:

- All markets are perfectly competitive.
- Markets are comprehensively established in the sense that all current and future property rights are assigned.
- Marketed goods are exclusive (ownership is singular and well defined) and transferable (goods can be bought, sold, or given away).
- The underlying social and legal systems guarantee that property rights are (reasonably) secure.
- There are no transaction costs involved in creating and/or maintaining any current or future market.
- There is perfect and complete information about all current and future markets.

Under these conditions, the marginal opportunity cost of any good with multiple uses or multiple demanders is equal to its marginal benefit. Marginal (opportunity) cost and marginal benefit then match the accounting price that can be read from the market, and economic efficiency is assured in the sense that nobody can be made better off without harming someone else.

It is not difficult, of course, to think of circumstances in which one or more of these conditions do not hold (and this is not news to the economics profession). Much of modern economics has been devoted to exploring how to measure and compare costs and benefits when these conditions break down. In reviewing empirical studies we try to identify the underlying assumptions in their valuation procedures.

1.6.2 Valuing Non-market Impacts

Another valuation concept is the distinction between "value in use" and "value in exchange." The latter refers to the market price of a good or service. Measuring economic costs makes use of market prices as far as possible, recognizing that it may be necessary to modify observed market prices if are economic distortions, such as externalities.

But all things desirable and valued are not necessarily bought and sold in a market place. Even if they are, the value in exchange is a marginal valuation, i.e., markets reveal the value placed on a bit more or a bit less of some product or service. But exclusive reliance on market prices can give rise to paradoxical results, e.g., the classic example comparing the price of water with that of diamond jewelry. Water is indispensable for life whereas diamond jewelry is purely a luxury. Yet the latter commands much higher prices than the former. The value of use for water is obviously something far above its value in exchange. This is a difference between marginal value (value of an increment more or less in consumption) and total value placed on something. In economic terms, the total value is measured by the sum of marginal valuations, or taking the area beneath a demand curve whereas the market price is only one point on a demand curve.

For most of the analysis in this study, we are interested in marginal valuations so the distinction between value in use and value in exchange is not so important. But the former can be important if it is necessary to value a quantum amount of some good or service, whether it is bought and sold in a market or not.

Transportation services often have valuable attributes that go unpriced in the economic sense. Markets simply do not exist for some attributes and some services (e.g., environmental quality, safety and human life); contemplating markets for some others (e.g., health services) has been questioned even given extensive competition for services and products. For others, markets that do exist fall short of being comprehensive or complete in the presence of externalities of production or consumption. In either case (or others), researchers have recognized the need to develop alternative means with which to assess the value of the services in order to understand the cost of the impacts. More precisely, they have tried to extend the scope of the economic paradigm so that implicit and explicit tradeoffs between development and conservation of unpriced resources can be explored within the structures of standard decision analytic tools such as cost-benefit analysis, cost-effectiveness analysis, and so on. Parikh and Parikh (1998) provide a primer on valuation with case studies.

To be more specific, economists have built a theory of choice on the basis of the notions of consumer sovereignty and rationality. Economists assume, therefore, that individuals are able to value changes in non-market goods and services as easily as they can value changes in marketed goods and services. The only difference between the two cases is that markets provide the researcher with some direct data with which to assess individuals' values of marketed products. Nevertheless, individuals should be able to tell researchers what they would be willing to pay for changes in non-market conditions or willing to accept as compensation for those changes. In fact, "willingness to accept" (WTA) payment for foregoing a good and "willingness to pay" (WTP) for a good are the two general yardsticks against which values are judged.

An individual's preference for "clean" environment will show up in the form of his/her willingness to pay (WTP) for it. Alternatively, the value may come from asking how much people are willing to accept (WTA) in the way of compensation for pollution.

It should be noted that WTA and WTP are seldom the same for most non-market goods or services. In fact, WTA and WTP can give wildly different estimates of the value of these services if there are no perfect substitutes (i.e., if it is impossible to fully compensate individuals unit by unit for their loss). When such a substitute does not exist, WTA > WTP. Cummings et al. (1986) reported that it is not uncommon for estimated WTA to be more than 10 times larger than estimated WTP. These differences might be result of the method of estimation, but they also reflect the fact that WTA and WTP are two different concepts that need not match.

Which measure to use to value a change in, say, environmental quality depends on the implicit assignment of property rights. If the individual is assumed to have a right to a higher level of environmental quality (i.e., a right to the improvement or a right to no deterioration), then WTA is the appropriate basis for valuation. Conversely, if the individual is assumed to have no such a right, then WTP is the appropriate measure. It is also noted that WTA and WTP have analogs in the market context in the concepts of compensating variation (CV) and equivalent variation (EV) (see, for example, Boardman et al. 2001). We shall use WTP as most of the empirical studies are WTP studies.

1.6.3 Valuation Methods for Non-market Impacts

There are two general approaches for valuing transportation attributes: use of questionnaires and interview techniques to solicit people's valuation of attributes, and empirical analysis of actual decisions that reveal implied valuations.

Contingent Valuation Methods and Stated Preference

Direct methods of valuation try to judge individuals' value for non-marketed goods by asking those individuals directly. Contingent valuation methods (CVMs), for example, ask people for their maximum WTP to effect a positive change in their environment or their minimum WTA to endure a negative change. Davis (1963) authored one of the earlier papers to report CVM results for environmental goods. Comprehensive accounts of these methods appear in Hanley and Spash (1993), Bateman and Willis (1995), and Boardman et al. (2001). This is a controversial method, and current environmental and resource literature continues to contain paper after paper confronting or uncovering problems of consistency, bias, truth-revelation, embedding, and the like. Nevertheless, CVM is one of the most commonly used methods in the estimation of an economic value for environmental goods (Mitchell and Carson 1989, Bishop and Romano 1998). Hundreds of CVM studies have been completed in the U.S. and Western Europe (Bishop and Romano 1998). Hanley et al. (1997) offer a quick overview of these discussions and a thorough bibliography.

"Stated preference" (SP) makes use of questionnaires to get people to indicate their preference for hypothetical travel cost and time alternatives. The SP method can estimate the influence of otherwise correlated variables (e.g., journey speed and comfort are often correlated). The potential shortcoming of SP methods is that they are based on hypothetical choices; interviewers might not give accurate replies (of course, questionnaire design and administrative procedures can help guard against this danger).

Revealed Preference Methods

Indirect methods of valuation, referred to as "revealed preference" (RP) methods, attempt to measure individuals' value for non-market goods by observing their behavior in related markets. Hedonic pricing (HP) methods, for example, assume that a person buys goods for their various attributes. Thus, for example, a house has attributes such as floor area, the number of bathrooms, the view it provides, access to schools, hospitals, entertainment, and jobs, quietness and air quality. By estimating the demand for houses with different sets of attributes, we can estimate how much people value noise and air quality. One can thus estimate "pseudo-demand curves" for non-market goods such as noise and air quality. The travel costs method is another method with which valuation estimates of the multiple criteria on which utility depends can be finessed out of observable behavior. The HP method was first proposed by Lancaster (1966) and Rosen (1974). Mendelsohn et al. (2000) brought the hedonic approach to the fore in the global change impacts arena. A consensus on the state of the science for these methods has not been reached yet. There is, instead, a growing literature that warns of caveats in their application and interpretation (e.g., health services) and/or improves their ability to cope with these caveats. Smith (2000) provides a careful overview of this literature and an assessment of progress over the past 25 years.

Of the two approaches, McCubbin and Delucchi (2003) suggested that the advantage of indirect RP methods is that they are based on actual behavior, while the advantage of direct SP methods is that they specify precisely and explicitly what is to be valued. In recent years, databases have been developed that combine RP and SP methods for the same population. The two methods can complement one another e.g., SP methods can separate the influence of correlated variables affecting traveler behaviour.

Both RP and SP methods are employed in all the externality categories that we review. The valuation methods are reviewed for all studies.

1.6.4 Valuing Future Goods and Selection of a Discount Rate

Several of the themes explored in this report examine long-term effects and a proper choice of discounting rate is of crucial importance in forecasting or scenario building. The selection of a discounting rate should take into account:

- *Impatience, or "time preference"*. People tend to prefer current consumption over later consumption;
- *Economic growth*. If people are richer in the future, a dollar now has greater (relative) value than a dollar later;
- *Changing relative price*. Certain impacts, such as on human health, may well be valued more highly in the future;
- *Uncertainty*. Because future consumption is less certain, it is worth less; and
- *Investment opportunities*. People face an opportunity cost of forgone interest when spending dollars now rather than investing them for future use.
- *Complexity*. Assets and actions may be from the private or public sectors, and may take into account both financial and social costs.

Selecting a discount rate allows costs and values occurring at different times to be compared by converting future economic values into their equivalent present values. Formally, the present value of some cost C_t that will come due in t years is:

$C_t / (1+d)^t$,

where *d* is the discount rate. The discount rate is non-negative because resources invested today in physical and human capital can usually be transformed into more resources later on.

In the standard neo-classical formulation, the discount rate *d* follows $d=\rho+\eta g$, with ρ the pure rate of time preference, η the consumption elasticity of marginal utility, and *g* the growth rate of per capita consumption. The growth rate of per capita consumption *g* is assumed to be equal to the growth rate of per capita income. The pure rate of time preference ρ varies between 0%, 1% and 3% per year. 0% is taken to be consistent with the principles of sustainability (Broome, 1992; Brown, 1997, Koopmans, 1967), whereas 3% is observed in markets (Nordhaus, 1994).

While there is wide consensus among economists that the social discount rate should be positive, there is less agreement about what this positive rate should be because of various conceptual and methodological issues (Boardman et al. 2001). The choice of discount rates will affect any valuation of future damage, and policy analysts and decision makers do not have the luxury of waiting for these issues to be resolved. Trying to resolve the discount rate debate is well beyond the mandate of this review, but it is an unavoidable issue. For the most part, where discount rates arise in empirical studies of the various environmental and social costs, we report on what rates are being used in practice. It will certainly not be "the last word," but the recommendations from Moore et al. (2004) may serve as an interim guide to choice of discounting procedures:

- if the project is intragenerational (does not have impacts beyond 50 years) and there is no crowding out of private investment, then discount all investment flows at 3.5%;
- if the project is intragenerational (has impacts within 50 years) and there is some crowding out of investment, then weight investment flows by the shadow price of capital of 1.1 and then discount at 3.5%;
- if the project is intergenerational and there is no crowding out of investment, then use a time-declining scale of discount rates;
- if the project is intergenerational and investment is crowded out, then convert investment flows during the first 50 years to consumption equivalents using a shadow price of 1.1, and then discount all of these flows at 3.5 %, and discount all flows after the 50th year using time-declining rates.

1.7 Externality Categories Explored in Considering the Full Costs of Transportation

Five themes have been considered in detail in this report: congestion and associated time delays; the valuation of life and accident costs (which are addressed separately); valuation of noise; the costs of air pollution and greenhouse gases. There are some potential additional externality categories that were deemed to be less important and thus not included.

1.7.1 Congestion Externalities and the Value of Time Travel Savings

In order to arrive at the social costs of congestion, one must measure congestion and the associated time delays, and the value that travellers place on travel time savings (VTTS) or delays. The vast majority of the literature on VTTS is associated with road transport, both urban and intercity. The concepts, measurement and developments in VTTS for road transport are reviewed before turning to VTTS applications for other passenger modes of transport and for freight. Reviewing the evidence, if a constant value of time is to be used, 50% of the average wage rate would be an appropriate figure. However, assuming a constant value of time is in our view not appropriate unless one has to rely on the thinnest data on the composition of traffic. Recent research has made substantial strides in decomposing VTTS and distinguishing various subgroups of the population and we therefore propose a segmentation.

In contrast to environmental and noise externalities, congestion externality costs are internal to the transport sector as a whole, hence they are considered an *intra-sectoral externality*. Unlike other externality categories reviewed, the relationship between marginal and average costs can be well-defined. Nonetheless, there are issues in distinguishing between the external element of the cost of congestion and the total or average cost of congestion. Suggestions for Canadian VTTS are made, but significant issues remain in ensuring that congestion models accurately represent Canadian conditions.

1.7.2 The Value of Statistical Life

This chapter reviews different methods of arriving at a value of statistical life (VSL). VSL is distinct from attempting to value a specific person's life. VSL reflects what individuals are willing to pay for an increase in the probability of living (reduction in the probability of dying). From the variety of methods used to establish VSL, court compensation awards are rejected as having little economic base. Wage risk studies are reviewed in some detail and their outputs compared with the increasing use of contingent valuation surveys where a representative sample of a population are asked how much they are willing to pay for a hypothetical reduction in risk. Contingent valuation is used as the basis of determining an estimate for the value of statistical life with reference to different modes of travel in Canada, but it is recognized that further work is needed to improve confidence in the figures presented. A value of 2002 $C 4.25million is proposed, with a range of $2.0 million to $7.5million.

1.7.3 Cost of Accidents

The cost of an accident is the sum of its component costs: the number of deaths x the VSL, the number of injuries x the cost of an injury, plus other costs. In practice, most academic research has focused on VSL and the cost of injury and the cost of accidents are rarely separated. The list of other costs the total cost of an accident should include are: property damage costs, time delay costs from congestion at accident sites, environmental (product release) costs, clean-up costs, and investigation costs. There are considerable risks of double counting costs in this type of analysis. For example, some estimates on cost of injury include property damage and time delay. From the VSL, a Value Of a Life Year (VOLY) maybe arrived at, and the concept of a Quality Adjusted Life Year (QALY) bears discussion, taking factors such as an accident victim's age and health into consideration. Accident statistics allow this discussion to be separated for different transportation modes.

1.7.4 Noise Costs

Noise costs are a product of two factors: the quantity of noise and the economic valuation of the noise. Therefore, two broad research paths are reviewed; firstly, how to develop means of measuring noise exposure and secondly, how to assess the different approaches to valuing noise. This chapter explores an externality where users of the transportation system internalize nothing while those outside the system internalize everything. The level of noise produced by transportation must be measured, and factors applied to allow for attenuation between source and receiver. The link between noise and economic pricing is then explored, with studies looking at how property values vary with noise contours providing the greatest volume of data. Practical experience of where noise charges have been applied, particularly by airports, provides a useful comparison with these hedonic pricing studies.

1.7.5 Air Pollution Costs

Air pollution refers to the impact of direct emissions from transportation on health and economic activity such as agricultural production. The nature of this relationship is reviewed as a precursor to assessing the costs of those impacts across a range of pollutants with very differing effects. Once emission factors have been estimated (factors which link pollutants and different transportation mode activities) there is an attempt to synthesise earlier findings on VSL and VOLY in order to suggest the externality costs of air pollution.

1.7.6 Greenhouse Gas Emissions

While still fraught with scientific uncertainty over the impacts of greenhouse gas emissions, the cost of climate change has been under considerable scrutiny by policy makers concerned with, in particular, energy and transportation. In order to arrive at estimates of that element of the cost of transportation associated with the effects of GHG emissions, this chapter explores the issues associated with measuring the impact of climate change at some length. Reviewing the literature on forecast impacts, and considering what discounting is appropriate for future effects, mode by mode emission factors are presented, which are then converted into estimates of social costs.

1.7.7 Other Externality Categories

This review concentrates on the recognised transportation externality categories most relevant to Canada, summarized above. There are some other externality topics that could be explored[3]. They were excluded either because they were thought to be relatively less important and/or there was limited research literature on which to base an analysis. These other externality topics include: (1) water pollution; (2) vibration damage to structures adjacent to transportation facilities; (3) visual intrusion, i.e., transport facilities or operation may interfere with people's ability to enjoy their surroundings and scenery; (4) 'barrier effects' such as the social and community disruption caused by transport facilities interfering with local movement; (5) security risks, i.e., risks posed to the public at large from possible terrorist acts; and (6) situations where market prices in other sectors do not reflect the underlying marginal costs and transport activities could exacerbate these economic distortions, i.e., "second-best" issues.

Water pollution issues can arise for all modes. Our review covers air and noise pollution which generally are more significant than water pollution from transport. There are some cases where costs are internalised (e.g., re-capture of fluids from de-icing of aircraft) but the problem of chemical run-offs from roads is a topic that warrants further investigation. Facility construction can affect streams and local ecological conditions. One topic that could be important concerns ballast water from ships. There are some dramatic examples of harm that can arise from the transfer of organisms from one region of the world to another.

Vibration damage caused by transport operations is a recognised and important externality category in the U.K. and Europe. It is important there because they have many narrow streets with historically-significant very old stone or brick buildings that are susceptible to vibration damage. For the most part, we judge this category to be of only limited significance in Canada. North American towns and cities generally are much younger than European cities and have evolved with greater awareness and provision for transportation. Serious vibration threats would be very site-specific as opposed to a national issue. There are potential vibration costs in modern cities but also note that some such potential externality costs will have been internalised through regulation of building standards and resulting construction costs.

Visual intrusion is where transport facilities and/or operations harm the satisfaction people otherwise would derive from scenery. It is a recognised externality category but

[3] A useful source exploring externality categories is Litman (1995).

there is much less literature on it than other categories, and it is particularly difficult to identify some metric to measure it. This could be a positive externality if transport facilities had an incidental effect of improving access to viewpoints (such as road facilities built through scenic areas) or if structures would have some aesthetic appeal (e.g., an attractive suspension bridge).

Barrier effects are situations where transport facilities and/or operations hamper movement and communication among community residents. It could also refer to interference with wildlife movements by non-urban transport facilities and operations. These effects are very site- and situation-specific. They could be important but we did not regard this category as one of broad national significance, nor is there an extensive literature from which to generalise.

Security threats are a possible source of externalities in that terrorist threats (such as airline hijacking) could pose significant risks to non-users of transportation (Waters and Zhang, 2004). But this is a relatively novel externality category, subject to debate on its validity and there is no developed literature to review.

Price-cost divergences in other sectors of the economy do not fit into standard concepts of externalities but they are situations whereby users make decisions where the prices they face do not reflect the full costs. Their decisions are not socially-optimal and this imposes costs on other sectors due to spillover effects. For example, the price of automobile commuting during peak periods is below the marginal social costs. This encourages auto use beyond optimal levels, and in turn stimulates auto-intensive activities in the economy. Suburban land development is stimulated and ultimately both residential and industry location can be affected. There are ‘downstream’ costs of inefficient location of economic activity. Another example: some argue that petroleum prices are below long-term sustainable levels. Setting aside the validity of this argument, suppose it is true. The consequence of under-pricing peak automobile use, with resulting stimulus to dispersed living, results in further increase in use of (assumed) under-priced petroleum. These are additional costs imposed by the lack of congestion pricing. However, we do not consider these second-round effects and second-best implications in our review of externality costs. Social benefit cost analysis of investment projects can be structured to recognise second-best implications, and this framework can be extended to pricing policies as well (Turvey 1974), but these are not addressed in this report.

1.8 Limitations of This Study

The thematic approach used in assembling the information in this report has been very effective in marshalling and synthesising the wealth of existing research information in the five major themes. However, one effect of pursuing themed research is that impacts which fall outside these themes, and which perhaps have limited research literature available, are not explored. These are identified in the section above, but it is important that there should be further analysis of these other externality categories.

Additionally, this report has been concerned with negative externalities, and marginal costs, and to what degree those costs have been internalized already. It is possible that positive externalities, i.e. benefits from transport for non-users, can also be identified. Such positive externalities are likely to be linked to specific modes and circumstances.

Given these limitations on the approach used in this report, it is recommended that the marginal cost estimation tables produced in this report are used as the starting point for a further modal analysis to identify other potential externalities. This would ensure that other costs associated with transport, beyond the six explored in depth here, can be identified and incorporated in future work.

There is one other limitation that we notice. The origin of nearly all the empirical valuation studies is to establish the appropriate valuation of externalities for use in public investment appraisal (social benefit-cost analysis). This context allows a good deal of averaging in developing estimates. For example, if one is improving a road system, variations in individual valuations of travel time savings (VTTS) do not matter providing that the average VTTS is known. All individuals benefit from the road improvement. But if one were going to implement congestion pricing, then it would matter how the VTTS varied among individuals. If the VTTS distribution is right-skewed (a limited number of those with high VTTS balances a larger number with low VTTS), a congestion charge based on average VTTS would underestimate the number of people who would be deterred by the congestion charge and overestimate the toll revenue that would be collected. In brief, the existing empirical literature on valuing externalities may not provide the level of detail that is necessary for evaluating potential pricing policies.

In the chapters below, we identify and discuss some future research topics that arise for the respective topics.

Chapter 1 References

Bateman, I. and Willis K. (eds.), (1995): *Valuing Environmental Preferences: Theory and Practice of the Contingent Valuation Method*, Oxford University Press. Oxford, United Kingdom.

Bein, P. (1997): "Monetization of Environmental Impacts of Roads", Ministry of Transportation and Highways. British Columbia, Canada.

BeTa (Benefits Table database) Version E1.02a, "Benefits Table Database: Estimates of the Marginal External Costs of Air Pollution in Europe", Created for European Commission DG Environment by NETCEN.

Bishop, R.C. and Romano, D. (1998): *Environmental Resource Valuation: Application of the Contingent Valuation Method in Italy*, Kluwer Academic Publisher. The Netherlands.

Boardman, A.E., Greenberg, D.H., Vining, A.R., and Weimer, D.L. (2001): *Cost-Benefit Analysis: Concepts and Practice*, 2nd Ed., Prentice Hall, Chapter 14, New Jersey.

Broome, J. (1992): *Counting the Cost of Global Warming*. White Horse Press, Cambridge.

Brown, P.G. (1997): "Stewardship of Climate - An Editorial Comment", *Climatic Change*, 37, pp.329-34.

Button, K.J. (1993): *Transport Economics*, 2nd Ed., Edward Elgar

Button, K.J. (1994): "Alternative Approaches Toward Containing Transport Externalities: An International Comparison", *Transportation Research,* A, 28(4), pp. 289-305.

Cummings, R., Brookshire, D. and Schultze, W. (1986): *Valuing Environmental Goods: An Assessment of the Contingent Valuation Method*, Rowman & Littlefield. Lanham, MD, USA.

Danielis, R. and Chiabai, A. (1998): "Estimating the Cost of Air Pollution from Road Transport in Italy", *Transportation Research,* D, 4, pp. 249-258.

Davis, R., (1963): "Recreational Planning as an Economic Problem." *Natural Resources Journal*, 3, pp. 239-249.

Elvik, R. (1994): "The External Costs of Traffic Injury: Definition, Estimation and Possibilities for Internalization", *Crash Analysis and Prevention*, 26(6), pp. 719-732.

Eyre, N., Downing, T.E., Hoekstra, R. and Rennings, K. (1997): "Global Warming Damages", *ExternE*. Brussels.

Hanley, N.J. and Spash, C. (1993): *Cost-Benefit Analysis and the Environment*, Edward Elgar Publishing Limited. Aldershot, UK.

Hanley, N.J., Shogren, J.F. and White, B. (1997): *Environmental Economics in Theory and Practice*, Oxford University Press. Oxford, United Kingdom.

Kanafani, A. (1983): "The Social Cost of Road Transport: A Review of Road Traffic Noise, Air Pollution and Accidents", Institute of Transportation Studies, University of California, Berkeley.

Koopmans, T.C. (1967): "Objectives, Constraints, and Outcomes in Optimal Growth Models." *Econometrica,* 35, pp. 1-15.

Litman, T. (1995): *Transportation Cost Analysis Estimates and Implications*, Victoria Transport Policy Institute (1995 updated), www.vtpi.org

Lancaster, K., (1966): "A New Approach to Consumer Theory." *Journal of Political Economy*, 74, pp. 32-157.

Levinson, D.M., Gillen, D. and Kanafani, A. (1998): "The Social Cost of Intercity Transportation: a Review and Comparison of Air and Highway", *Transport Reviews*, 18(3), pp. 215-240.

McCubbin, R.R. and Delucchi, M.A. (1999): "The Health Cost of Motor-Vehicle-Related Air Pollution", *Journal of Transport Economics and Policy*, 33(3), pp. 253-86.

Mendelsohn, R., Andronova, A., Morrison, W. and Schlesinger, M. (2000): "Country-Specific Market Impacts of Climate Change", *Climatic Change*, 45, pp. 553-569.

Mitchell, R., and Carson, R. (1989): *Using Surveys to Value Public Goods: The Contingent Valuation Method*, Resources for the Future, Washington DC. USA.

Moore, M.A., Boardman, A.E., Vining, A.R., Weimer, D.L., and Greenberg, D.H., (2004): "Just Give Me a Number! Practical Values for the Social Discount Rate", Working paper, Sauder School of Business, The University of British Columbia.

Nordhaus, W.D. (1994): *Managing the Global Commons: The Economics of Climate Change*, The MIT Press, Cambridge.

Parikh, J.K. and Parikh, K.S. (1998): *Accounting and Valuation of Environment: Vol. II, Case Studies from the ESCAP Region* Economic and Social Commission for Asia and the Pacific Region, United Nations. New York, NY, USA.

Quinet, E. (1990): *The Social Cost of Land Transport*, OECD Environment Monographs, 32, Paris.

Rosen, S. (1974): "Hedonistic Prices and Implicit Markets: Product Differentiation in Pure Competition", *Journal of Political Economy*, 82, pp. 34-55.

Smith, V.K. (2000): "JEEM and Non-Market Valuation", *Journal of Environmental Economics and Management*, 39, pp. 351-374.

Turvey, Ralph, (1974): "How to Judge when Price Changes will Improve Resource Allocation," *Economic Journal,* Royal Economic Society, vol. 84(127), pp.825-32, Dec.

US DOT (United States Department of Transportation), (2000): *Addendum to US 1997 Federal Highway Cost Allocation Study (HCAS)*, Federal Highway Administration, final report.

Chapter 2: Congestion Externalities and the Value of Travel Time Savings

2.1 Introduction

One of the most significant types of social costs of many transport operations is that associated with congestion. This is a classic example of externalities: users recognize that travel times and costs are higher under congestion, but individuals only recognize the costs they themselves incur and do not recognize the delay costs they impose on others. The full marginal social costs of a decision to operate on a congested system are greater than the costs recognized by an individual operator. It is an intra-sectoral externality in that the total costs of delay are borne collectively by transport users and not imposed directly on the rest of society, but it is an externality nonetheless.

Measuring the costs of congestion involves two components:

1) measuring the amount of delays borne individually and collectively by transportation users; and
2) estimating the value users place on these delays, i.e., the valuation of travel time savings (VTTS) or delays.

We address the latter first.

Both theoretical argument and empirical evidence confirm that people do place a value on time savings, and the evidence is that that valuation is significant. For example, the majority of economic benefits of nearly all transport investments are the estimated values people place on time savings brought about by the infrastructure investments. The importance attached to measuring VTTS has made it a prominent research issue in transport economics.

There is extensive literature on VTTS. The vast majority of the literature is associated with road transport, both urban and intercity. We review the concepts, measurement and developments in VTTS for road transport, and later turn to VTTS applications for other modes of transport. The literature on VTTS includes a number of survey articles that have reviewed both conceptual and empirical literature. There were a number of reviews of VTTS commissioned in the late 1980s and early 1990s. Our approach is to summarize and synthesize that literature, and then focus on subsequent research. There have been some advances in the VTTS literature. We identify those and draw on them to discuss the implications of VTTS estimates for a Canadian study of the full costs of transportation.

Ten sections follow, eight on VTTS, a longer section on congestion and a short section suggesting further research needs. The VTTS topics are: (1) a brief section on the underlying basis for valuing time savings; (2) the consensus on VTTS for road passenger transport circa early 1990s; (3) recent advances in VTTS research and estimates for road transport; (4) a review of VTTS literature concerning other passenger modes; (5) business travel time savings; (6) the value of freight time savings; (7) a review of a number of ongoing issues in measuring and interpreting VTTS estimates and how the estimates may be used; and (8) a summary that draws on the VTTS literature to make recommendations for values appropriate in the Canadian context.

2.2 The Basis for Valuing Delays or Time Savings

2.2.1. The Conceptual Basis for Valuing Time Savings

There is a compelling conceptual basis for time savings having a monetary value. If time saved (or time lost) is incorporated into production of goods and services, there is a direct link between increments of time and incremental valuable output. There is no conceptual dispute over the relevance of time saved if it translates into incremental output; the only debate is on the measurement of the value to be assigned to work time savings. For non-work time savings, there is more debate although the conceptual arguments are still compelling. In economic theory, households are presumed to trade leisure time for work, the wage rate being the marginal compensation for sacrificing time for money. In this situation, the incremental value of time would be indicated by the (before-tax) wage rate. If households do not control the number of hours worked, this could mean the incremental value of time could be above or below the wage (Moses and Williamson, 1963).

The next conceptual advance was to recognize that wages not only compensate for loss of leisure time, but also must compensate for any (marginal) disutility associated with working. Note that individuals may prefer working to not working overall, but it is generally presumed that there is disutility of work at least at the margin (Johnson, 1965; Oort, 1969; Evans, 1972). Hence the VTTS of non-work travel would be valued at something less than the wage rate because the latter must compensate households for the loss of leisure time as well as the marginal disutility of work.

But focusing on the income-leisure tradeoff was not sufficient to address the valuation of time savings. "Much of the early work was concerned with the tradeoff between time spent in work and time spent in leisure, and in itself has no direct relevance for the transport problem, which is concerned with time savings in specific activities." (MVA Consultancy, 1987, p.34)

It is plausible that the value of incremental time savings would depend on opportunities to make use of the time saved. This led to formulations that explicitly incorporated time as a resource, consumed to engage in activities just as a budget is consumed by the prices paid for goods and services. This concept originated from Becker (1965) and developed by Evans (1972) but especially by DeSerpa (1971). More fundamentally, does time enter directly in utility functions (time itself is valuable) or does it arise indirectly because time limits constrain consumption activities? Both concepts can be relevant. A concise and useful summary of DeSerpa's three concepts of time valuations is in Mackie, Jara-Diaz and Fowkes (2001) (a more thorough discussion is in MVA Consultancy, 1987, Chapter 3, p.33ff; Jara-Diaz, 2003 and see Appendix A to this chapter)[4]:

"He postulated a utility function dependent on all goods and all time periods (which he soon called "activities"), including work and travel. The technical constraints established that consumption of a given good required a minimum assignment of time. Within this framework, DeSerpa defined the value of time as a resource value of extending the time period, equivalent to the ratio between the marginal utility of (total) time and the marginal utility of income, μ/λ [also labeled the value of leisure time]. The second is the value of time allocated to a certain activity (value of time as a commodity), given by the rate of substitution between that activity and money in the utility function…. The third concept is the value of saving time in activity i ….[which is] equal to the algebraic difference between the value of time assigned to an alternative use (the resource value or value of leisure) and the value of time as a commodity." (Mackie, Jara-Diaz and Fowkes 2001, p.93.) [the latter component of valuation arises because consumers may have to allocate more than the desired amount of time to an activity, i.e., they do not have complete flexibility in adjusting time spent on activities]

Expressed still another way, there is a distinction between the value of time per se, and the value of time involved in a particular activity. They may be closely linked but are not necessarily identical.

In their review, Mackie, Jara-Diaz and Fowkes (2001, p.94) suggest two additional effects of time savings: "…the variation in goods consumption due to the substitution of travel for other activities…[and] the possibility of re-timing activities in order to undertake them according to a preferred schedule…." (e.g., Small, 1982). The latter may be particularly important. Especially in urban travel, but in travel generally, trips often serve more than one purpose and more than one destination. These are part of the broader organization of one's spatial life and activities. The usefulness of time savings likely will vary from one person to another, and vary day to day depending on the complexity of schedules and alternatives and hence the ability to modify activities in response to time savings (or delays). Note that a VTTS would quite likely be higher for permanent time savings that can be incorporated into activity schedules, compared to short term ephemeral time savings.

Looking over the conceptual foundation for VTTS, there are compelling arguments that travel time savings will have value. The VTTS can be only loosely linked to the wage rate which establishes a basis for the opportunity cost of leisure time, but the VTTS is influenced by several other factors including the flexibility of working hours, the disutility of work, the disutility of travel conditions, the flexibility in scheduling spatial activities and the relative utilities or disutilities of those activities. But there is no formula to produce specific numerical values for VTTS as a percentage of the wage. The VTTS is likely to vary both among individuals and for the same individual depending on a number of circumstances. There is no substitute for empirical investigation of VTTS and how it is

[4] A still more comprehensive review of the conceptual basis for the valuation of time savings is Bruzelius (1979).

related to circumstances. Hence the vast majority of VTTS literature focuses on empirical investigations rather than reliance on conceptual arguments.

2.2.2. Methods for Estimating VTTS

There are several approaches for estimating people's valuation of time savings. Broadly they are of two types: observed behaviour where people tradeoff time and money, or studies that rely on questionnaires to elicit people's valuation of time savings.

The majority of earlier studies used various "revealed preference" (RP) approaches. Situations are identified where people appear to exercise a choice between two activities that incur different costs but save time. For example, people may choose a faster toll bridge to avoid a slower but unpriced alternative. Examples of RP studies include the choice of toll routes, speed-choice models (imputing the VTTS by motorists' willingness to incur higher vehicle operating costs at higher speeds in order to save time), residential choice and travel times (people may accept a longer commute in exchange for lower land prices away from the city centre). The most common subject of RP studies is mode choice, inferring a VTTS from the observed choice between the faster but more costly automobile versus taking transit. A danger in all RP studies is the possibility that the choices people make may involve more than time-money tradeoffs. For example, automobiles offer greater comfort, privacy, and flexibility of departure time compared to transit. An imputed VTTS may be reflecting several variables rather than just time. Researchers have to devise ways of separating the influence of different variables on people's choice.

The second broad approach to estimating VTTS are "stated preference" (SP) or "stated choice" models.[5] These make use of questionnaires to get people to indicate their preference for hypothetical travel cost and time alternatives. The SP method can estimate the influence of otherwise correlated variables (e.g., journey speed and comfort are often correlated). The potential shortcoming of SP methods is that they are based on hypothetical choices; interviewees might not give accurate replies (of course, questionnaire design and administrative procedures can help guard against this danger).

In recent years, databases have been developed that combine RP and SP methods for the same population. The two methods can complement one another (e.g., SP methods can separate the influence of correlated variables affecting traveler behaviour) and provide a cross-check on their respective estimates of VTTS.

The methods of valuing non-market commodities are firmly based on the concept of *willingness to pay* (Bates and Whelan, 2001). In the present context, non-market commodities are aspects of travel which cannot directly be traded for money such as time savings. Given prices, the traveler arranges her expenditure to maximize utility U^* subject to a budget constraint I. An improvement made without charge increases the

[5] Direct estimation is another more direct approach in which people are offered cash payments to accept a delay or take a slower routing (Hauer and Greenough, 1982).

traveler's utility. The willingness to pay for such an improvement (also called *compensating variation*) is defined as the amount of money CV that has to be subtracted from the traveler's budget to bring her precisely back to the original utility level U^*. Hence, the traveler is indifferent between not having the improvement and having the improvement at a cost of CV.

The indirect utility function, denoted by V, has as its arguments the budget constraint I and the base journey time T (all other arguments are assumed to be fixed). An improvement that that reduces travel time by dT can then be expressed as

$$V(I,T) = V(I - CV(dT), T - dT)$$

The empirical methodology aims to estimate $CV(dT)$, the valuation of the travel time savings. The concept of willingness to pay in the travel time savings context is broader than the more narrow definition that might imply that estimation requires a situation in which travelers are given the choice of paying an amount of money in order to reduce their travel time.[6]

2.3 The Consensus on VTTS in the Early 1990s

The choice of the early 1990s to review the status of VTTS studies is an arbitrary time period, but it so happens there were a number of review studies conducted in the late 1980s and early 1990s. It is convenient to draw from these review studies and then essentially update our knowledge based on research and findings that have taken place in the past decade.

2.31 VTTS Review Studies

As noted, although there are literature and studies of VTTS issues dating back many years, there were several major reviews of VTTS commissioned in the late 1980s. Their origin was a desire to examine and assess the VTTS estimates being used to evaluate transport infrastructure investments, particularly road investments but also urban transit investments where savings in road congestion costs (including VTTS) were important.

Probably the largest and most thorough review of VTTS was that carried out in the UK by MVA Consultancy in collaboration with the Institute of Transport Studies at Leeds University and the Transport Studies Unit of Oxford University (MVA Consultancy, et al., 1987). This review was funded by the UK Department of Transport. The report reviewed both conceptual foundations and empirical approaches. A number of behavioral hypotheses were developed and investigated, a number of studies and surveys were

[6] The narrow definition of willingness to pay (WTP) is often used in comparison to willingness to accept compensation (WTA) in contingent valuation studies with the commonly observed result that WTP values are lower than WTA values.

commissioned in connection with the study. They found that the VTTS varied with a number of personal and journey characteristics.

In the United States, the revisions of the American Association of State Highway and Transportation Officials (AASHTO) guidelines for highway investment appraisal included a review of VTTS estimates (Texas Transportation Institute, 1990). They reviewed a number of studies and approaches, and tended to emphasize speed-choice or route-choice models rather than rely on mode-choice studies for estimates of VTTS. The latter involve choice of modes which is not a characteristic of the vast majority of highway users. Speed-choice models examine motorists' behavior in willingness to incur higher costs of higher speed driving in exchange for time savings; similarly, route-choice studies compare motorists' choices of more costly but faster routes. The route-choice and speed-choice models produced VTTS estimates of about 60-88 percent of the wage, compared to generally lower estimates from mode-choice studies (Texas Transportation Institute, 1990, pp. 86-88), and recommended a VTTS of about 80 percent of the wage.

Miller (1989) and Beca Carter Hollings & Ferner (1991) carried out VTTS studies for New Zealand. They reviewed a number of VTTS studies, and recommended a base VTTS of about 60 percent of the wage with adjustments *inter alia* for driver as opposed to passenger. Ted Miller's work was also influential in highway project evaluation in the U.S.; his recommendations were incorporated into HERS (Highway Economic Requirements System) and into recommendations from the U.S. Department of Transport (1997).

Bates and Glaister (1990) carried out a review for the World Bank. It was mostly a conceptual review. They drew on empirical evidence from MVA Consultancy (1987) and the Netherlands' value of time study. Other significant studies include the Netherlands' Value of Time Study (HCG, Hague Consulting Group, 1990). They explored the implications of various personal and trip attributes on VTTS. Subsequent studies were carried out in other countries including Norway and Sweden.

Lawson (1989) reviewed the VTTS literature up to that time and made some conclusions and recommendations for Canada, a selection of which are mentioned below:

- VTTS-estimates for non-work purposes exhibit large variation within a range of 20%-80% of the average wage rate.
- Employers might be willing to pay more than the gross wage for time savings on work trips although few studies have focused on this.
- VTTS increases with income independently of the mode of travel but less than proportionately.
- VTTS varies systematically across modes, with higher-priced modes having higher VTTS.
- VTTS does not vary across non-work trip purposes.
- Waiting and walking time is valued twice to four times in-vehicle time

- Evidence points out that the unit value of time is lower for small travel time savings and falls with the length of the trip

Waters (1992a, 1996) provides a summary and compilation of a large number of VTTS studies. Various studies were reviewed and their results expressed in Table 2.3.1 as a percent of the average wage for the sample.[7]

[7] People will make tradeoffs between time and money focusing on their after-tax income. However, these data rarely are available. As a result it is common practice to express the estimated monetary value of time as a percent of the gross or before-tax wage.

Table 2.3.1: Early Empirical Estimates of Travel Time Savings (VTTS)

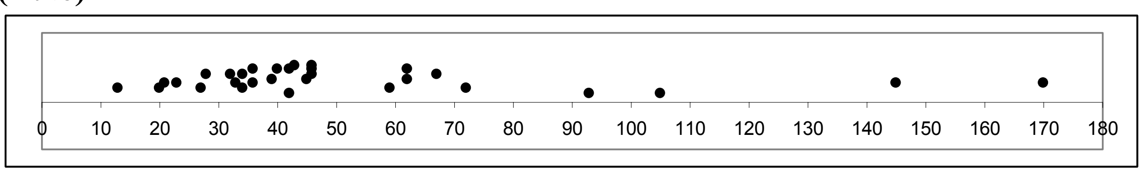
Author(s)	Country	VTTS as % of Wage Rate	Trip Purpose	Mode
Dawson and Smith (1959)	UK	86%	Interurban	Auto
Mohring (1960)	USA	22-43%	Commuting	Auto, Transit
Claesson (1961)	Sweden	64%	-	-
Claffey et al. (1961)	USA	65%	Interurban	Auto
Becker (1965)	USA	42%	Commuting	Auto, Transit
Beesley (1965)	UK	33-50% [A]	Commuting	Auto
Lisco (1967)	USA	40-50%	Commuting	Auto
Thomas (1967)	USA	72%	Commuting	Auto
Quarmby (1967)	UK	20-25%	Commuting	Auto, Transit
Lave (1986)	USA	42%	Commuting	Bus, Auto
Slopher (1986)	UK	21-32% [A]	Commuting	Auto, Transit
Oort (1969)	USA	33%	Commuting	Auto
Lee and Dalvi (1969)	UK	30%	Commuting	Bus
Hansen (1970)	Norway	36%	Commuting	Auto, Transit
Thomas and Thompson (1970)	USA	40-85%	Interurban	Auto
Howe (1971)	Kenya	102%	-	-
Lee and Dalvi (1971)	UK	40%	Commuting	Auto
Wabe (1971)	UK	43%	Commuting	Subway, Rail
Charles River Associates (1971)	USA	32%	Commuting	-
Dawson and Everall (1972)	Italy	60-89%	Interurban	-
Talvittie (1972)	USA	12-14%	Commuting	Auto, Transit
Kentner (1973)	Germany	91%	-	-
		40%	-	-
Algers et al. (1974)	Sweden	21%	Commuting	Auto, Transit
Hensher and Hotchkiss (1974)	Australia	2.7%	Commuting	Hydrofoil, Ferry
Hensher and Delofski (1974)	Australia	39%	Interurban	-
Kraft and Kraft (1974)	USA	38%	Interurban	Bus
O'Farell and Markham (1975)	Ireland	86%	-	Auto, Rail
McFadden (1975)	USA	28%	Commuting	Auto, Transit
Ghosh, Lees and Seal (1975)	UK	73%-89%	Interurban	Auto
McDonald (1975)	USA	45-78% [A]	Commuting	Auto, Transit
Ghosh et al. (1975)	UK	73%	Interurban	Auto
Guttman (1975)	USA	63%	Leisure	Auto
		145%	Commuting	Auto
Hensher (1977)	Australia	39%	Commuting	Auto
Hensher and McLeod (1977)	Australia	35%	Leisure	Auto
Nelson (1977)	USA	20%	Commuting	Auto, Rail
Hensher (1982)	Australia	23-45%	Commuting	Auto
Hauer and Greenough (1982)	Canada	46%	Commuting	Auto
Edmonds (1983)	Japan	67-101% [E]	Commuting	Subway
Thomas (1983)	Malaysia	42-49% [B]	Commuting	Auto, Bus, Rail
Algers and Widlert (1985)	Sweden	52.5%	Commuting	Taxi, Bus
Chui and Farland (1985)	USA	20-30%	-	All Modes
Deacon and Sonstelie (1985)	USA	82%	Interurban	Auto
Hensher and Truong (1985)	Australia	52-254% [A]	Leisure	Auto

Guttman and Memashe (1986)	Israel	1055	Commuting	Auto, Transit
Fowkes (1986)	UK	59%	Commuting	Auto, Bus
Hau (1986)	USA	27-59% [C]	Commuting	Rail, Coach
Winston and Associates (1987)	USA	46% [D]	Commuting	Auto, Bus
Horowitz (1987)	Australia	75%	Interurban	Auto
Bates et.al (1987) Route Choice	UK	68%	Interurban	Auto
		43%	Commuting	Auto, Transit
Bates et al. (1987) Survey	UK	62%	Commuting	Auto, Transit
Chui and Farland (1987)	USA	82%	Interurban	Auto
Mohring et al. (1987)	Singapore	60-120% [A]	Commuting	Bus
Hensher (1989)	Australia	36%	Commuting	Auto
Hensher (1990)	Australia	34%	Commuting	Auto
Cole Sherman (1990)	Canada			
	Comparison	93%	Commuting	Auto
		116%	Leisure	Auto
	Logit	170%	Commuting	Auto
		165%	Leisure	Auto

Source: Waters (1992, 1996), Bruzelius (1979), Cherlow (1981), Miller (1989) and TTI (1990).
[A] Varies with income of the traveler.
[B] Estimates are sensitive to the data selected.
[C] Varies with income of the traveler and the model used.
[D] paper use 5.71% of daily income in its model (8 hour day is assumed).
[E] Inferred values (study actually valued waiting time).

A plot of results for urban commuting by car is in Figure . It shows a wide range of estimates but VTTS estimates cluster between 35 to 60 percent of the wage rate.

Figure 2.3.1.: Scatter Plot of Commuter Time Savings as a Percent of Average Wage (Auto)



Source: Waters (1996).

There was some indication that estimated VTTS might be rising over time (Waters, 1996). A review of VTTS values used for road project evaluation in various countries and jurisdictions was consistent with the empirical evidence. There are various unresolved issues regarding VTTS estimates and a discussion of the ongoing debate on those issues can be found in Section 2.8.

2.3.2 VTTS Employed by Various Public Agencies, Ca. Early 1990s

The economic evaluation of transport projects incorporating valuation of travel time savings has been in use in some places since about 1960. Nonetheless, by 1990 the practice varied considerably across countries and jurisdictions. Some state/provincial highway authorities relied on ad hoc technical criteria including "sufficiency ratings," and some were explicit political allocations of road funds. Building on a review for British Columbia (Waters, 1992a), Waters (1996) reported the values being used for VTTS in a number of countries and road jurisdictions (further details are in Waters 1992b). Some used various valuations depending on type of vehicle and user, while others adopted a single figure. Table 2.3.2 lists the base VTTS figures expressed in 2002 C$.[8] There is a ten-fold range of VTTS used for road project evaluation, but a clustering around $5 to $8 per hour for non-work VTTS. At least part of the latter variation could be explained by differences in income levels across countries. A VTTS of about $7.00 per hour would be representative, which would be about 50 percent of the (before tax) average wage. It should be borne in mind several jurisdictions would apply various adjustments to increase or lower the base VTTS depending on travel conditions, user characteristics, trip purpose, etc.

[8] The figures presented in **Table 2.3.2: Summary Comparison of Values of Travel Time Used for Road Project Evaluation in Various Countries and Government Agencies around 1990.** must be regarded as approximate. There were rounding errors in the original conversion from different currencies and years, and now these figures have been indexed to 2002 C$ from 1990 $AUS.

Table 2.3.2: Summary Comparison of Values of Travel Time Used for Road Project Evaluation in Various Countries and Government Agencies around 1990. [9]

Country/jurisdiction	$/vehicle hr. (non-work time)	$/person hr. (non-work time)	$/person hr. (work time)
United States			
AASHTO (used by several states)	$ 20.87	$ 16.05	$ 16.05
California	$ 10.17	-	-
Florida	$ 20.34	$ 17.25	-
New York		$ 6.34	-
Canada			
Transport Canada		$ 7.27	$ 24.29
Ontario		$ 3.52	$ 13.19
Quebec		$ 2.47	$ 11.79
Alberta		$ 7.14	$ 15.48
British Columbia		$ 6.99	$ 20.97
Europe			
United Kingdom		$ 5.98	-
Germany		$ 1.64	$ 9.92
Finland		$ 5.36	$ 23.95
Holland (base figure) (avg adjusted) Sweden (rural)		$ 4.32 $ 7.84 $ 6.69	$ 5.61 $ 12.23 $ 36.14
Australia			
New South Wales (rural)		$ 7.85	$ 29.65
South Australia (rural)		$ 3.87	$ 14.65
New Zealand		$ 5.14	$ 16.01

Source: Waters (1992b).

2.3.3 Current Practice of Transport Canada and AAHSTO

Current Canadian practice employed for investment appraisal is outlined in the most recent *Guide to Benefit-Cost Analysis in Transport Canada* dating from September 1994. According to the guide, the average travel-time savings for business trips should be valued at the hourly cost of an employee to the employer. The value of business travel-time savings is reported (at time of issue) to be $40.80 per hour for air travelers, $29.05 per hour for automobile travelers, and $28.70 for bus and rail travelers.[10] Recognizing

[9] These figures are dated and might not reflect current practice of the specific jurisdiction.
[10] All figures are in 2002 C$. However, these numbers have not been updated since 1994 to reflect increased real wages.

that not all time traveling might be wasted, the Department of Transportation has adopted the practice of reducing the values of time by 25% in situations in which work can be done while traveling.

For non-business travelers, Transport Canada does not distinguish between modes used or the traveler's income.[11] The value of time for adults is 50% of the national average wage[12], or $9.00, while the value for children under the age of 17 is half the adult's value. If travelers cannot be separated into adults and children, the guide suggests a weighted average consisting of 25% children. If the composition of travelers into business and non-business is not known, then the guide suggest using the following percentage of business travelers: 58% for air travelers, 16% for rail travelers, 6% for bus travelers and 10% for auto travelers.

Furthermore, small travel time savings below 5 minutes should not be included in the benefit calculation but reported separately enabling decision-makers "to weigh those effects as it sees fit."

Freight value of time is calculated by multiplying the freight by the amount of time saved and the carrying cost of the inventory where those carrying costs should be proxied by the prime interest rate. Benefits of freight travel time savings due to distributional and logistics improvements (for example, Just-In-Time practices) will be considered separately.

The updated AAHSTO guidelines for assigning values of time in highway project analysis (AAHSTO, 2003) take 50% of the wage rate as the standard value for commuting and local personal travel by car and bus. The value of time is increased to 70% for personal intercity (automobile) travel to reflect the positive distance elasticity. Waiting, walking and transfer time is valued at twice the standard rate. The value of business travel time savings is 100% of total compensation (incl. labor overhead) for automobile and bus travel and truck occupancy is assumed to be one.

2.4 Recent Advances in VTTS Research and New Estimates

Starting in the late nineties, a few developments have improved the understanding and interpretation of previous estimates as well as sharpening existing VTTS estimates through superior data. Important advances in methods and data will be outlined in this section. None of these new developments renders previous estimates useless; they improve the understanding of biases and drawbacks of traditional empirical methods used in VTTS-research. Advances in VTTS research have come on several fronts:

---

[11] It is evident that such an approach of fragmenting one group of travelers (business) while purposely bunching another (non-business) is inconsistent even when equity considerations are taken into account.

[12] The specific reference to the national average wage rate implies that no regional differences are taken into account, probably in an attempt to eliminate the bias in favor of project in urban, high-income regions.

The establishment of toll roads in California has created a wealth of excellent data regarding automobile commuters and their travel decisions that shed new light on the VTTS. Several studies in recent years have greatly benefited from such superior data sets.

Apart from providing specific VTTS estimates related to those toll-roads, this new wave of studies based on the superior data from toll-roads has in addition helped clarify several methodological characteristics of traditional VTTS-studies. Although there is no consensus regarding the preferred investigation method, researchers in the field have been well aware that estimates based on stated preference data tend to result in lower values of time compared to estimates based on a revealed preference approach (Brownstone et al. 2003). The ability to collect overlapping SP-data/ RP-data from the toll road experiments offers an opportunity to investigate the quite large differences of estimates in previous studies between those two methodological approaches. Travelers' familiarity with toll-roads through personal experience frames the hypothetical choices of SP-data in a context commuters are likely to understand, a crucial requirement for meaningful SP-estimates. Combining the two sources of information allows researchers to benefit from the controllability of SP-data in addition to the realism of RP-data.

Typical VTTS estimates jointly capture several related but different phenomena about the benefits of travel time savings and recent research has attempted to disentangle the separate effects.[13] For example, recent superior data sets have allowed researchers to separate the value of travel time savings from reliability (variance of travel time savings). Such new insights as well as sharpened estimates about the different valuation of time spent in congested and uncongested traffic have important implications for the external cost of congestion and other relevant policy issues.

2.4.1 Stated Preference Studies

The most popular approach to estimate VTTS has been transportation mode choice models. The value of travel time savings is inferred from urban commuters' trade-off of travel time and cost as revealed by their choice of transportation mode. The drawback of this method is that mode choice models tend to capture differences in the "disutility" from spending time on crowded public transport buses or trains versus spending time alone in a car. With respect to automobile users, the VTTS-estimates are generally upward biased since the relative comfort, convenience and privacy are less desirable on alternative transport modes. Such differences can lead to misleading conclusions and are inappropriate to estimate the value of time for automobile commuters.[14]

Stated preference data (SP) have other statistical advantages over revealed preference data (RP). Explanatory variables in RP-data might not exhibit enough variation to

[13] See the special issue on value of travel time savings of *Transportation Research Part E: Logistics and Transportation Review 37, 2001*.

[14] Small (1992a) shows how the value of travel time is influenced by the traveler's opportunity cost of work (disutility of work). In addition, estimates from mode choice models further include the disutility of alternative travel modes.

identify crucial parameters with confidence. SP-data allows for the independent variation of single explanatory variables. In addition, contrary to RP-data it is able to capture more than the first travel choice of commuters, additional information that can help identify the parameters of interest. Nonetheless, SP-data has some drawbacks in itself. The survey must be designed to generate an accurate ordering and appropriate econometric techniques have to be employed to obtain consistent and efficient estimates. The complexity of stated preference surveys can lead respondents to make inconsistent choices, a situation in which the implicit valuation intervals of two choices do not overlap. Saelensminde (2002) shows based on a Norwegian value of time study by Ramjerdi, Rand, Saetermo and Saelensminde (1997) that failure to exclude such inconsistent choices with the stated preference method can result in a substantial upward bias in VTTS estimates.

In two recent studies, Calfee and Winston (1998) and Calfee, Winston and Stempski (2001) employed the SP approach focusing solely on automobile commuters' stated value of time under varying travel conditions (pricing and congestion). The survey respondents were automobile commuters in major U.S. metropolitan areas who were accustomed to preference surveys and who regularly drove to work and faced some congestion.[15] The different scenarios presented offered different combinations of travel time savings, congested versus uncongested time and different scenarios for the use of the collected revenue if there was a toll road. In addition, a 'smart car' technology has been introduced under some scenarios in order to avoid a toll road policy bias.[16] Based on a rank-ordered logit model[17], the results suggests that commuters' average value of travel time savings ranges from 14-26% of the average wage rate with a mean around 19%, a significantly lower value compared to other studies. Special scenarios have been designed to conclude that none of these savings reflect the value of smaller variation in travel times (while holding the size of time savings constant). The results are insensitive to the payment mechanism or the use of the collected revenues. Furthermore, the results suggest that commuters value travel time savings in congested traffic three times as much as savings of uncongested travel time. Consistent with the main bulk of studies[18], VTTS is found to vary with income, in specific, commuters' VTTS as a fraction of the wage rate increases less than proportionately with income.

Consensus from previous literature is that VTTS increases with income and time savings in congested traffic are valued considerably more than savings in uncongested traffic,

[15] Research on the stated preference method has shown that it is crucial that the survey respondents are familiar with hypothetical choice in such surveys (Bates, 1988). The respondents in this particular study are members of a nationwide mail panel (National Family Opinion).

[16] If the time savings are the result of a public intervention such as toll roads, responses may capture to some extent the commuters' preference for or against toll roads apart from the value of time. Hence, the scenario 'smart cars' involves a box that guides users through traffic and allows time savings without any tolls imposed.

[17] The rank-ordered logit – as other conventional ordered models – can produce biased and inconsistent estimates because they restrict the 'spacing' of consumer preferences. However, Calfee, Winston and Stempski (2001) show that the derived value of time estimates are surprisingly robust relative to more flexible statistical procedures such as the mixed logit model.

[18] MVA consultancy (1987).

although typically not by a factor of three. Given that stated preference studies tend to obtain lower VTTS estimates, the estimates derived in these two studies are mostly in line with previous studies, especially considering these stated preference studies do not include any value of reliability in the VTTS estimates.

A stated preference study has recently been conducted in the Canadian context by Steer Davies Gleave (2004) who conducted over six hundred SP-interviews with car drivers and over 150 interviews with road freight operators in the BC's lower mainland for an evaluation of the New Fraser River Crossing.[19] Based on this research, an average value of time of C$12.20 per hour for car drivers was derived that has been additionally split by mode into commuting (C$10.40), business (C$18.40) and other trip purposes (C$12.50).

Based on the same framework, Steer Davies Gleave (2004) have also derived the value for road freight vehicles: The estimated average value of time was C$34.97 per hour, which can be split into the value of time for light trucks (C$28.47) and heavy trucks (C$40.65).

2.4.2 Toll-Roads Experiments

Beginning in 1994, a series of demonstration projects with congestion pricing have created an exceptional wealth of data that allows researchers to gain insights previously unattainable due to data limitations. Two projects in Southern California and one in the Houston area have combine high-occupancy lanes and congestion pricing into "High Occupancy/Toll (HOT) lanes.[20] A set of express lanes in which traffic flows fast on an otherwise free to use but congested road is offered to people who are willing to pay a time-varying toll.

The State Route 91 project (SR91) in Orange County (CA) (California, USA) is a set of express lanes of 10 miles linking employment centres and residential communities. The electronic toll collection has a time-varying pricing structure in which prices vary by hour, day of the week and direction of travel. The Interstate 15 project (I-15) allows single occupancy vehicles to use reversible carpool lanes on an eight mile segment that links the employment-centres of San Diego with suburbs. The toll is electronically collected and it employs 'dynamic pricing', i.e. the price is varied in real-time to prevent the express lanes from being congested.

Brownstone, Ghosh , Golob , Kazimi, and van Amelsfort (2002) employed RP- data from the I-15 road congestion pricing project in San Diego. They estimated the median value of road users' willingness to pay for time savings is $38 (2002 C$) per hour, which

[19] All figures from this study are in 2004 C$.
[20] Those lanes are sometimes referred to 'Lexus lanes' because it is thought that those with higher incomes hence luxury cars would be more willing to pay tolls..

accounts for 88% percent of the average wage rate in California.[21] The authors argue that the result overestimates the VTTS, partly because toll lane users can potentially benefit from improved driving conditions and safety on top of the value they place on time savings. Lam and Small (2001) measure the value of time and reliability from revealed preference survey data on actual behavior of commuters on State Route 91 in Orange County, CA (SR91) in 1998. Their estimates suggest that the value of median travel time is around $24 (2002 C$) per hour or 61% of the average wage rate in that sample. Small, Winston , and Yan (2002) use an overlapping RP- and SP-data set from State Route 91 in California. The median estimated value of time based on commuters' revealed preferences is $25 (2002 C$) per hour or 87 percent of the average wage. Results compiled from different studies on the SR91 and the I-15 projects by Brownstone and Small (2003) suggest that the median value of time based on revealed preference data is typically between 50%-90% of the average wage rate.

2.4.3 Time Savings and Variability

Researchers have been well aware that VTTS estimates are a compound of several separate characteristics related to travel time. Typical estimates are composed of the "value of time" (VOT), i.e. the marginal rate of substitution of travel time and money in the agents' indirect utility function as well as the "value of reliability" (VOR) the willingness to pay for reductions in the variability of travel times. VOT and VOR could not be identified in revealed preference studies due to data limitations.[22] The superior data from toll roads provides an opportunity to disentangle the two separate effects and establish their relative weight in the compound estimates. Brownstone and Small (2003) employ data from the SR91 project in Orange County which contains sources of independent variation in travel time, travel cost and reliability (variation in travel times), a necessary requirement for the identification of the separate effects of VOT and VOR.

Measuring reliability requires a set of observations of speeds across days (by time of day), which are derived from loop detectors. Some measure of the upper tail of the distribution of travel times is preferred, since the standard deviation will not adequately capture traveler preferences. The most common theory why travelers do not like unreliable travel times is the unexpected arrival time at work (Bates, Polak, Jones and Cook, 2001). These costs are unlikely to have a symmetric effect; costs of unexpectedly arriving late at work supposedly exceed early arrival costs. As a measure of the chance to be substantially later than expected, Lam and Small (2001) as well as Brownstone and Small (2003) use the difference between the 90^{th} and 50^{th} percentile travel times. Given this measure it is found that reliability (VOR) is measured somewhere between 95%-140% as highly as median travel times. Small, Winston, and Yan (2002) using overlapping RP- and SP-data from State Route 91 in California) estimate the median

[21] Although the estimates have been translated into 2002 C$ and adjusted for purchasing power differences, average incomes are higher in California and the estimates would have to be adjusted using the income elasticity of VTTS (see section 2.8.7) for VTTS-recommendations for Canada.

[22] In recent years, studies based on stated preference have started to create scenarios that allow disentangling the separate effects of VOT and VOR (see Calfee and Winston, 1998).

value of reliability at $24 per hour (~60% of average wage rate per hour), where the difference between the 90^{th} and 50^{th} percentile travel times is employed as a reliability measure. The authors then multiply these values by the actual travel times and reliability differences in the sample and find that travel times account for about two-thirds and reliability for one-third of the quality differential between free and express lanes.[23]

Key findings from recent stated preference studies and toll-road experiment studies including their key findings of the value of reliability are summarized in Table 2.4.3:

Table 2.4.3: Recent VTTS Studies

Authors	Year	Project	RP/SP	Findings
Calfee, Winston, (and Stempski)	1998/ 2001	Major US Metropolitan Areas (United States)	SP	• Median VTTS 19% (14-26%) of average wage rate. • Variability excluded in estimate • VTTS congested/uncongested approx. 3 • VTTS varies less than proportionately with income
Saelensminde	2002	Norway	SP	• Inconsistent choices in SP-data result in significant upward bias of VTTS
Brownstone and Small	2003	State Route 91 (Orange County, CA) Interstate 15 (San Diego, CA) (United States)	RP/SP	• Median VTTS 50-90% of average wage • VOR (90^{th}-50^{th} percentile of travel times) valued at 95-140% of median travel time (1/3 of quality differential). • Overlapping RP-SP set: median SP half of median RP • VOR and VOT not sensitive to error structure (contrary to Hensher 2001b)
Hensher	2001b	Sydney-Canberra Corridor (Australia)	SS	• Fewer restrictions on the error structure can double VTTS: tendency towards higher mean estimates as restrictions are relaxed. • Error structure implies behavioral role of unobserved influences • Tendency to underestimate VTTS
Abay, Axhausen, and König	2003	Switzerland	SS	• VTTS $18.75 • VTTS congested/uncongested approx. 1.25
Brownstone and Steimetz	2003	Interstate 15 San Diego, CA (United States)	RP/SP	• Median VTTS ~70% of average wage • Considerable heterogeneity 20% (part-time workers) - 150% high income commuters
Brownstone, Ghosh, Golob, Kazimi and van Amelsfort	2002	Interstate 15 San Diego, CA (United States)	RP	• Median VTTS 88% of average wage rate. • Variability excluded in estimate. • VTTS significantly higher than other studies. • Possible overestimate of VTTS due to quality of toll lane (safety, better condition).

[23] Lam and Small (2001) find that women have a roughly twice as high a value of reliability (VOR) than men. Scheduling flexibility seems to be smaller for women in general as they are running on tighter schedules. This fact might explain the consistent finding across nearly all studies that women are more likely than men to choose the toll road.

Lam and Small	2001	State Route 91 (Orange County, CA) Interstate 15 (San Diego, CA) (United States)	RP	• VTTS 72% of average wage rate. • VOR (90^{th}-50^{th} percentile of travel times) is valued at 50% of average wage rate,
Small, Winston, and Yan	2002	State Route 91 (Orange County, CA) Interstate 15 (San Diego, CA) (United States)	RP/SP	• Median VTTS 87% of average wage rate. • VOR (90^{th}-50^{th} percentile of travel times) is $24 (60% of average wage) • People with low VTTS choose to live far from workplace. • Large heterogeneity in motorists' preferences for speed and reliability.
Steer Davies Gleave	2004	Lower Mainland (BC, Canada)	SP	• Average VOT 2004C$ 12.20 • Trip purpose: Commuting C$10.40 Business C$18.40 Other C$12.50

2.4.4 Travel Time Savings in the UK

A study was commissioned by the UK Department of Transport, which purpose it was to review the evidence, relevant principles, and practical considerations and to make recommendations regarding values of travel time savings. The meta-analysis undertaken by Institute for Transport Studies at the University of Leeds (Mackie et al., 2001) reviews the evidence in the UK as well as other jurisdictions.[24]

Mackie et al. (2001) consider both theoretical and empirical evidence. On the empirical side, the two main sources of evidence are the AHCG report and the Meta-Analysis Dataset. The AHCG report was commissioned by the UK Department of Transport in 1994 to study the valuation of travel time savings on the road and was conducted by a consortium of Accent Marketing and Research and the Hague Consulting Group (AHCG). The report was published in 1999. The second source consisted of the Meta-Analysis Dataset which includes the results of many studies for private and public sector clients that provides an independent check on the AHCG findings in addition to extending the scope to VTTS for public transport and time-series evidence, topics not covered in the AHCG report. All empirical evidence is restricted to studies conducted in Great Britain. Such empirical evidence drawn from these two sources is considered against the relevant theoretical literature and evaluation practice in various European countries. Theoretical reasoning is not only relevant for business VTTS, but also provides a framework for considering the values for non-working time. The review of evidence by Mackie et al. (2001) is quite extensive and the key findings are discussed in the relevant sections, particularly Section 0 and Section 2.8.

[24] The summary report is Mackie et al. (2001) and a shorter version of the same findings is Mackie et al. (2003). The report is based on the six working papers in the same series of reports: Bates and Whelan (2001a), Fowkes (2001a), Fowkes (2001b), Wardman (2001b), Bates and Whelan (2001b) and Wardman (2001c).

2.5 VTTS for Other Modes

Two main results emerge when in-vehicle VTTS is compared across different modes: First, studies generally find that *for a given set of individuals*, the value of travel time savings varies across modes. Compared to travel time savings for car, car users have a higher VTTS for bus and a lower VTTS for rail other things being equal (Mackie et al., 2001). This is a comfort or quality effect and might be decomposed into various attributes such as reliability, chance of a seat, crowding, etc.

On the other hand, average VTTS on different modes vary because of the different social and income composition of the traffic and different distributions of journey length. Mackie et al. find that rail and car have similar valuations while valuation for bus travel is about half that of other modes, which indicates that aggregating across individuals to the level of "user types" reverses the valuation pattern. It is not the mode per se, but the characteristics of traffic which causes the average VTTS on bus to be low. This second effect is a person-effect rather than a modal effect and should be handled through proper adjustment of income, journey and other socio-economic characteristics across modes.

It has been the convention to differentiate the value of time by mode. There are no objections to such an approach in so far as the differences across modes reflect users' valuation of differences in comfort, cleanliness and other characteristics of spending time on each mode. Hence, the interest is restricted to VTTS variations due to innate modal quality differences. From a theoretical standpoint, it would be preferable though to tie the modal values that vary for the same individual to specific quality attributes rather than time. The current practice of lumping all these "quality" attributes into the time coefficient have made it difficult to find statistically robust values. Further research to decompose the modal quality characteristic from the value of time should certainly be encouraged.

2.5.1 Rail Travel Time Savings

Most studies assessing travel time savings on rail assess the evidence in comparison to road VTTS. As previously mentioned the major issue in explaining variation across modes is the distinction between "user type" variation and intrinsic "mode" variation.

The first British value of time study by MVA consultancy (1987) is characterized by the inability to segment by user type and hence the results are a combination of user type and mode effects. Table 2.5.3a indicates that for urban travel bus users have lower values than car users, which is consistent with user type effects dominating mode effects. For inter-urban travel, the pattern is reversed and the relationship between bus and car suggests that mode effects are strong.

Table 2.5.3a: Ratio of VTTS across Modes (MVA Consultancy, 1987)

	Car	Bus	Rail
Urban Commute	**1**	**0.65**	**0.65**
Urban Leisure	**1**	**0.30**	**-**
Inter Leisure	**1**	**1.05**	**1.55**

The coefficient for car is normalized to 1.
Source: MVA Consultancy (1987).

Somewhat similar patterns of the user effect dominating the mode effect can be observed in the estimates for the Dutch value of time study by Gunn et al. (1999) reported in Table 2.5.1b:

Table 2.5.1b: Ratio of VTTS across Modes (Gunn et al., 1999)

	Car	Train	Bus/Tram
Commute	**1**	**0.75**	**0.69**
Business	**1**	**0.64**	**0.43**
Other	**1**	**0.88**	**0.83**

The coefficient for car is normalized to 1.
Source: Gunn et al. (1999).

Estimates of rail travel time savings in Canada are presented in Table 2.5.1c and contrasted with other stated preference studies. Road VTTS results from the same studies are shown for comparison purposes. In addition, estimates of the value of reliability (VOR) for rail and road travel by Cole-Sherman (1990) are reported in Table 2.5.1d:

Table 2.5.1c: Value of Rail and Road Travel Time Savings (Cole-Sherman, 1990)

Mode	**Value of Travel Time Savings**			
	Ontario/Quebec[A]	**New York State**[B]	**Illinois**[C]	**Ohio**[D]
Rail				
Business	**$ 36.2**	**$ 37.7**	**$ 39.9**	
Non-business	**$ 27.8**	**$ 30.5**	**$ 19.0**	
Car				
Business	**$ 36.5**	**$ 38.5**	**$ 33.2**	**$ 23.2**
Non-business	**$ 24.8**	**$ 38.5**	**$ 19.9**	**$ 19.3**

All figures are in 2002 C$.
Sources: [A] Cole-Sherman (1990): Figures presented are the average estimate from the two methods.
[B] Cole-Sherman (1989): New York State Rail Ridership Study.
[C] Transmode (1987): Illinois Inter-City Rail Passenger Upgrading Study—Market Analysis.
[D] Transmode (1985): Market Analysis of High Speed Rail Services in Ohio.

Table 2.5.1d: Value of Reliability in Rail and Car Travel

Mode	Value of Reliability (VOR) per person	
	Business	*Non-business*
Rail	**$ 74.8**	**$ 54.9**
Car	**$ 67.1**	**$ 53.1**

All figures are in 2002 C$.
Source: Cole-Sherman (1990).

2.5.2 Air Travel Time Savings

There exist a few old revealed preference studies from the United States that have estimated the value of air travel time (VATT). De Vany (1974) estimates the VATT to be close to the average wage rate, which is consistent with the findings by Brown and Watkins (1971). Gronau (1970) used a similar approach in assuming that the value of time is proportional to the wage, and found the best model fit if the proportional coefficient is equal to one. The consensus view at that time was that air travelers value their time at their wage rate and such values for air travel time have been incorporated in many studies.[25]

We suggest that no substantial emphasis should be placed on VATT derived from these early studies. They are generally are outdated, do not benefit from theoretical and empirical advances of recent years and tend to ignore the heterogeneity among different types of travelers (personal, business, or general aviation, etc). There have been a few more recent studies as well as an updated version of recommendations on the value of air travel time by the US Department of Transportation that is based on expert consultations.

Cole Sherman Consulting (1990) estimates VATT and the value of reliability (VOR) in air travel using Canadian revealed preference data based on an extensive four-mode transportation behaviour survey along the Windsor-Toronto-Ottawa-Montreal corridor. Individuals were given survey questions during their travel. Results from a binary logit-model and the comparison method_show very similar results, which correspond closely with previous stated preference studies such as Cole-Sherman (1989) and Transmode (1985, 1987). The values for air travel time from the above mentioned studies are represented in Table 2.2.2a: while Cole-Sherman's estimates for the value of reliability in air travel are shown in Table 2.2. 2b:

Table 2.22a: Recent Studies on the Value of Air Travel Time

Mode	Value of Air Travel Time			
	Ontario/Quebec[A]	New York State[B]	Illinois[C]	Ohio[D]

[25] See for example Carlton, Landes and Posner (1980).

Air				
Business	**$ 85.7**	**$ 73.8**	**$ 78.0**	**$ 38.6**
Non-business	**$ 45.9**	**$ 46.5**	**$ 26.6**	**$ 31.8**

All figures are in 2002 C$.
Sources: [A] Cole-Sherman (1990): Figures presented are the average estimate from the two methods.
[B] Cole-Sherman (1989): New York State Rail Ridership Study.
[C] Transmode (1987): Illinois Inter-City Rail Passenger Upgrading Study—Market Analysis.
[D] Transmode (1985): Market Analysis of High Speed Rail Services in Ohio.

Table 2.2.2b: Value of Reliability in Air Travel

Mode	**Value of Reliability (VOR) per person**	
	Business	***Non-business***
Air	**$ 103.0**	**$ 59.7**

All figures are in 2002 C$.
Source: Cole-Sherman (1990).

The US Department of Transportation issued guidelines and recommended values for aviation passenger travel time savings that are derived from the wage rate. The recommended values are derived from the *Air Travel Survey* conducted in 1998 by the Air Transport Association of America, escalated by the increase in median annual income for U.S. households over the two years from 1998 to 2000. The value for business travel is 100 percent of the annual income category in the survey for "business" divided by 2000 hours of work per year. The value for personal travel is 70 percent of the annual income category in the survey for "Other" divided by an assumed 2000 hours of work per year. When considering general aviation passengers as a separate category, a value of 70 percent of the median hourly income is established for personal travel and 100 percent of median hourly income for business travel. The fractions of 70 percent and 100 percent have been recommended by a panel of transportation economists. The High and Low columns in Table 2.2.2c represent a sensitivity range of plausible values based on variation in panel member opinions.

Table 2.2. 2c: US Department of Transportation Guidelines on Air Travel Time Savings

Category	**Value of Air Travel Time Savings per person per hour**		
	Recommendation	**Sensitivity Range**	
		Low	**High**
Air Carrier			
Personal	**$ 28.8**	**$ 24.8**	**$ 37.1**
Business	**$ 49.6**	**$ 39.7**	**$ 59.5**
All Purpose	**$ 35.4**	**$ 29.5**	**44.1**
General Aviation			
Personal	**$ 39.0**	**NR**	**NR**
Business	**$ 55.7**	**NR**	**NR**
All Purpose	**$ 46.0**	**NR**	**NR**

NR - No recommendation
All figures are in 2002 C$.
Source: US Department of Transportation (2003).

Evidence from the Cole-Sherman and other stated preference studies suggests very high values for air travel time savings. Such high estimates are not plausible to us for two reasons: First, the Cole-Sherman study covers several modes and the estimates for travel time savings are unreasonably high for all modes covered, which suggests that the survey design might be poorly designed or otherwise biased in favor of high estimates. Second, the values of air travel time savings in Canada in 1990 exceed the higher bound of the sensitivity range of the US Department of Transportation recommendations based on industry experts. This happens even though there has been real income growth in Canada over the last decade on top of the current income difference to the United States. Since the income elasticity of travel time savings is positive the plausible upper bound to which the Cole-Sherman studies should be compared is even lower than the US guidelines suggest.

Our current best evidence comes from the US Department of Transportation guidelines. In the Canadian context, such recommendations should be adjusted using the income elasticity (see Section 2.8.7) to reflect income differences that exist between the two countries.

2.5.3 VTTS Variation across Modes

It is common for studies to show different VTTS by mode, e.g., VTTS for auto well above that for bus or rail. But it is also generally thought that the differences can be explained by attributes of travelers, vehicle characteristics and/or travel conditions. For example, a low VTTS for bus users may reflect lower average incomes of bus riders compared to other modes. Similar to Mackie et al. (2001), our suggestion is that, apart from adjustment to VTTS values based on the socio-economic characteristics (trip-purpose, income, etc.), no further differentiation by mode is recommended. But also note that if one does not recognize and correct for all relevant attributes, there may remain apparent mode differences in VTTS reflecting the unmeasured attribute differences of respective mode trips.

2.6 Travel Time in Employer's Business

There exist two main theoretical approaches to the valuation of travel time savings in employer's business. The first one is termed *cost-saving* or *wage-rate* approach. Firms are assumed to hire labor input up to the point at which the gross wage rate including labor related overheads is equal to the marginal product of the labor input. Therefore, travel time savings during work time permits either an increment of output value equal to the wage rate of the worker or release of the labor input into the market where it can be reemployed at the going wage rate. Either way, the value of the time savings is equal to the wage rate and labor related overheads.

The cost-savings approach depends on some crucial assumption such as competitive labor and goods markets, no production indivisibilities with respect to time, all released time goes back into work, travel time has zero productivity and the utility of the individual's utility of traveling equals the utility of working.

An alternative approach is due to Hensher (1977) who investigates the willingness to pay for travel time savings in a framework in which both the interest of the employee and the employer are considered. The approach can be best summarized using the following equation:

$$VBTT = [(1 - r - pq)MP + MPF] + [(1 - r)VW + rVL]$$

where $VBTT$ is the value of business travel time savings, MP is the marginal product of labor, MPF is the extra output due to reduced travel fatigue, VW is the value to employee of work time relative to travel time, VL is the value to employee of leisure time relative to travel time, r is the proportion of travel time saved used for leisure, p is the proportion of travel time saved at the expense of work done while traveling and q is the relative productivity of work done traveling relative to work done at the workplace.

Quantifying all these variables might be the biggest drawback to the Hensher approach. VL is the individual's private VTTS and can be obtained using standard methodology, the variables r, p and q are in principal measurable although there might be practical difficulties, VW is more difficult since it relates to relative disutility on monetary terms and MPF is typically ignored.

In the absence of indivisibilities, an hour of travel time savings provides the employer with an extra hour of productive work. Even if production indivisibilities for individual workers exist, the threshold result (AHCG 1999) implies that in the aggregate such production indivisibilities play no role.[26]

Delivery people, truck and public transport drivers are professions in which the work done during employer's business time is actually traveling. As travel conditions change, this allows them to become more productive, i.e. travel further in a given time period. For drivers, VW is equal to zero and it is reasonable to assume that p is zero as well, i.e. no work other than driving is undertaken during travel.

Interestingly, the cost-savings approach can be shown to be a special case of the Hensher approach. The equation simplifies to the cost savings approach if

[26] Production indivisibilities occur if for example the travel time savings are too small for a bus driver to fit in another trip. However, if it is assumed that the amount of spare time is uniformly distributed between zero and the amount of time needed to run one more trip, then on average over the whole population, the indivisibilities iron out. The argument is similar to the standard argument about production non-convexities in the aggregate economy.

$$r = 0, p = 0, VW = 0, MPF = 0, MP = w$$

where w is the gross wage rate. Such a situation corresponds well with drivers. For traveling salesman or service engineer the differing issue seems to relate to VW, whether an employee would rather be doing productive work or traveling. On balance it is not unreasonable to assume $VW = 0$.

As a general guideline, the cost savings approach seems to be appropriate for drivers and professions in which work is constrained to a remote location. However, for so called "briefcase travelers" whose work activity is not driving and who are not constrained to work at a remote location, the cost savings approach is not appropriate.

Attempting to extract direct VTTS estimates one should not confuse two different sources of valuation of travel time savings, those related to employee costs and those related to vehicle costs.

2.6.1 Briefcase Travelers

The question for briefcase travelers - whose work activity is not driving and who are not constrained to work at a remote location - is whether the values for r and p are sufficiently different from zero. Although it is hard to estimate VW for business travelers, it might be a good practical approximation to assume it to be zero.

Since business travelers who work during travel tend to work for a short time, realistic travel time savings will most likely not have any impact on the proportion of travel time savings which is at the expense of work done whilst traveling. Fowkes (1986) finds that the true value of p lies in an interval between zero and an estimated upper bound which is reported to be 0.03 for car and 0.21 for rail.

Estimates for q, the relative productivity of work done traveling relative to work done at the workplace range from above unity for car to 0.98 for air travel and 0.95 for rail travel although a substantial upward bias cannot be dismissed since respondents in the survey are likely to overestimate their productivity while traveling.

In regards to r, the proportion of travel time saved used for leisure, Fowkes (1986) finds that the true value lies in an interval between zero and an upper bound which is estimated to be 0.32 for car and 0.42 for rail and air travel.

The above arguments imply that the Hensher formula will result in a weighted average of the marginal product of labor, MP, and the individual's private VTTS, VL. Since $VL < MP$, the Hensher formula will give lower values than the wage rate approach. Based on plausible assumptions, Fowkes (1986) suggest that VBTT might be around 80-90% of the wage rate for car and about 65-75% for air and rail travel.

The AHCG study (1999) estimates the value of travel time savings on employers business by using Hensher's equation and dropping MPF as well as setting VW equal to VL.

2.6.2 Coaches and Buses

The conventional approach for coaches and buses is to account separately for the driver's time using the cost savings approach, the vehicle operating effect, and the value of predominantly non-working time for passengers.

There is another, more direct method to estimate the value of travel time savings for buses and coaches which involves obtaining stated preference data from bus and coach *operators*. Such a design might offer new and independent information into factors affecting the valuation of travel time savings by operators themselves, differing from the conventional approach of adding values of time for passenger and driver. A major problem is the issue of double-counting if the utility gain of passengers from the time savings is added to the operator's value of time. Under proper stated preference survey design, the operators are expected to include expected fare increases that could be charged to passengers for faster service, which will be a fraction of the utility gain to passengers. Simply adding the two figures would partially imply double counting.

Mackie et al. (2001) question the validity of stated preference surveys such as AHCG (1999) since they doubt the context in which the trade-offs between travel costs and travel time is stated. Specifically, they question the operator's ability to take into account the elasticity of travel demand to travel time variations and the potential for recouping part of the savings through increased fares.

2.7 The Value of Freight Travel Time Savings (VFTTS)

Although it is harder to find formal estimates of the value of freight time savings (VFTTS) in the literature compared to passenger VTTS, freight transport represents a substantial portion of the value of total time savings. Estimates for the Banque Européenne d'Investissement indicate that around one third of the time benefits in the EU are identified with freight transportation, in other countries the share can be up to 50%.[27] Despite the apparent importance of freight time savings, studies and techniques for assessing and valuing the various components of freight travel time savings have been limited in number.

The issues related to the freight value of time are to a certain extent similar to passenger values of time, but differ in some important aspects. Travel time savings for passengers may enter the utility function directly or indirectly as a resource constraint on travelers' decisions. The latter characterization applies to freight: time is a resource used in the

[27] See Massiani (2003).

production function (although it is rarely explicitly modeled in empirical production studies).

Freight transport has some unique characteristics that can probably explain why the topic has not been investigated in as much detail as passenger value of time. First, while the decision maker in passenger travel is most likely the traveler him/herself, goods cannot decide and different persons are involved in the decision making process at various stages. Producers and trading firms have a demand for freight transportation that they partly meet themselves (own account transport) while they contract out the remaining part to carrier firms (hire and reward transport). Hence it is difficult to identify a single decision maker and the agent who will take advantage of the time savings. Second, reliable and complete information on freight transport generally is not available due to the commercial confidentiality of transport and logistics costs. Third, the intrinsic heterogeneity of shipments requires a higher number of attributes to characterize a shipment compared to passenger trips.

The freight value of time consists of three components: The value of time savings for the operator (driver), savings of vehicle operating costs, and the value of time savings to the freight carried. It is quite easily established that the truck driver's or the rail engineer's time valuation follows similar principles as general business time valuation. However, the valuation of freight travel time savings is a larger and more inclusive concept than inventory capital costs and the transit time of the vehicle and the driver. Historically, most applications of VFTTS were limited to the costs associated with drivers/operators of transport vehicles. One might also include the costs associated with vehicle fleets as they are affected by time savings or delays (Waters, Wong and Megale, 1995). It is more difficult to appropriately value time savings for freight shipments themselves, i.e., the cargo.

Massiani (2003) identifies the various dimensions for valuing freight travel time savings.

- The value of reducing transportation time.
- The value of reliability in consignment hours.
- The value of flexibility in organizing shipments at shipper's request.
- The value of frequency for fixed schedule transport services.
- The value of continuity against unexpected events that can impede the service (weather, strikes, etc.).
- The value of information on the time attributes of the shipment (real time information on likely arrival time).
- The value of arising from assigning a certain (production) task to a certain time (for instance, based on the availability of specific production factors), e.g., just-in-time production systems.

Most of these dimensions are not easily quantifiable and given current data limitations, it is rarely possible to infer implicit valuations from shippers' behaviour regarding time and cost tradeoffs. Hence, of the few studies looking at freight value of time, most of them restrict themselves to the transportation time dimension.[28] Nonetheless, in interpreting existing studies it is essential to have a clear understanding of which (limited) dimensions the studies attempt to capture.

Considering that most of the above mentioned dimensions are hard to quantify, the majority of studies focus on the *duration* of the transportation operations. Although the dimensionality is reduced, new issues arise related to what exactly should be the adequate measure of duration. Massiani (2003) distinguishes three measures of duration by their breadth: The narrowest definition includes only the *(trip) travel time* itself, i.e. the time it takes to move the good from one location to another. For most shipments such a narrow measure excludes important aspects of the total time associated with freight shipments. More broadly, *transportation time* includes logistics operations such as warehousing, loading and unloading, border crossing, cross-docking, etc. that occur between the time the good leaves the origin location and before it is available at the destination. Going one step further, one might consider *delivery time*, which includes in addition the delay necessary between the moment the shipper makes an arrangement with a hauler for a consignment and the time when the good is actually available for use by the consignee.

For a full cost evaluation of transportation it is therefore essential to consider the appropriate measure of duration when arriving at estimates of the value of time in freight transportation. While the *(trip) travel time* measure misses important aspects of time in freight transportation, the broadest measure, *delivery* might include aspects of transportation that are unrelated to the value of time, especially when such a time value is used to establish social benefits of travel time savings lost in congested traffic.[29] Most reviewed studies on freight travel time focus on *trip travel time*, the narrowest of the three measures as it is clearly defined and typically well understood by survey respondents.

Further complications arise because time has important effects on the supply side as well as on the demand side of freight transportation. Time is valuable to transport operators, since it affects the logistics and operational design of their fleet and actual operations. On the other hand, demanders, i.e. shippers, place a value on faster and more reliable transportation. Almost all studies on the freight value of time focus solely on one side of transport operations.

It is important to highlight some of the differences and similarities the freight value of time has with more traditional travel time savings. Transportation time can sometimes be reduced without reducing travel time, which presents a peculiar difficulty in using freight transportation time savings in cost benefit analysis relating to the potentially large

[28] A few studies formally recognize travel time reliability as a composite part of the freight value of time.

[29] Focusing on *transportation time* as a duration measure does exclude organizational benefits that arise if the hauler is able to reduce the delay between the arrangement time and the loading time. For example, if reduced congestion allows the hauler to increase frequency, the benefit to the shipper of reduced delay between arrangement and loading will not be captured by *transportation time*. Such benefits fall outside the duration dimension of time (see the list of dimensions of time in freight transportation above). Many think that these are important elements to understand VFTTS, analogous to those linking passenger VTTS to its impacts on spatial scheduling of consumer activities.

discrepancy between travel time savings and transportation time savings. When a transport hauler can save time on the road (through reduced congestion), he can reduce total transport time (travel time plus other logistical operations) by an amount that can sometimes differ significantly from the initial travel time savings.

Freight travel time savings in the long-run are another important issue to consider in the interpretation of the studies. Most estimates of VFTTS are derived from hypothetical choice situations (SP) or market-based data that only include short-run trade-offs. Indirect or reorganization benefits (through logistics improvement) of freight travel time savings include opportunities to reorganize the distribution and logistics process, an effect unlikely to be captured in most studies. It is expected that there is a lot of firm-level heterogeneity with respect to those indirect, long-run effects. Hence, it is expected that all the estimates provided underestimate long-term values that include indirect benefits. Based on interviews with industry experts and shippers, de Jong (2000) estimates that the total (direct and long-term indirect) benefits of time reductions in road transport are about twice the size of direct benefits.

The next few sections look at methods and recent studies investigating the VFTTS. This discussion is followed by a section on the current practice employed by various jurisdictions regarding the VFTTS.

2.7.1 Methods Used in Freight VTTS Research

The methods used in freight VTTS research used can be classified into factor cost methods and modeling studies. The factor cost method attempts to find the costs of all input factors that can be saved through travel time savings. Reduced travel time releases production factors that can be alternatively employed. Modeling studies can be further distinguished according to the type of data used in the investigation: stated preference studies (SP) and market based revealed preference studies (RP). Considering the difficulty of obtaining market-based data on costs and rates of freight transportation, the advantage of the stated preference method is the availability of data based on hypothetical choice situations. However, SP-data is not market-based and the typical problems of SP-data such as framing, inconsistency and unrealistic choice situations are the drawbacks of this approach. Only a few recent studies have combined stated preference data with revealed preference data, an innovative way to overcome potential shortcomings of either set of data.

2.7.2 Factor Cost Methods

Factor cost methods have somewhat fallen out of favour since they can produce overly conservative estimates. They do not account for the potential increase in revenue associated with time savings nor do they appropriately capture benefits for shippers not captured through the market price. De Jong (2000) reports that road transport studies from the Netherlands in the late eighties and early nineties based on factor cost methods have come up with estimates in the range of $ 30.35-32.87 (2002 C$) per shipment (truck load) per hour.

2.7.3 Stated Preference Studies

Wynter (1995) conducts a stated preference survey of the value of time of interurban road freight transport in France. The transporters were asked to indicate, based on their current choice, the increase that would lead them to switch to the alternative choice in a setting in which the two choices available are a toll autoroute or free road.[30] The data set contains a random sample of 356 shipments by medium to long-distance freight transporters throughout France for which there existed reasonable toll-road and free-road itineraries.[31] No distinction is made among the type of good shipped nor does it take into account the amount shipped. The results indicate that the value of time for freight transport increases with distance and is approximately log-normally distributed implying that there are a few observations with extremely high values of time:[32]

Table 2.7.3a: VFTTS (Wynter, 1995)

Distance	Mean Value of Time per Shipment
100 km	$ 79.6
200 km	$ 89.7
500 km	$ 120.0
1000 km	$ 170.4

Source: Wynter (1995).
All figures are in 2002 C$ per hour.

Accent Marketing & Research and Hague Consulting Group (1995) conducted a value of time study for the UK Department of Transport, part of which analyzed the VFTTS. Interviews were carried out with firms that operate goods vehicles on public roads using a stated preference survey design that presents various scenarios with different transport time, transport costs, information on delay and unexpected delays. The study was

[30] For those transporters whose current choice was to use the toll road, the increase corresponds to a higher toll. The increase for the other set of transporters currently using free roads comes in the form of an increase in travel time supposedly due to congestion.
[31] The exclusion of shipments for which there existed no alternative itinerary (free road or toll road) introduces a sampling bias. While such exclusion is necessary to guarantee consistent and reliable stated preference survey design, it poses some problems since the applicability of estimates derived from such a restricted sample to the population of all freight transports is questionable. The value of time estimates apply only to a subset of shipments, the ones that have a reasonable alternative itinerary. Shipments without reasonable alternative itinerary on the free road or the toll road will decrease as the toll or travel times increases. Setting the value of time equal across the two sub-samples might introduce bias.
[32] The result that the value of time for freight transport increases with distance is consistent with the fact that a larger proportion of long-distance trips is assigned to costly but faster toll highways compared to short distance shipments.

segmented by type of firm carrying out the transport (own account operations versus hire and reward operations) as well as by type of truck (high value versus low value goods).

A binary logit model was estimated using the stated preference data. The results indicated no major differences between the high value and the low value segment of freight operations. However, it appears that the own account segment of transport operations is more cost sensitive and the hire and reward segment more time sensitive. In addition, the chance of an unexpected delay of 30 minutes and more is about three times as important for hire and reward operations relative to own account operations.[33]

Table 2.7.3b: UK VFTTS Study (AM&R and HCG, 1994/95)

Segment	Value of Freight Time per shipment (truck load) per hour	Valuation of a 1% Change in Probability of Delay of 30 min or more
Hire and Reward – Low Value	**$ 56.5** **(7.0)**	**$ 129.5** **(4.9)**
Own Account – Low Value	**$ 46.2** **(8.3)**	**$ 39.7** **(5.6)**
Hire and Reward – High Value	**$ 61.2** **(10.9)**	**$ 102.8** **(6.2)**
Own Account – High Value	**$ 46.2** **(6.0)**	**$ 31.8** **(3.0)**

Source: Accent Marketing & Research and Hague Consulting Group (1995).
Standard deviations are given in brackets. All figures are in 2002 C$ per hour.

Instead of segmenting freight transportation by type of truck and type of firm, an earlier study by Jong, Gommers and Kloosters (1992) in the Netherlands segmented the analysis by mode (road, rail and inland waterways) as well as four broad categories of goods: low value raw materials and semi-finished goods, high value raw material and semi-finished goods, finished goods with loss of value (perishable) and finished goods with no loss of value. Contextual stated preference interviews were conducted with 119 shippers in which respondents were asked to choose between various alternatives with travel time and travel time reliability (percentage not on time) as attributes among others. Based on the interviews, a logit model based on percentage differences between attribute levels was estimated.[34] The coefficients of travel time and reliability have the expected sign; reliability measured as the percentage of shipments that are not on time is somewhat less important than travel times per se. Applying the trade-off ratios from the logit model estimated in percentage differences to the transport cost per hour, one can back out the freight value of time per shipment per hour:

Table 2.7.3c: VFTTS (Jong, Gommers and Kloosters, 1992)

[33] Similar to the value of time for passenger travel, the freight value of time can be decomposed into the travel time itself and its variability.
[34] Models with absolute differences between attribute levels proved to be of lower statistical quality.

Segment	Implied Freight Value of Time (per shipment[A] per hour)
Road (raw or semi-finished – low value)	**$ 48.3**
Road (raw or semi-finished – high value)	**$ 53.4**
Road (finished – loss of value)	**$ 45.4**
Road (finished – no loss of value)	**$ 41.1**
Road (total)	**$ 45.4**
Rail (Full Train Load)	**$ 1013.7**
Rail (Wagonload)	**$ 41.1**
Inland Waterway (Barge)	**$ 280.5**

Source: Jong, Gommers and Klooster (1992).
All figures are in 2002 C$ per hour. Due to a lack of observations, all goods categories are pooled for inland waterways and rail transport. The Road (total) row was calculated as a weighted average based on ton kilometer of the values for the four road segments.
[A] Shipment size for roads is a truck load, for rail it is either a full train load or a wagonload and for inland waterways the shipment size is a barge.

As the results in the table suggest, the VFTTS is higher for semi-finished goods which can be explained by the effect of transport delays on further processing costs. Furthermore, perishable finished goods have, as expected, a higher freight value of time relative to finished goods with no loss of value. The freight values of time obtained from this earlier Dutch study are broadly in line with the UK estimates. Although the perishable nature of a good is a proxy for the shipment's time sensitivity, data limitations have so far frustrated further attempts to investigate the issue of time sensitivity of the shipment in more detail.

Based on Australian data, Wigan, Rockliffe, Thoresen and Tsolakis (2000) estimate a stated preference model in which they segment road freight transport by the length of haul into "Intercapital", "Metropolitan" and "Metropolitan Multidrop" in order of decreasing haul length. Furthermore, they distinguish between the freight travel time and reliability measured as the portion of designated delivery that was late.

Table 2.7.3d: VFTTS (Wigan, Rockliffe, Thoresen and Tsolakis, 2000)

Segment	Freight Travel Time (per pallet per hour)[35]	Value of Reliability (per 1% change of portion of late deliveries)
Intercapital*	**$ 0.65**	**$ 2.51**
Metropolitan*	**$ 1.28**	**$ 1.23**
Metropolitan Multidrop	**$ 1.37**	**$ 1.93**

Source: Wigan, Rockliffe, Thoresen and Tsolakis (2000).
All figures are in 2002 C$ per hour.
* Full truck load

Kurri, Sirkiä and Mikola (2000) estimate a logit model of within mode valuations of VFTTS for road and rail transport in Finland based on stated preference data. The authors decompose VFTTS into transport time and reliability of service which is measured by duration multiplied by the frequency of unexpected delays. The commodity-segmented freight specific values of time reported below would be added to the value of driver time savings and reduced vehicle operating costs.

Table 2.7.3e: VFTTS (Kurri, Sirkia and Mikola, 2000)

Road – Segment	Transport Time (per hour)		Average Delay[A] (per hour)	
	per 1,000kg	per shipment[B]	per 1,000kg	per shipment[B]
Forest Industry	**$ 0.35**	**$ 9.26**	**$ 5.16**	**$ 142.83**
Metal Industry	**$ 2.52**	**$ 24.97**	**$ 67.77**	**$ 717.67**
Electronics	**$ 3.99**	**$ 13.76**	**$ 125.96**	**$ 444.21**
Daily Goods	**$ 1.79**	**$ 25.59**	**$ 73.21**	**$ 1087.63**
Technical Products	**$ 1.15**	**$ 7.74**	**$ 44.35**	**$ 294.43**
Total	**$ 1.77**	**$ 12.79**	**$ 55.07**	**$ 407.11**
Rail- Segment	**Transport Time (per hour)**		**Average Delay[A] (per hour)**	
	per 1,000kg	**per shipment[B]**	**per 1,000kg**	**per shipment[B]**
Chemical Forest Ind.	**$ 0.19**	**$ 5.97**	**$ 3.50**	**$ 102.56**

[35] The authors prefer to measure the value of freight travel time per pallet to avoid the bias created by the shift towards the use of larger vehicles to transport a given amount of freight.

Mechanical Forest Ind.	**$ 0.06**	**$ 2.23**	**$ 0.43**	**$ 13.75**
Chemical Industry	**$ 0.15**	**$ 6.69**	**$ 0.97**	**$ 29.94**
Metal Industry	**$ 0.14**	**$ 4.66**	**$ 0.38**	**$ 16.73**
Total	**$ 0.12**	**$ 4.19**	**$ 0.58**	**$ 20.61**

Source: Kurri, Sirkiä and Mikola (2000)
[A] Interpretation of the value of average delay is somewhat difficult as an unexpected delay of 40 minutes during 5% of the shipments would result in an average delay of 2 minutes.
[B] Shipment size is a truckload for roads and a rail car for the rail mode.
All figures are in 2002 C$ per hour.

The most important conclusion from this study is that it is not really the transport time per se that matters but rather the reliability of freight transport time. The value for the average delay is a multiple of the value of transport time per hour. As expected, the freight value of time is lower for rail transport that road transport which can be traced to the different composition of goods and the self-selection characteristics of the two transport modes. Care should be taken when transferring aggregate freight values of time derived from Finnish data since the forest and metal industries are characterized by many heavy long-distance shipments, making the average value of time lower. Preferably, one would use VFTTS that are segmented by commodity to take account of the different composition of freight shipments.

Kawamura (2000) estimates a logit model for road transport based on stated preference data from Southern California, a region where respondents are familiar with toll road scenarios. Similar to the Dutch study, the respondents are classified into own account and hire and reward operations.

Table 2.7.3f: VFTTS (Kawamura, 2000)

Road Freight Travel Time (per shipment/truck load per hour)	**Mean**	**Mode**	**Median**
Own - Account	**$ 21.78**	**$ 4.20**	**$ 12.5**
Hire and Reward	**$ 34.65**	**$ 9.65**	**$ 22.65**
Total	**$ 28.96**	**$ 5.94**	**$ 17.20**

Source: Kawamura (2000)
All figures are in 2002 C$ per hour.

The mean, mode and median columns give an idea of the distribution of freight values of time. Similar to other studies, Kawamura finds that the distribution is skewed to the right by a small portion of the sample population with extremely high values of time. Unfortunately, this study does not segment the value of time by commodity nor does it incorporate the value of reliability, found to be important by other studies.

In a similar study, Small, Noland, Chu and Lewis (1999) estimate a conditional logit model again using stated preference data from California. However, the authors distinguish between travel time and reliability, measured through schedule delay. Although, the data was segmented into four industries, the small sample size (20 observations) unfortunately did not allow for disaggregate estimates of the value of time.

Table 2.2.3g: VFTSS (Small, Noland, Chu and Lewis, 1999)

Road Freight Travel Time (per shipment/truck load per hour)	Travel Time	Schedule Delay
Average (Aggregate)	**$ 182.33-243.78**	**$ 469.44**

Source: Small, Noland, Chu and Lewis (1999).
All figures are in 2002 C$ per hour.
The reported estimates are significant at the 5% -level despite the small sample size.

The estimates from this study are a multiple of the ones obtained by Kawamura (2000) but should be viewed with caution since the sample only consisted of 20 observations. Given the expected skew to the right of the distribution of freight value of time, it is easily comprehensible how a small sample can potentially arrive at such large estimates. Nonetheless, this study seems to confirm that reliability, here measured by schedule delay, is in fact an important part of freight travel time savings.

2.7.4 Hedonic Pricing Studies

Hedonic pricing studies are widely used in economics to estimate shadow prices that consumers place on certain characteristics of a commodity. It assumes that the good under investigation has various attributes which provide utility to consumers. The quantity of a particular commodity may be decomposed into a number of constituent characteristics which determine its quality. A part of the price of that commodity may be associated with each characteristic and variations in quality may thus be valued. The application of hedonic price theory to quality changes was pioneered by Zvi Griliches and has found applications in the analysis of housing demand and environmental economics. The most common application of hedonic pricing estimates the consumer's willingness to pay for the different attributes of the good, but it is frequently used to estimate the demand and valuation for non-existing multi-attribute goods as well.

Estimates based on hedonic pricing are able to overcome some of the shortcomings of stated preference techniques (SP) because they rely on real market data, similar to the revealed preference approach (RP). Hedonic pricing studies are similar to the revealed preference approach in that they do not rely on the construction of potentially unreliable pseudo observation for unused alternatives. Unfortunately, there have not been many studies done on freight value of time that rely on real market data.

As one of the few examples, Massiani (2003) estimates a hedonic pricing model for VFTTS on a small data set of 58 observations of road and railway shipments in Europe. Since the selection of observations might not represent the population of all freight transports, the numerical results should be interpreted as an indication rather than a precise estimate. Specifically, the sample relates to shipments with higher value, tonnage, price, duration and lower distance relative to the complete sample of interview data.[36]

Massiani (2003) estimates different formal specifications of the hedonic pricing equation but the results are very similar. The estimate of the mean value of time per shipment from this small sample study is negative (!) $25.3 (2002 C$).[37] The median value is positive though $0.80 (2002 C$), considerably lower than the estimate obtained from stated preference surveys. However, the standard deviation in all specifications is more than five times the estimate, a consequence of the small sample and we doubt that the estimates provided are reasonable. Although current hedonic pricing studies cannot provide reasonable information for VFTTS, more elaborate hedonic pricing models based on larger and more reliable data sets offer a promising avenue for future research.

2.7.5 Current Practice

Waters, Wong and Megale (1995) compiled a summary of commercial vehicle values of time used by 14 agencies in various countries for evaluating costs-benefits of highway projects. While the methods differ among agencies, the values were determined based on factor cost methods that typically included labor, vehicle operation, and cargo handling and storage.

Table 2.7.5: Practice of Valuation of Time Savings for Commercial Vehicles around 1995[38]

Jurisdiction	***Number of Axles***	
	2	***4***
United States		
AASHTO (1977)	**$ 22.14**	**$ 25.31**
Chui & McFarland (new AASHTO)	**$ 23.03**	**$ 34.28**
HERS*	**$ 32.92**	**$ 41.82**
California*	**$ 22.85**	**$ 22.85**
Florida*	**$ 19.20**	**$ 22.96**
New York*	**$ 22.23**	**$ 22.23**

[36] The complete interview data are presented in Guilbault, Piozin, Rizet (2000).
[37] The author argues that the profit of shippers might be increasing in duration for some values of duration while decreasing for others.
[38] These figures are outdated and might not reflect current practice in those jurisdictions.

Canada		
Alberta*	**$ 27.98**	**$ 27.98**
Quebec*	**$ 16.79**	**$ 18.13**
Ontario*	**$ 44.51**	**$ 44.51**
Australia/ New Zealand		
Australian Road Research Board & New South Wales	**$ 15.10**	**$ 15.38**
Queensland	**$ 15.49**	**$ 16.97**
South Australia	**$ 14.96**	**$ 15.22**
NZ Road Project Evaluation Manual	**$ 17.80**	**$14.61**
Norway and Sweden		
State Highways	**$ 22.32**	**$ 22.32**
Municipal Roads	**$ 14.34**	**$ 14.34**

Source: Waters, Wong and Megale (1995).
All figures are in 2002 C$ per hour.
* Values are obtained by telephone interview, 1991-1992.
Values might differ relative to published figures due to different indexing procedures.

2.7.6 Summary and Applicability

Estimates on the value of freight travel time savings (VFTTS) exhibit a large variation and there is neither a consensus on the appropriate methods of investigation nor on the set of actual estimates, which are sparse to begin with. For those reasons, we advise that the following suggestions should be considered with care and if possible adjusted based on new evidence.

Nonetheless, there are a few clear lessons emerging from the recent set of empirical studies. First, freight time values employed by jurisdictions as reported by Waters, Wong and Megale (1995) as well as estimates based on the factor cost approach substantially undervalue the VFTTS.

Second, as with passenger VTTS, the mean value of VFTTS is likely to be heavily influenced by a few extremely high values of time as the distribution of values is skewed to the right (Wynter, 1995 and Kawamura, 2000). While this characteristic of the distribution might not matter for investment appraisal, it clearly has behavioral implications for road pricing.

Third, the value of freight time savings clearly depends on the type of good shipped, a phenomenon affirmed by all empirical studies that segment the market by goods type.

But the variety of goods with different attributes is immense. The literature provides very little guidance for adjusting VFTTS by commodity type.

Fourth, the empirical findings on the relationship of the freight value of time with the distance of the shipment are contradictory. Wynter (1995) finds that the value of VFTTS is increasing with distance while estimates from Australia (Wigan, Rockliffe, Thoresen and Tsolakis, 2000) indicate that the value of time falls as the distance of the shipment increases. The problem of identifying the relationship of VFTTS with distance is complicated by the changing composition of goods from short-haul to long-haul shipments. If perishable goods are indeed shipped over long distances, this will likely result in very high values of time, but everything else equal, perishable goods are less likely to be shipped over large distances. The important issue is the changing composition of goods shipped as the distance increases. Theoretically, one would like to hold the composition of goods the same as the distance shipped is increased, but such a study has - to our knowledge - not been undertaken yet. Given the current ambiguity of empirical evidence, we suggest that estimates of the freight value of time should not be adjusted for distance, especially if one cannot control for the different composition of goods shipped.

Fifth, there is evidence provided by several studies that the most important aspect of freight travel time might not be the reduction in travel time per se, but the increased reliability of delivery/schedule time. The values for reliability and schedule delay exceed the values for the freight time savings multiple times. As a consequence, any research effort has to investigate how the reduction in travel time affects the variability of travel times. If such time savings are of small magnitude it could be appropriate to assume that the variability is unchanged. This will however be an unreasonable assumption if the time savings are a substantial part of the overall travel time. This report has not investigated the relationship between travel time and variability and conclusions should probably be based on traffic simulation models.

Considering the above arguments, reasonable estimates on the mean freight value of time for the road mode range from $45-$200 per shipment.[39] If it is possible to control for the variability of travel times, appropriate mean values of freight travel time are at the lower end of the range from $45-$60. If variability is not taken into account we would argue that mean values up to $100 could be reasonable under certain circumstances. We emphasize that the freight value of time for most shipments is significantly below the suggested mean value, i.e., it is a skewed distribution, and this should be taken into account depending on the purpose of the research agenda.

If the composition of goods transported were the same, it is not evident that other modes such as rail transport or inland waterways should be treated differently. However, since the characteristics of the modes differ, so will the composition of the goods transported on each mode. While rail transport could be similar in speed to road transport, transportation on inland waterways will be slower and likely to transport goods that have

[39] All figures are in 2002 C$.

a lower time value.[40] Using the values for road transport per shipment for a rail wagonload might be appropriate for container trains, but is not appropriate for low-valued bulk shipments. If transport speed on the rail is substantially slower than road – and it certainly is for inland or coastal waterways – the freight values should be adjusted downward to reflect the different composition of goods that will be carried.

Although, this is not taken into account by our suggested values of freight value of time, the distinction between the short-run and long-run estimates of freight values of time is more important for freight than for passenger travel times. For road or congestion pricing purposes, short run estimates for freight value of time are the appropriate measure since they govern behavior until transport operators are able to adjust their distribution and logistic networks in the long-run. Once transport operators have adjusted their networks to make full use of the travel time savings, freight values of time will be higher. It is expected that given a fixed road user charge for freight, traffic volume will initially be reduced and then gradually increase as distribution and logistic networks adjust. While the present evidence is thin, de Jong (2000) argues that - from a long-run perspective - freight values of time up to twice as high as the ones suggested above are reasonable.

Given the limited set of empirical studies, the importance of freight travel time savings (up to 50% of total time savings) and the significance of reliability and variability in contrast to the time savings per se, we strongly feel that further investigation into the freight value of time is warranted.

2.8 Ongoing VTTS Issues and Recent Evidence

There are a number of ongoing issues or debates regarding properties of VTTS. This section briefly reviews the various issues, comments on what has been the consensus, and what recent studies have concluded. The issues addressed are:

- How does trip purpose affect VTTS?
- Are time savings valued the same as time delays?
- Are waiting time savings valued more highly than traveling time?
- Does VTTS vary with the size of blocks of time savings?
- Are negative VTTS plausible?
- Does VTTS vary with journey length?
- What is the link between VTTS and income levels?
- Is VTTS a composite measure of several journey characteristics besides time savings per se?
- Does VTTS differ for walking, waiting and traveling in congestion?
- Are VTTS results from one region and circumstances transferable to other locations and time periods?
- What are the differences in short term versus long term valuation of travel time savings.

[40] Since this research is concerned with the freight valuation of time, the most important characteristic that differs across these modes is clearly the speed of transportation.

Before addressing these issues, we comment on the implications of the purpose of measuring VTTS.

2.8.1 The Purpose of Measuring VTTS

The traditional and primary reason for measuring VTTS is for evaluating transport infrastructure projects. VTTS estimates are the major economic benefit of almost all transport infrastructure investments, so it is an important research topic. It is well-recognized that the VTTS can vary substantially from person to person, from day to day, and for different trip purposes and travel conditions. For purposes of investment appraisal, it is acceptable to use "average" figures for VTTS, which could mean mode or median figures for the variations in VTTS in the population are asymmetric.

For the present study, there is interest in VTTS as a component of externalities that are a part of the full economic costs of transportation. While an average figure for VTTS could be acceptable for estimating the total costs associated with modes and aggregate transport operations, the requirements may have to be more exact if one is contemplating the use of Pigouvian taxes such as congestion charges. Behavioral response to price changes is the purpose of socially optimal pricing. If VTTS varies among users depending on their characteristics and other factors, then one needs more exact estimates of VTTS to be able to calculate optimal prices/taxes compared to the VTTS figures adequate for broad calculations. The literature on VTTS is dominated by studies looking for representative or average figures, possibly with some indication of variance and the distribution of VTTS values. One must recognize that the underlying purpose of existing VTTS studies might affect the quality and specificity of VTTS estimates that are required.

2.8.2 VTTS and Trip Purpose

The purpose of trips affects the value that travelers place on trips and this may affect the valuation of time savings on those trips. This is particularly the case if trip purpose is linked to time and activity constraints. Arriving late for work generally is a more serious matter than delays associated with a shopping trip.

The VTTS literature has long distinguished between work and non-work journeys. There is substantial evidence that business trips have a higher VTTS than non-business trips. Some studies have further distinguished non-work journeys between commuting and leisure trips. Recent studies, AHCG (1999) and a meta-analysis by Mackie et al. (2001), confirm the consensus built by earlier studies that the value of time for commuting purposes is slightly higher than for leisure trips but that the values are fairly similar and no distinction between the two sub-purposes of non-work journeys is warranted.

2.8.3 The Sign of Travel Time Savings

It is plausible that unexpected delays could cause greater disruption to people's everyday lives than unexpected time savings. However, only a small minority of VTTS studies focus on this distinction. For example, ACHG (1999) find that for any level of variation around the original journey time, gains (time savings) are valued less than losses. Their basic model assuming a linear specification for the value of time was rejected, suggesting that their data support a non-linear specification around the origin.

However, the ITS-study (Mackie et al., 2001) criticized the ACHG findings and re-estimated the model with the same data set but including an inertia term to capture the fact that respondents might systematically prefer the current situation. The presence of inertia in transport behavior is well-attested. The inertia-term was found to be highly significant and no significant differences between travel time savings and travel time losses remained.

In the long run it might not make much difference as travelers can adjust their schedule of activities in either case. The primary way this issue is addressed in the recent VTTS literature is the growing recognition that "reliability" or certainty of trip times is an important factor separate from the expected amount of travel time. More certain travel times enable one to organize activities to adjust to those travel times, whereas the need to meet time schedule constraints requires travelers to build in contingency time. There is no sound empirical basis to distinguish travel time gains and losses once VTTS is separated from the value of reliability (VOR), which indirectly recognizes that unexpected time losses and delays may be more costly than similar time savings.

2.8.4 The Size of Travel Time Savings

There is an ongoing debate between those who advocate a constant unit value for time savings, and those who promote a discounted unit value approach, in which the benefits of each unit of travel time saved is reduced, potentially to zero below some threshold. The conventional approach in road project evaluation is to treat all time savings as equally valuable. There are examples of situations where even small time savings/ delays are important (e.g., impatience in waiting for dial tones on phones) but in studies that explicitly examine the size of time savings and VTTS, some researchers find empirical estimates of non-uniform VTTS depending on the size of time savings. As a consequence, the constant unit value approach has attracted criticism (Welch and Williams, 1997).

The empirical evidence is not conclusive, but most studies that focus on it confirm that small time savings are perceived to be of less value than larger blocks of time. For example, AHCG (1999) find that for non-work related journeys, a time saving of five minutes or less has negligible value. Individual perceptions are however not the sole consideration and evidence of lower utility attached to small travel time changes should not be taken at face value for several reasons (Mackie et al., 2001): If we allow for adjustments past the immediate short-term, such results are inconsistent with theoretical expectations of indifference curves. In addition, they imply extremely high marginal values of time around the threshold and inconsistent "trading" between time and money around the threshold.

There are several explanations for the observed phenomenon. First, the empirical data could in fact reflect real perception and preferences. Second, respondent's perception of the choice situation in stated preference surveys is defective which leads them to refuse to trade money and time at a reasonable rate. This could occur because they believe such time savings do not actually come to pass or are minor compared with day-to-day variation in car journey times. Hence, data collected from such SP-surveys are unreliable. Third, respondents may take the SP choice at face value, but perceive themselves to be in a short-run context with slack time. Long term adjustments to small travel time savings might be too complex to consider.

From the current evidence it is often impossible to figure out which of the previous argument applies to a particular study. Nevertheless, arguing on similar lines as (Mackie et al., 2001), such evidence of negligible value of small travel time savings should not be considered definite due to the artificial nature of SP-surveys used to derive these estimates which often require large imaginative leaps of respondents about long-term adjustments to small time savings.

Apart from questioning the current evidence, one can advance on theoretical grounds a distributional and a decompositional argument for treating large and small time savings the same:

- Small time savings might not be valuable for most travellers since threshold due to indivisibilities exist below which the travel time savings do not have much value. The distributional argument suggests that such thresholds will be distributed across the population as will the "slack time" which is insufficiently large to be allocated to more satisfying use. Travel time savings then will have zero or a very small value to some travellers, while to others who are close to a threshold, the value of small travel time savings will be substantial. Under certain assumptions, this is equivalent to a conventional constant unit approach (Fowkes and Wardman, 1988). Highly skewed values of travel time savings allow for a similar argument: Perhaps most travellers place a very low value on small time savings, but a few might place extremely high values even for small time travel savings in which case the high and low values average out over the population.

- The decompositional argument suggests that over time, road improvements must be seen in the aggregate, i.e. in the context of the whole road network. If small travel time savings were ignored or discounted, inconsistencies arise due to the substantial benefits accruing to the whole network. Several small travel time savings add up to a significant improvement that is valued by travellers. Discounting small travel time savings would imply that many road and traffic improvements would not take place and yet their cumulative impact on time savings can be substantial.

In our view, there is a compelling case for the uniform valuation of time savings for public investment appraisal independent of the size of travel time savings. But in terms of individuals' actual willingness to pay and modify their behavior, it may be necessary to recognize that small time savings might not be valued the same as larger blocks of time. Thus the issue of the valuation of small travel time savings may require further analysis and debate when contemplating price or tax adjustments related to small time savings.

2.8.5 Are Negative Values of Time Reasonable?

One of the basic assumptions of transport planning/investment is that the time spent traveling would rather be spent on other activities such as working, shopping, leisure, etc. Hence, travel is a derived demand and people should be willing to pay for travel time savings. An obvious counterexample is an activity in which travel itself is the purpose, such as walking, hiking, running, or a pleasure drive. Travel time should be treated differently for these activities.

Nonetheless, even if one considers the choices normally modeled to derive VTTS estimates, it does not follow immediately that the value of time savings must be strictly positive. The value of time will only be positive if there is a binding time constraint, otherwise the value of time should be zero. It is reasonable to assume that there is a binding long-term constraint in the leisure-work tradeoff investigated by choice models. The closest transport related choice model reflecting such a long-term choice is the joint work location - mode-to-work model. Travelers will carefully trade off long-term combinations of costs, travel times and comfort and the time constraint should be clearly binding, resulting in a positive value of time. However, in the typical one-day cross-sectional data used in most empirical studies, the time constraint is unlikely to be binding. There is a lot of buffer time in many persons' days. Hence, it is consistent with theory to find that a lot of people have values of time very close or equal to zero.[41]

Negative values of time are conceivable in short-term situations in which time constraints are not binding. Particular example could be cycling home from work in sunny weather, a lively conversation with another passenger on public transit or simply dreading the activity next in the schedule (dentist). As a result, one cannot a priori exclude negative values of travel time savings.

How are negative values of time treated in empirical studies? Negative values of time can be a sign of inconsistent choices in stated preference studies (Saelensminde, 2002). By presenting two alternative choices to the respondent, all characteristics of the

[41] Although a lot of people will have values of time close to zero, some travelers will have very high values of time. The use of average values of time works fine for infrastructure investment issues. Questions relating to behavioral responses of traveler such as road pricing are another matter as the complete distribution of values of time is relevant.

alternatives should be stated, and if so, the parameter measuring those other positive attributes should account for the observed negative values of time such that travel time always has a non-negative value. Interestingly, Bates and Whelan (2001a) show that even if the data are consistent and no negative values of time are observed, it is possible that the estimate could come out negative, due to assumptions of the model that allow the value of time to go negative. The explanation for this phenomenon lies on the technical assumption of the logit-model in situations in which a large proportion of respondents refuse to trade time for money in stated preference studies at any of the rates offered. It suggests that apparent negative values of time might not be a feature of the data, but rather that an appropriate estimation model would not allow the value of time to go negative.

In revealed preference studies, typically two alternatives are compared in which a faster but more costly alternative is compared to a slower but cheaper (maybe even free) alternative. Given this setup, a number of cut-off values are observed, which allow researchers to estimate the distribution of travel times, but this setup is not able to differentiate between zero values of time and negative values of time. In mode choice models, it is theoretically possible to estimate negative values of time if the slower mode has appealing quality/comfort characteristics. Such negative values (over the whole population) are however more a sign of the inappropriateness of mode choice studies (since the quality/comfort differences get attributed to time) than evidence of negative values of time in the aggregate population.

2.8.6 VTTS and Length of Journey

There are two chief sources of variations in VTTS which are due to characteristics of the journey (length) and the traveler (income). A number of studies have investigated the VTTS in relation to the length of a journey. A small time saving may be relatively more important for short journeys than for long ones (proportionality). On the other hand, the marginal disutility of traveling might be higher for long journeys compared to short ones as fatigue, boredom and discomfort set in. In addition, the composition of journey purposes varies with distance. On aggregate, the value of time is expected to increase with distance and this effect is in fact one of the most frequently detected effect in empirical studies.

ACHG (1999) reports a distance elasticity of VTTS of 0.37 while the meta-analysis by Mackie et al. (2001) finds the elasticity to be 0.26. These findings are in line with earlier research, which typically finds a positive link between VTTS and journey length. There is clear evidence of a positive distance effect, which is of relevance for transport modeling. A distance elasticity of around 0.3 appropriately reflects the empirical evidence. Such a distance elasticity is of crucial importance (together with the income elasticity of VTTS) if values are to be transferred across different regions and countries as explained in more detail in section 2.8.10.

2.8.7 Relationship between VTTS and Income

There are two separate issues that need to be considered: The first issue is concerned with the form of the empirical relationship between income and VTTS and second issue with the relevance of this relationship for investment appraisal and full costs investigation.

Economic theory would predict that VTTS would rise with income, since the money value of time for non-work travel is the ratio of the marginal utility of time and the marginal utility of money. The official recommendation in several countries (e.g. Britain) is to increase the value of non-work travel time over time in line with income growth. There is however no theoretical reason why the income elasticity for private travel should be unity. Personal preferences will reveal how an individual allocates additional income to time savings. All that can be reasonably concluded on theoretical grounds is that time savings are not an inferior good and hence the income elasticity is expected to be positive. In fact, the positive relationship between VTTS and income is often used as a consistency check to determine whether the estimates are reasonable.

A large amount of recent empirical evidence indicates that the income elasticity for the value of time spent in private travel is less than unity. This first British national value of time study by MVA Consultancy et al. (1987) finds that an income effect is apparent and that the income elasticity is less than unity. Waters (1994) used the MVA Consultancy results to postulate a square root relationship between VTTS and income. The second British study (AHCG, 1999) again finds that VTTS is positively relate to income and reports an income elasticity of around 0.5. Gunn and Rohr (1996) find based on Dutch data a strong positive relationship between VTTS and income that is not one of proportionality, which was confirmed in a follow-up study by Gunn et al (1999). A meta-analysis by Wardman (2001a) using British evidence suggests an income elasticity of 0.51 but the confidence interval is so wide that the estimate is not statistically different from zero. Mackie et al (2001) add a considerable amount of evidence to Wardman's data set (combined 1167 observations from 171 studies) and report income elasticity in the range of 0.72-0.82. The empirical evidence provides strong support of a positive relationship between VTTS and income with an income elasticity of around 0.75.

Another issue is whether or not governments, in making investment decisions, should accept VTTS that increases with income. Some countries have officially excluded any link between VTTS and income for evaluating public transport investments, based on an equity principle (Waters, 1992b). Governments may not wish to use techniques of analysis that would favor the wealthy as opposed to low income groups. Because wealthy people have higher VTTS, allowing higher VTTS with income would tend to favor projects benefiting wealthier members of society. This practice gives rise to an inconsistency in project evaluation because demand curves for other goods (including the demand for travel) do reflect income differences in the people represented by the demand curves. There is a systematic difference of treatment of monetary and time benefits in project evaluation. Even if an equity principle is invoked to ignore differences in VTTS due to incomes in public investment appraisal, the influence of income must be recognized in discussions of pricing, taxation and predicted behavioral response.

2.8.8 VTTS as a Composite Measure

It is recognized that one of the factors explaining differences in VTTS from one study to another are that VTTS estimates may be measuring more than just time savings. The following three examples will help illustrate the need to decompose simple VTTS measures. It is well recognized that faster modes tend to offer higher travel quality. If quality and comfort is not explicitly modeled in the estimation process, the measured willingness to pay for faster modes may also be explained partly by the higher quality and comfort of the journey. Another example is that VTTS is often found to be higher under congested driving conditions than in free-flow traffic. The higher VTTS under congestion is not a valuation of time per se but is linked to the disutility of more stressful driving conditions. Still another example is the uncertainty of travel time in general. A simple VTTS estimate might embody both the value of time lost/saved and the effect of reduced reliability of journey time.

If a VTTS estimate is actually a composite measure of time and correlated costs/benefits, this might not matter much for investments that affect travel time and correlated benefits alike. However, for evaluating diverse transport projects, and/or trying to identify the willingness to pay and responsiveness of travelers to specific time savings, it is desirable to separate correlated components that might be embodied in simpler estimates of VTTS. It is evident that studies on VTTS have moved in the direction of a better disaggregation of components of travelers' demand for travel. One of the reasons for the popularity and usefulness of SP methods is their ability to separate otherwise correlated factors in travel demand.

The VTTS under congestion may embody a further complication. The slower travel times during congestion may be partly a deliberate decision by drivers to travel slower to reduce the risk of accidents. This is measured as time costs but strictly speaking it should be allocated as an internalized cost of accident risk borne by drivers. However, there are almost no estimates of how large this time cost would be (but one attempt to estimate these costs is Steimetz (2003).

2.8.9 Waiting, Walking, and Travel Time Savings in Congestion

There exists a large body of evidence relating to valuations of travel and service attributes such as walking time, waiting time and other travel attributes. Valuations for such service quality attributes are often expressed in terms of in-vehicle time as such figures can be more readily interpreted in terms of monetary values and are also more transferable spatially and in time.

Most studies find that the valuation of time savings are larger for waiting and walking time than time spent in-vehicle traveling. Quarmby (1967) was probably the first major study on this issue and several others followed. Quarmby found that wait and walk time savings were valued about 2.5 to 3.0 times higher than traveling time savings. Subsequent studies tended to find slightly lower differentials. A widely adopted convention in transport planning is to value walking and waiting time at twice the in-vehicle time for non-business trips. This convention is used in Great Britain for road and rail transport and is widely adopted in many other countries (Wardman, 2001a). In a review of international evidence by TRRL (1980) covering 10 disaggregate studies, walk time was on average valued close to twice in-vehicle time and wait time was valued around three times in-vehicle time.

Wardman (2001a) has re-evaluated the empirical evidence from Britain based on a collected set of 290 time valuations of walk time, wait time, access time and combined walk and wait time, which are presented in Table 2.8.9a. The reported average values are with the exception of access time significantly below two.

Table 2.8.9a: Overall Time Valuations (relative to in-vehicle time = 1.0)

	Mean	Std. Deviation	Std. Error	Observations
Walk Time	**1.66**	**0.71**	**0.06**	**140**
Access Time	**1.81**	**0.75**	**0.10**	**52**
Walk and Wait Time	**1.46**	**0.79**	**0.10**	**64**
Wait Time	**1.47**	**0.52**	**0.09**	**34**

Source: Wardman (2001a).

The convention of weighting waiting and walking time at twice the value of in-vehicle time is generally not applied to business travel time savings based on the argument the employers are only concerned with overall reductions in travel time that increase productivity. While employees might value waiting and walking time higher than in-vehicle time, this is only a small part of the overall valuation of time savings (AHCG, 1999). Wardman (2001a) reports an average business value of waiting and walking time of 1.8 times in-vehicle time although the sample has only 13 observations and is most likely too small to heavily rely on this estimate.

Wardman's meta-analysis suggests that waiting and walking time have similar valuation although the current convention of valuing them at twice in-vehicle time might be on the high side. In addition, if one assumes that the business travel values in the sample indeed approximate a company's willingness to pay, then there is weak evidence against valuing business waiting and walking time at the same as business in-vehicle time.

Apart from waiting and walking time, various studies have shown that travelers have higher values for travel time savings in congested conditions. More difficult driving conditions, greater stress and frustration and perhaps arrival time uncertainty lead to higher time valuations on congested roads. It is therefore crucial to distinguish free-flow travel time and congested travel time as travelers value it differently and have different willingness-to-pay to realize time savings depending on road conditions. Evidence from the meta-analysis of 21 studies carried out by Wardman (2001a) is presented in Table 2.8.9b and suggests that traveling in congested traffic is valued 48% more highly on average than in free-flow conditions, and the valuation varies little with journey purpose. This figure is somewhat smaller than the 67% reported in the review by Miller (1989).

Table 2.8.9b: Valuation of Travel Time in Congestion

	Mean	Std. Deviation	Std. Error	Observations
Congested Time	**1.48**	**0.32**	**0.07**	**21**

Source: Wardman (2001a).

Recent estimates of the valuation ratio between congested and uncongested traffic continue to exhibit significant variation. Calfee, Winston and Stempski (2001) estimates are based on data from major US metropolitan areas and they find that travel time savings in congested traffic are valued 200% higher than under free-flow conditions. On the other hand, a recent Swiss study by Abay, Axhausen and König (2003) find the time values in congested traffic to be only 25% higher.

However, one should remember that the concept of time savings in congested traffic is not necessarily precise since there are different degrees of congestion and definitions vary across studies. Hensher (2001a) further distinguishes between free-flow time, slowed-down time and start/stop time. The typical value of time savings in congested traffic is a mixture of the latter two of Hensher's dimensions. Based on a sample survey from seven regional centers in New Zealand, Hensher reports a ratio of coefficients of slowed-down to free-flow time of 1.08 and a ratio of coefficients of stop/start time to free-flow time of 2.14. The ranking of the VTTS component stays the same across alternative assumptions of the random component of the underlying utility expressions but the ratio of coefficients for slowed down time to free-flow time can go up to 1.44 and the ratio of coefficients for stop/start time to free-flow time can go up to 2.8. This suggests that time savings associated with noticeable traffic congestion is approximately 2.5 times the value for free-flow travel and double that for slow traffic conditions.

Estimates by Hensher (2001a) are more in line with conventional practice of valuing travel time savings in congested traffic at twice the free-flow value. Since overall estimates group the last two of Hensher's dimensions together, the resulting estimate will be influenced by the composition of the trip time under slow but moving conditions and stop/start traffic. It seems that traveler's valuation is slightly higher for time spent in slow moving traffic but they really dislike stop and go conditions. Further research might shed more light on the valuation of time savings under various levels of congestion which will likely reduce the variation of estimates observed in recent studies. Currently, there is no strong evidence to abandon the conventional practice of valuing travel time savings in congested traffic at twice the free-flow value as long as it is not applied to traffic that moves only marginally below free-flow speed.

2.8.10 Transferability of VTTS Findings

Many empirical studies from all around the world have investigated the valuation travelers place on travel time savings. Such results have been extensively researched and reported over the years (Bruzelius (1979) and Wardman (1998)). Much less effort has gone into the search for the stability of the coefficients and the transferability of VTTS relationships. There is generally a lack of data (small sample size, few comparable studies) on which such temporal and spatial comparisons could be based. If data exists, differences in definitions have clouded the issue. Instead of attempts to "prove" transferability, many researchers are forced to a much weaker conclusion that there is "insufficient evidence to prove the contrary" (Gunn, 2001).

In a recent comparability study, Gunn (2001) assembles six major European studies from France, the Netherlands and the UK with the aim of testing spatial and temporal transferability. The data analyzed partially consists of both RP- and SP-data. Two estimations of the same model structure on compatible data sets drawn from the same country and the beginning and end of a ten year period are used to test for temporal stability. Spatial stability on the other hand is tested using evidence from the same model structure and comparable data set drawn from two different countries.

The results indicate that many relationships seem stable and transferable, over time and between regions. Specifically, the following two major relationships were found to be stable: VTTS increases less than proportionally with income and VTTS increases with journey length. Furthermore, when there are systematic differences between coefficients across regions, they are to a large extent interpretable in terms of known characteristics of the region. In fact, Gunn found that income and trip duration are the most important *systematically* varying effects.

Comparison studies such as Gunn (2001) could certainly be helpful in informing the transferability debate from European or Australian results into a North American context. In the absence of evidence to the contrary, our belief is that results from jurisdictions around the world are appropriate for use in the Canadian context as long as major differences across regions in terms of income are adjusted.

2.8.11 Short Term and Long Term VTTS

Still another issue is the time horizon that underlies a VTTS estimate. The longer the time horizon, the more adjustment and substitution possibilities exist. The responsiveness of travelers to time savings/losses can differ between the short run and long run. Calfee and Winston (1998) note that most studies exhibit a downward bias when long-term VTTS are considered because commuters with high time values have made residential and workplace location decisions that result in a shorter commutes with less congestion. They also note that this could mean substantial latent demand, i.e., commuters who have previously avoided congested roads will be lured back onto the roads by uncongested travel. This needs to be recognized in predicting response to improved travel conditions.

2.9 Summary of VTTS Results and Recommendations

This section restates the major conclusions and provides recommendations for VTTS. The conclusions regarding VFTTS have been summarized at the end of Section 0.

If the method for estimating total congestion costs assumes a constant value of time, 50% of the average wage rate would be an appropriate figure. However, assuming a constant value of time is in our view not appropriate unless one has to rely on the thinnest data on the composition of traffic. Recent research has made substantial strides in decomposing VTTS and distinguishing various subgroups of the population. For such reasons, we propose the following segmentation and adjustments to the value of travel time savings:

- No distinction based on trip purpose for non-work related journeys should be made and travel time savings on leisure and commuting trips should both be valued at 50% of the average wage rate.
- Travel time savings on business trips should be valued at the gross wage plus labor related overheads.
- The value of travel time savings varies with income and income elasticity of 0.75 reflects the current state of the evidence. Additionally, VTTS varies with distance and a positive distance elasticity of 0.3 is appropriate. Income and distance are the two most important sources of variation across studies, regions and modes.
- No adjustment across different modes apart from accounting for differences in socio-economic characteristics of travelers (e.g. income, trip-purpose) or of the trip (distance, wait times).
- Small travel time savings should be valued based on the constant unit approach and travel savings and travel losses should be valued symmetrically; however, if predicting behavioural reactions such as for pricing policies, it may be necessary to treat small time savings differently from large ones.
- Travel time savings in congested traffic should be valued at twice the rate in uncongested traffic.
- A weighting factor of two for walking time and two-and-a-half for waiting time relative to in-vehicle time is consistent with recent evidence.
- Recent evidence has shown that travel time reliability is a substantial part of travel time savings. Without any further knowledge on how reliability varies with the level of congestion on the road it is impossible to make any recommendations although our belief is that incorporating reliability is crucial.

- Special attention should be paid to the fact that all VTTS values and all proposed adjustments are averages. There is some evidence that the VTTS-distribution over the population is right-skewed (a few people have very high values while the majority has quite low values). While this might not be of relevance for investment appraisal, behavioral changes to the imposition of a congestion toll will depend on the VTTS-distribution as the "disappeared" traffic under road pricing would suggest.

2.10 Modeling Congestion and Its Implications for Measuring the Externality of Time Delays

Efficient pricing requires that market prices appropriately reflect social costs. Any implementation of measures attempting efficient pricing will have to rely on estimates of all elements of social marginal cost including external costs. Congestion costs are a crucial component of the social cost. Estimating the social cost of congestion requires models that allow investigation of the change in journey time and travel time reliability caused by a change in traffic on a particular mode.

In contrast to environmental and noise externalities, congestion externality costs are internal to the transport sector as a whole, hence they are considered an *intra-sectoral externality.* The crucial issue is to distinguish between the external element of the cost of congestion and the total or average cost of congestion. The total cost of congestion is borne by the sum of users themselves. However, under congestion, each additional user inflicts costs on other users as well as on himself. The external element, the costs inflicted on others, is the relevant part for pricing purposes.

Efficiency requires that road users pay the marginal external cost that they impose on society as a whole. This is different from the requirement that road users pay the *total* amount of social cost unless coincidentally the marginal social cost and the average social cost are the same. For congestion costs the marginal social costs exceed the average social cost since drivers impose congestive externalities on other road users.

Apart from road congestion in the form of traffic jams, congestion can affect other transportation modes as well. For rail, the major issue is not so much congestion as the *scarcity value* of a specific slot or path allocated to particular firm, i.e. the value of its next best use.[42] When the traffic volume approaches full capacity, other transporters are unable to obtain their preferred slots. In addition, hub-and-spoke networks established by major air carriers have led to increased problems of airport congestion, in which landing slots become increasingly scarce. This section will look at theoretical models of congestion for the various modes in an attempt to isolate the incidence of the costs and the extent to which they are internalized by the individual travelers.

---

[42] This cost is an externality only if it is borne by another operator. If the next best use is by the same operator, then those costs are already internalized.

2.10.1 Road Congestion

Traffic congestion on a road occurs when the cost of travel is increased by the presence of other vehicles. The congestion externality arises because additional road users increase travel times for other vehicles. Travel time increases either because increased traffic density forces drivers to go slower due to the reduced gap between vehicles, because greater attention is required to drive safely or because queuing might occur at junctions or bottlenecks.

Congestion models can be divided into two groups: static time-independent models and dynamic, time-dependent models. The former and more traditional way of estimating the levels of congestion employs static speed-flow curves that differ with the characteristics of the road (urban-rural, number of lanes, etc).[43] In urban areas however, heavily congested roads are often the result of a bottleneck. Bottlenecks require dynamic, time-dependent models based on queuing (Small, 1992b). Queues form whenever the traffic volume exceeds capacity at the bottleneck. The queue builds up and slowly dissipates as the demand falls. Vehicles arriving when the queue starts impose delays on all the subsequent vehicles for the duration of the queue. This external cost of congestion declines steadily through the duration of the queue. Dynamic bottleneck models were pioneered by Vickrey (1973) and subsequently extended by Arnott, de Palma and Lindsey (1988). The following discussion on the two strands of models is adopted from Lindsey and Verhoef (2000).

2.10.1.1. Time-Independent Models

Time-independent models of traffic congestion are a starting point for more realistic but more complicated time-dependent models. Static models provide a reasonable characterization of slow evolving (stationary) traffic conditions. The exposition here focuses on the short-run and does not consider optimal infrastructure investment in the long-run. Traffic streams are described by three variables: density k (vehicles per lane per kilometer), speed v (km/h), and flow q (vehicles per lane per hour). Traffic flow is the product of traffic density (vehicles/km) and speed (km/h), hence these three variables are related by the equation $q = kv$. Everything else equal, as more vehicles enter the same road, traffic density increases, travel speed falls and travel time increases. The *fundamental diagram of traffic flow* introduced by Haight (1963) plots any one variable against another summarizing the speed-density curve, the speed-flow curve and the flow-density curve in one diagram as shown in Figure 2.10.1.1a.

[43] Excellent reviews of static congestion models are Mohring (1976), Small (1992) or Hau (1998).

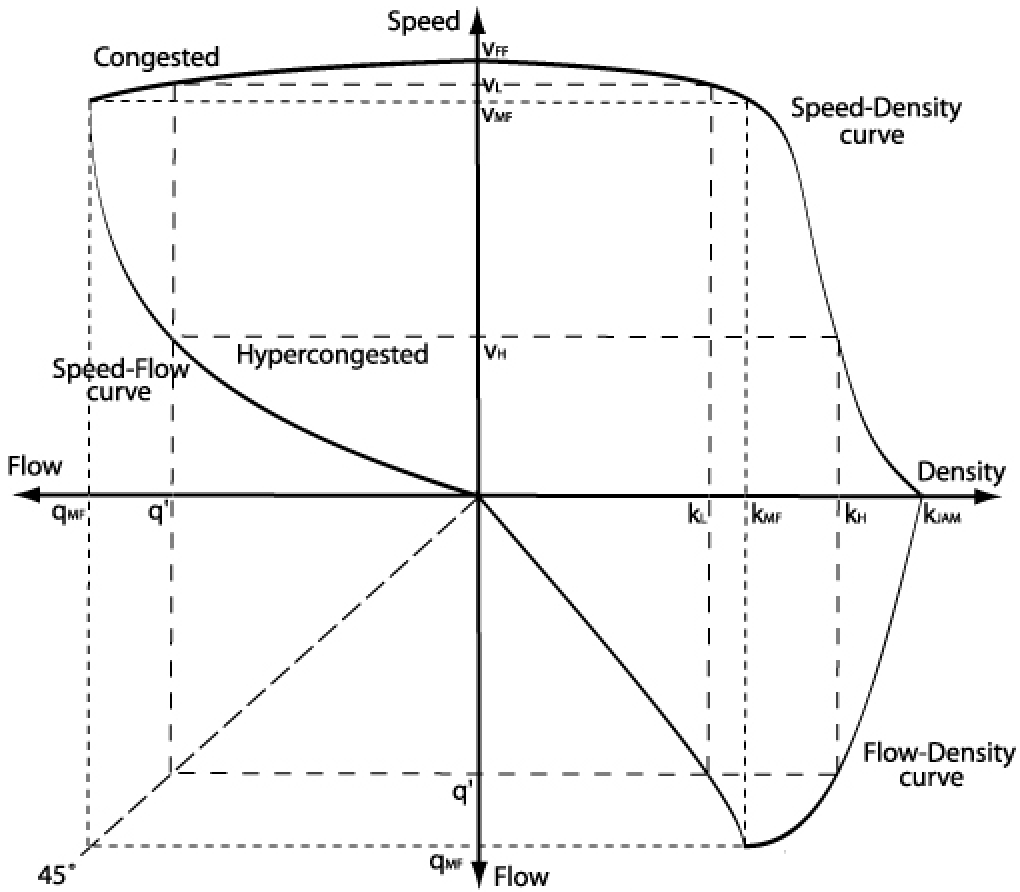


Figure 2.10.1.1.a: Fundamental Diagram of Traffic Flow

As density increases, speed declines for safety reasons although initially speed remains close to free flow speed v_{FF}. At higher density, speed starts to drop rapidly first to the maximum flow-speed v_{MF} and finally reaches zero at the traffic jam density k_{JAM}. It is interesting to note that any flow $q' < q_{MF}$ can be achieved either by a combination of low density and high speed (k_L, v_H) or high density and low speed (k_H, v_L). The upper branch of the speed flow curve is referred to as *congested* while the lower branch is *hypercongested*.[44] Congestion occurs whenever speed is below free-flow speed v_{MF}.

Starting with Walters (1961), the speed-flow curve can be transformed for economic analysis. Traffic flow is interpreted as the quantity of trips supplied by the road infrastructure per unit of time. The two major categories of road congestion costs are time costs and vehicle operating costs as they vary by type of vehicle and speed (fuel, tires, etc).[45] Typically, changes in vehicle operating costs are small relative to time costs and

[44] Hypercongestion has attracted a lot of attention in the literature and occurs routinely on non-uniform roadways through queues upstream of an overloaded bottleneck. It is however debatable whether hypercongested conditions can arise on a along a uniform stretch of road.

[45] If vehicle operating costs are subject to taxes, such taxes should not be included in the calculation since they do not represent a real resource cost but are simply a transfer between vehicle operators and the government (but variable taxes or user charges are a measure of willingness to pay so they may be

can affect the costs positively as well as negatively. In general, congestion costs are dominated by time losses. Hence, it seems appropriate to focus on time costs. Denote by α the (common) unit cost of travel time, D the trip distance, c the trip cost other than in-vehicle travel time[46] and $v(q)$ the travel speed expressed as a correspondence of traffic flow.

Hence, we can generate a trip cost curve expressing travel cost in terms of traffic flows as shown in Figure 2.10.1.1b:

$$C(q) = c + \frac{\alpha D}{v(q)}$$

It is mainly the time cost element that gives the trip-cost curve its upward sloping structure. The curve starts to climb before traffic reaches maximum capacity since congestion delay sets in rapidly at levels still below capacity. The backward bending part of the curve means that the time costs continue to rise when traffic flow is reduced after full capacity is reached. The positively sloped portion of the trip-cost curve corresponds to the congested branch of the speed-flow curve while the backward bending portion corresponds to the hypercongested branch. Any point on the negatively sloped portion of the trip-cost curve (q', C_H) is clearly inefficient as the same number of trips is accomplished but the costs are higher relative to the corresponding point on the upward sloping portion (q', C_L).

included in measuring benefits). In addition, if congestion (slower speeds) leads to reduced accidents, those benefits should be included as well as the cost of paying more attention to the road in congestion.

[46] Other trip costs apart from in-vehicle travel time include waiting time, walk access time, fuel costs, etc. These other trip costs are assumed to be independent of congestion.

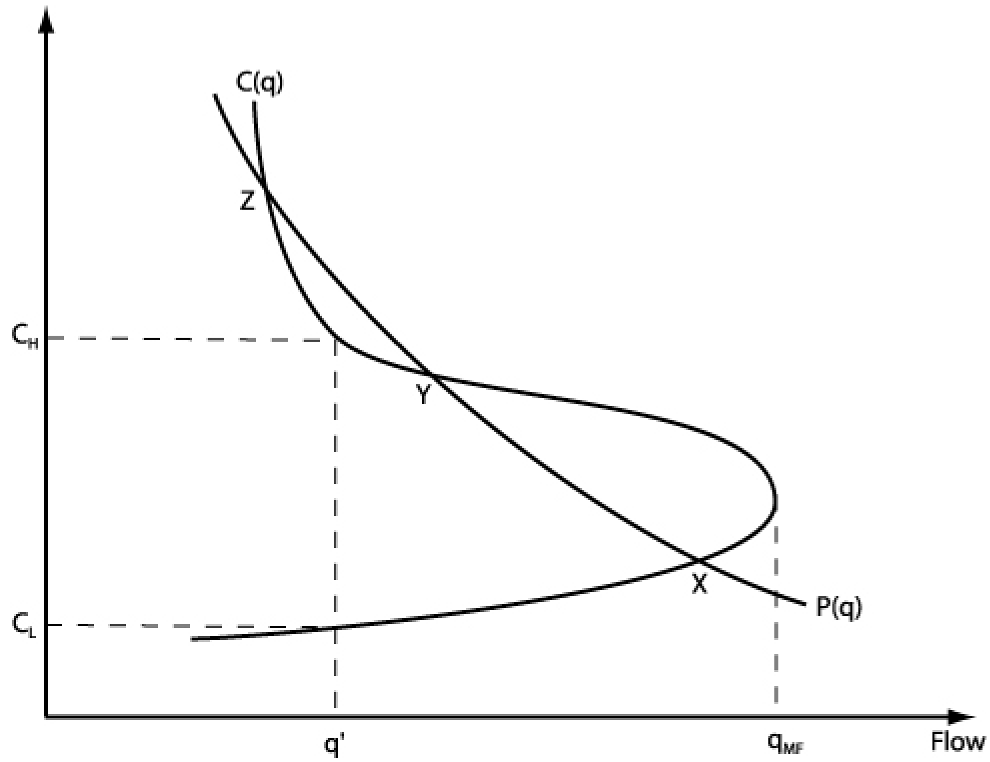


Figure 2.10.1.1b: Travel Demand P(q) and Backward-Bending Travel Cost Curve C(q)

A travel demand curve $P(q)$ can be added to the diagram if flow is similarly interpreted as the quantity of trips demanded per unit of time. Commonly in economic analysis the focus is on the equilibrium in the upward sloping (congested) portion of the speed flow curve.[47] Given the trip cost curve one can derive the marginal social cost curve and the socially optimal use of the road. $C(q)$ measures the average social cost of a trip[48], the total social cost is $TC(q) = C(q)q$ and hence the social marginal cost of an additional trip is

$$MSC(q) = C(q) + q\frac{\partial C(q)}{\partial q}$$

Rising average costs imply that marginal costs are above average costs and the difference is the marginal congestion externality – the additional delay a driver imposes on other drivers. As illustrated in Figure 2.10.1.1c, the unregulated equilibrium flow is q_E, the intersection of average cost, $C(q)$ and demand, $P(q)$. The socially optimal amount of congestion is not q_E but rather q^*, the intersection of the social marginal cost $MSC(q)$

[47] The diagram shows two potential hypercongested equilibria Y and Z. There is a debate about whether these potential equilibria are in fact stable but the general consensus is that hypercongestion is a briefly passing phenomenon in reality and should be properly modeled with time-dependent dynamic models.

[48] Since the exposition is focused on congestion cost, other social cost such as air pollution or accidents are ignored, as are potential external social benefits .

and demand $P(q)$. The socially efficient equilibrium can be supported with a congestion toll equal to

$$\tau^* = MSC(q^*) - C(q^*) = q^* \frac{\partial C(q^*)}{\partial q^*}$$

which is exactly the marginal congestion cost imposed by an additional traveler on others (at the optimum). Such a congestion toll results in a pareto-efficient allocation and is typically referred to as a Pigouvian tax (Pigou, 1920).

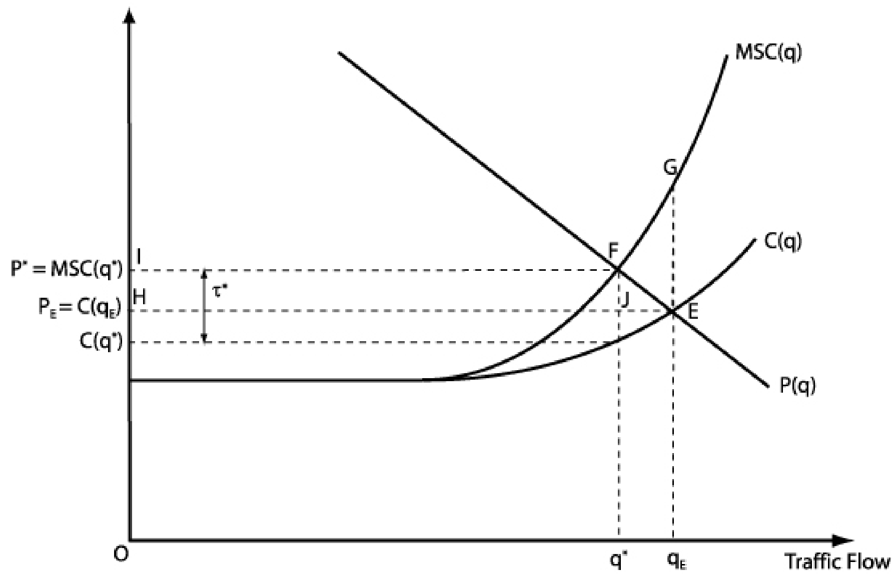


Figure 2.10.1.1c: Equilibrium Road Usage and the Optimal Congestion Toll

The imposition of the optimal congestion toll raises social welfare by the amount of the triangle EFG. Ignoring government revenue for a moment, there are essentially four groups to consider for welfare impacts: Drivers still on the road once the toll is imposed essentially face a tax increase equal to the toll τ^*. They are worse off by the area HIFJ because the optimal congestion toll is higher than their time savings. As a consequence, the aggregate toll revenue collected by the government, $\tau^* q^*$, exceeds the total amount of time savings.[49] Individuals who are priced off the road either because they give up traveling or switch to another mode suffer a collective loss equal to the amount JFE. Furthermore, so-called "tolled-on" travelers on other modes could be negatively affected if alternative modes become congested. The last group is the government, which collects the toll revenue equal to $\tau^* q^*$. The equity impact of a congestion toll however cannot be analyzed without considering the governmental use of the toll revenue. If toll revenue is

[49] Remember that the analysis assumes a uniform value of time across the population. Considering that empirical estimates of the distribution of value of time are severely right-skewed, this relationship might well be reversed.

used on some government spending project, one has to consider the equity impact of those specific projects. If the toll revenue is used to reduce other distorting taxes one has to consider such a distributional impact of a changed tax regime.

From the traditional speed-flow relationship, one can calculate the external element of time costs in algebraic form in more detail (Newbery, 1990). The time cost per kilometer is the time per kilometer multiplied by the appropriate value of time

$$t = \frac{b}{v}$$

where t is the time cost, b the appropriate value of time and v is the vehicle speed in km/h. The total time costs per kilometer for a specific flow level q is

$$T = tq$$

where the flow level is measured in passenger car units. The marginal cost of adding another vehicle is then given by

$$\frac{dT}{dq} = t + q\frac{dt}{dq}$$

The marginal time costs of an extra vehicle is the cost it incurs itself - t, and the increase in time costs incurred by other vehicles multiplied by the number of vehicles. Total differentiation of the vehicle time costs per kilometer gives

$$\frac{dt}{dq} = -\frac{b}{v^2}\frac{dv}{dq}$$

which can be substituted back in, resulting in

$$\frac{dT}{dq} = t - q\frac{b}{v^2}\frac{dv}{dq}$$

The first term on the right hand side is the time cost borne by each user themselves, the second term represents the marginal external costs (MCT):

$$MCT = -q\frac{b}{v^2}\frac{dv}{dq}$$

The above expression shows that the marginal external cost varies by the volume of traffic q, the resulting speed v, which varies by road and traffic volume, the slope of the speed-flow relationship and the value of time b. According to this model, an efficient road pricing scheme will have varying charges according to those characteristics.[50]

[50] For example, weather conditions affect the speed-flow relationship of a road. To account for this, road toll charges in San Diego, California may be doubled during adverse weather conditions.

Both, graphic and algebraic analysis has been based on the assumption of a uniform value of time incorporated in the concept of a representative driver. In reality, the value of time is heterogeneous. The optimal toll should then be based on a weighted average of the different drivers' marginal value of time. This would relax the conclusion that all drivers still on the road are worse off due to the toll (ignoring the impact of the toll revenue collected by the government).

An obvious objection to this traditional, static link-flow approach is the fact that the traffic flow on road stretches is a very poor guide to traffic conditions in densely meshed urban road networks. Most traffic interactions and congestion delays take place at intersections or bottlenecks and not on the road stretches in between. Such dynamic effects are ignored in the static models and casts doubt on analysis and general conclusions based on the traditional speed-flow relationship.

There have been several empirical studies of congestion costs based on traditional speed-flow diagrams and two approaches will be reviewed in more detail. A classic reference is Small and Keeler (1977) who use data from a large scale study compiled by the Institute of Transportation ad Traffic Engineering (ITTE) for the Bay area (California). They find that a quadratic relationship between volume (flow) - capacity ratio (q/k) and speed (v) fits the data well, where capacity (k) refers to the engineering standard (Highway Research Board, 1965):

$$\frac{q}{k} = \alpha + \beta v + \gamma v^2$$

Their results provide further evidence for the theoretically well-established backward-bending portion of the speed-flow relationship. Given the capacity k of the road in terms of car-equivalents per lane per hour, one can invert the upper portion of the estimated equation (positive root) and take the reciprocal to get travel time per km/h:. The estimated relationship will depend on the maximum design speed of the road, weather, terrain, vehicle types, driving habits and the characteristics of the road (interchanges, etc.).

A more direct approach is outlined in Mohring (1976). One could attempt to estimate straightforward the travel time as a function of the volume capacity ratio:

$$T = f\left(\frac{q}{k}\right)$$

The average and marginal travel times can be easily calculated from the estimated results. Coleman (1961) for example proposes the following specification:

$$T = \alpha - \beta\sqrt{\left(1 - \frac{q}{k}\right)}$$

From the estimated relationship, the appropriate measure of congestion costs can then be obtained using a suitable measure of the value of time.

2.10.1.2. Time-Dependent Models

Dynamic or time-dependent congestion models allow traffic flow to vary over time and space. Such models can be of macroscopic or microscopic nature. The most widely used dynamic macroscopic model is the *hydrodynamic model* developed in the 1950s by Lighthill and Whitham (1955) and Richards (1956). The hydrodynamic model assumes that stationary speed-density relationships carry over to non-stationary conditions. If vehicles neither suddenly appear nor disappear along a stretch of the road, the partial differential equation, referred to as the *conservation equation*, governs the flow and density at each location x at each point in time t:[51]

$$\frac{\partial q(x,t)}{\partial x}+\frac{\partial k(x,t)}{\partial t}=0$$

To illustrate the workings of the hydrodynamic model consider Figure 2.10.1.2aa. Traffic is initially in a congested stationary state A with speed v_A, density k_A and flow q_A. Suppose that the inflow onto the road suddenly drops at time t_0 from q_A to q_B, moving traffic to state B on the flow-density curve. This new state B propagates downstream along the road as a shock wave with speed w_{AB}. Since entering vehicles travel faster than the shockwave, they will catch up to the shockwave at speed $v_B - w_{AB}$, thereby leaving state B at a flow rate $k_B(v_B - w_{AB})$. Since vehicles neither appear nor disappear from the road, vehicles must enter state A at the same flow rate, which is equal to $k_B(v_A - w_{AB})$. This equality and the speed-flow-density identity $q = kv$, one can obtain the speed of the shock wave, the slope of the line connecting state A and B:

$$w_{AB}=\frac{(q_A-q_B)}{k_A-k_B}$$

Notice that the wave speed w_{AB} is less than the speed in either state.

The trajectories of representative vehicles are shown by arrows in Figure 2.10.1.2ab. Appropriately scaled time and location axes mean that the slopes of vehicle speeds matches Figure 2.10.1.2aa. Prior to the drop in inflow, vehicles are moving north-east at speed v_A. At time t_0 when the inflow drops, the slope of the trajectories of incoming vehicles increases to v_B. Once these vehicles approach the shockwave they instantaneously slow down to v_A resulting in a kinked trajectory. Notice that the spacing between vehicle trajectories is greater in state B than in state A since state A is characterized by larger traffic flow $q_A > q_B$. Furthermore, in this time-space diagram, no intermediate speeds and densities occur, vehicles are either traveling at speed v_A and density k_A or at speed v_B and density k_B. This particular shockwave illustrated in Figure 0.1.2a is called a *forward-recovery* shockwave since it propagates a reduction in density

[51] A discrete version of the conservation equation still applies in instances in which the proper derivatives do not exist.

downstream along the stretch of road. The reverse situation, moving from state B to A, would result in a *forward-forming* shockwave while a transition from state C to B would result in a *backward-forming* shockwave.[52]

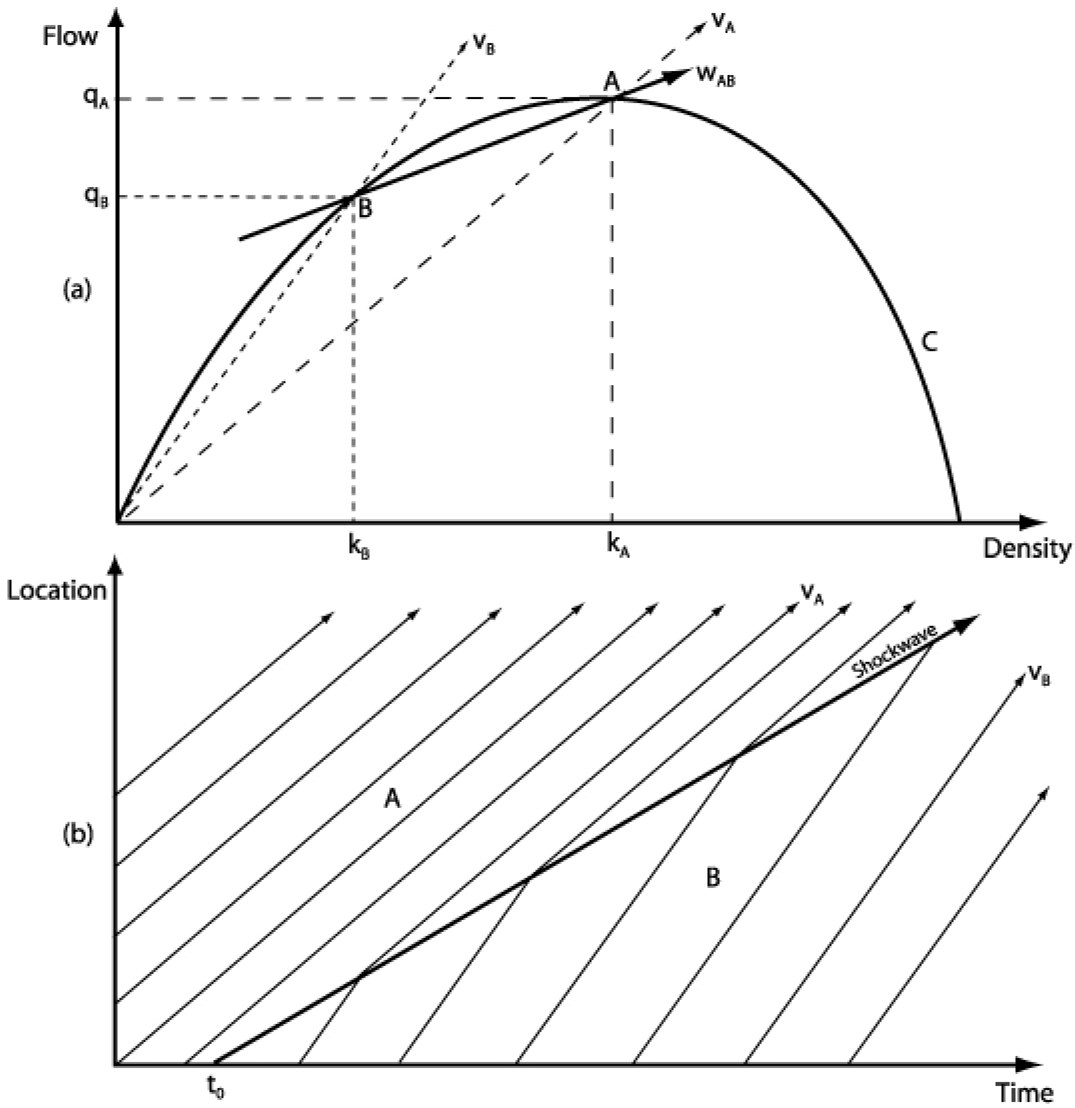


Figure 2.10.1.2a: (a) Transition on the Flow-Density Curve; (b) Trajectories in Time-Space Diagram

While shockwave analysis based on the hydrodynamic model may be useful in examining discrete changes in traffic conditions such as temporary capacity reductions, its assumption of a given speed-density relationship at each point in time and space independent of recent or anticipated road conditions limit the accuracy of the predictions. In addition, the model cannot account for flow instabilities such as stop-and-go conditions; vehicles are assumed to adjust their speed instantaneously. Furthermore, it is

[52] See May (1990) for a comprehensive review of the hydrodynamic model and several other types shockwaves that could potentially occur.

tedious to derive solutions for the hydrodynamic model analytically or using diagrams when the inflow varies continuously over time.

The models introduced so far do not explicitly model the congestion processes and hence suffers from ambiguity once urban bottlenecks are considered (Vickrey, 1969). To illustrate this point, consider a single bottleneck; say an entry point to the downtown business district, in which congestion occurs during the morning peak hours. The bottleneck has a fixed capacity and as the number of drivers arriving at the bottleneck exceeds the capacity a queue starts to form. There are three types of ambiguity associated with models that focus solely on the flow during a specific time interval. First, it is not clear exactly what the number of drivers during a specific interval is, whether it is the number passing through the bottleneck or the number of drivers joining the queue. Second, the private cost in an interval depends not only on the number of users in that specific interval but depends also on congestion in previous intervals though the length of the queue. Third, the addition of a driver in a specific time interval increases the queue length (and hence the social cost) not just in that interval, but in later intervals as well. Urban congestion is inherently a dynamic phenomenon and the next few paragraphs will analyze a special dynamic model, the *bottleneck* model that specifically focuses on urban congestion in the form of bottlenecks.

This strand of dynamic congestion models started with the seminal paper by Vickrey (1969) who provided an explicit model of the congestion technology. User's behavioral decisions are modeled explicitly based on time-of-use decisions, whereby road users trade off the cost of using the facility at an inconvenient time against the congestion cost of using the facility when it is crowded. Equilibrium in the model is obtained when the queue length over time is such that no driver can reduce her overall trip price (including time costs) by changing the departure time.

The *bottleneck* model assumes that the congested portion of the speed-flow curve at the bottleneck is horizontal up to the maximum flow capacity s. If the incoming flow at the bottleneck exceeds s, the excess flow accumulates in the form of a queue that propagates upstream as a backward-forming shockwave. The constant flow s at the bottleneck is a reasonable approximation of observed behavior at typical bottlenecks such as bridges, tunnels, city entrances, etc.

The queue evolution in a bottleneck model is shown in Figure 2.10.1.2b. The $D(t)$ curve represents the cumulative number of vehicles that have passed through the bottleneck while the $A(t)$ curve denotes the number of vehicles arriving at the tail of the upstream queue of the bottleneck. Before time t_0, the arrival rate is less than the capacity of the bottleneck and no queue forms ($A(t)$ and $D(t)$ coincide). However, between time t_0 and t_E a queue exists, initially increasing because the flow rate exceeds the bottleneck capacity and later shrinking as the flow rate drops below s. The vertical distance $Q(t)$ measures the length of the queue at each point in time while the horizontal distance $Q(t)/s$ measure the length of time spent in the queue by a vehicle arriving at time t. Total queuing time is the area between $A(t)$ and $D(t)$.

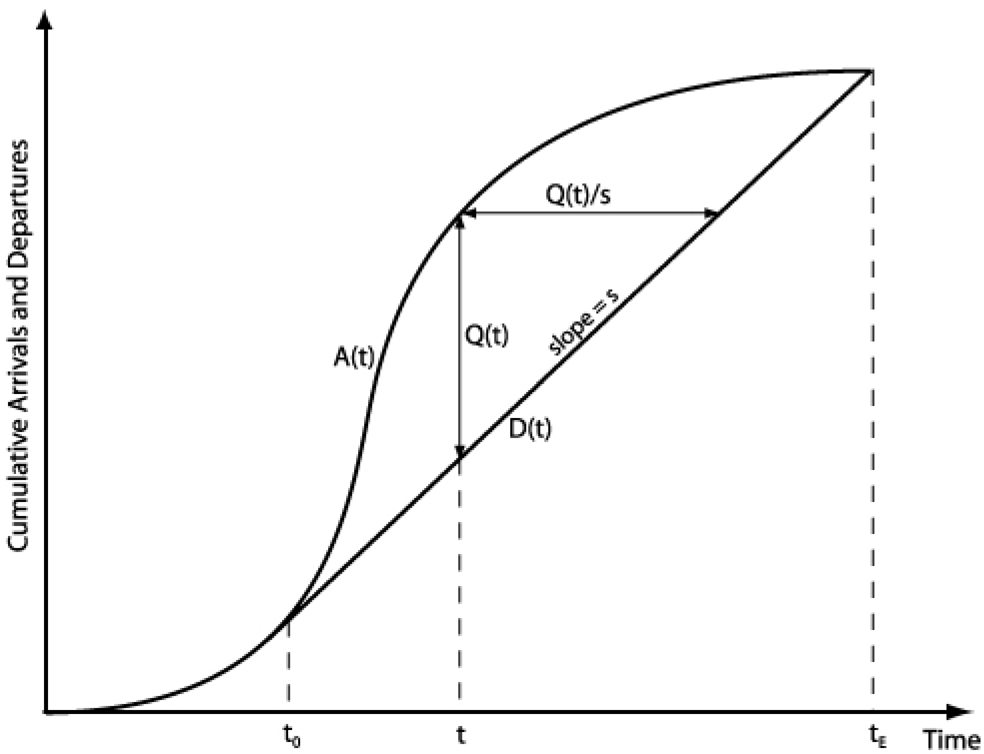


Figure 2.10.1.2b: Queue Evolution in the Bottleneck Model

Total travel time losses predicted by this simple bottleneck model might however be exaggerated due to the fact that queues are not dimensionless points in space (so-called vertical queues) but rather occupy a stretch of the road. Vehicles in the queue are not stationary but move forward rather slowly. Vehicles arriving at the tail of the queue would take time to reach the actual location of the bottleneck even in the absence of a queue. Hence, individual delay is typically less than $Q(t)/s$ and the area between $A(t)$ and $D(t)$ overstates total time delay. Travel costs are generally assumed to depend on delay rather than time spent in the queue and failure to account for the physical length of the queue could potentially overstate travel time losses.[53]

Up to now, the bottleneck model has focused on congestion once vehicles have entered the traffic stream without incorporating the determinants of inflows, travel demand. Clearly, people care about the time they are traveling. If trips were evenly spread out most likely there would be no congestion. Hence, it is necessary to formally incorporate how trips can be substituted in time.

An extreme assumption is that trips are not inter-temporally substitutable and only depend on the cost of the trip at that particular moment in time. A more realistic approach is to use the more general concept of *schedule-delay cost* introduced by Vickrey (1969). It assumes that each individual (vehicle) has a preferred time t^* to complete the trip and

[53] The counter-argument says that travel time lost is more "costly" if it occurs in heavily congested traffic such as a queue. Empirical studies consistently confirm that travel time is valued higher in congested traffic.

incurs a cost for arriving early or late. It is typically assumed that the costs are asymmetric but linear. Individuals incur costs of β per minute of arriving early and costs γ per minute of arriving late. Empirical estimates provided by Small (1982) indicate that $\beta < \alpha < \gamma$, where α is the unit cost of travel time.

Equilibrium in the bottleneck model incorporating schedule-delay costs is shown in Figure 2.10.1.2c, an augmented version of Figure 2.10.1.2b.

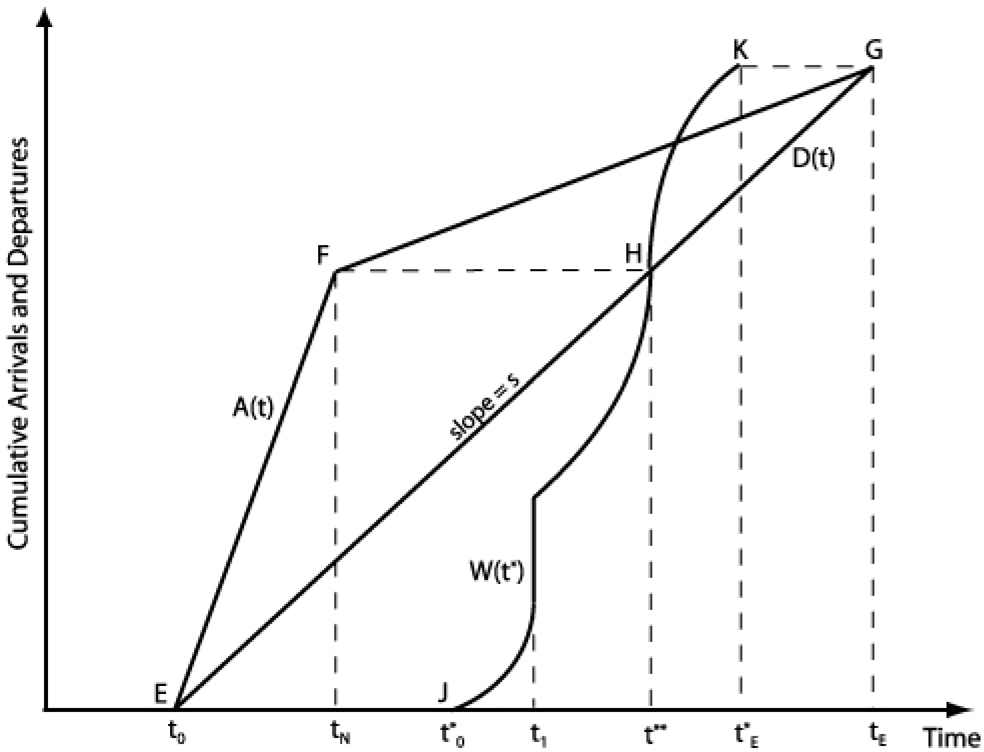


Figure 2.10.1.2c: Equilibrium Trip Timing on the Bottleneck Model with Schedule-Delay Cost

The added element to the figure is the curve $W(t^*)$, which represents the distribution of t^* across the population. The distribution of t^* extends from t_0^* to t_E^* with a mass point at t_1. It is assumed that all travelers have the same values of time α, β and γ, that demand for trips is price inelastic, i.e. a fixed number N of individuals are commuting. For simplicity it is assumed in addition that free-flow travel times before and after the bottleneck are zero and the queues are vertical (zero length).

Within this simple framework, commuters only have to choose at which time t they will join the queue behind the bottleneck. A Nash-equilibrium in this model is defined as an allocation of time t for each vehicle such that no traveler can reduce their trip cost by changing t, taking all other travelers choices of t as given. Trip cost is then composed of queuing time cost, schedule-delay cost and fixed travel costs independent of t. It follows that in a Nash-equilibrium, the sum of queuing time cost and schedule delay cost must be independent of t. Since schedule delay costs are assumed to be linear, the result is a piecewise queuing pattern as shown in. Figure 2.10.1.2c

The solution consists of four parameters, t_0, t_N, t^{**} and t_E, which are determined by four equations. First, the congested period is long enough so that all N take their trip, $s(t_E - t_0) = N$. t^{**} is defined as the time at which the number of individuals who want to have made their trip by then actually have done so, $W(t^{**}) = s(t^{**} - t_0)$. The model is closed by the fact that individuals who depart at time t_N and arrives at the preferred time t^{**} incurs the same total trip cost departing at t_N as if they would have departed early at t_0 or late at t_E, $\beta(t^{**} - t_0) = \alpha(t^{**} - t_N) = \gamma(t_c - t^{**})$. As in Figure 2.10.1.2b, the total queuing time is given by the difference between $A(t)$ and $D(t)$. It is important to account for schedule delay costs which consist of total time early EHJ and total time late GHK, which are of substantial magnitude compared to queuing time.[54]

Failure to incorporate schedule-delay cost may considerably underestimate gains from congestion pricing, since a substantial portion of the gains results from change induced in the time pattern of road use over the congested period (Arnott, de Palma and Lindsey, 1993). Transferring this argument to the estimation of social congestion costs emphasizes the need to incorporate costs arising because travelers switch to a less preferred travel time due to congestion.

Since capacity at the bottleneck is independent of the length of the queue, the amount of time individuals spend in the queue is a deadweight loss. Queuing can be eliminated by imposing a time-varying toll equal to the cost of queuing time in the no-toll equilibrium.[55] In Figure 2.10.1.2c, the optimal toll would rise linearly starting at t_0 to a maximum at t^{**} just to decrease (linearly) again to zero at time t_E. The toll exactly offsets queuing time cost, **(**)**, private costs of individuals are therefore unchanged. Aggregate schedule-delay costs are also unchanged since with a fixed bottleneck capacity, both the timing and the duration of the travel period are the same.[56]

2.10.1.3 Congestion Externality and Road Pricing

The key significance of the foregoing discussion is that how congestion is modeled can make a significant difference in measuring the congestion impact of an incremental vehicle entering the network. In the traditional speed-flow relationship, measuring the marginal social costs on the system are relatively straightforward. But if congestion is

---

[54] The model becomes more complicated if individuals not only differ by their desired arrival time t^*, but also by their travel time costs (α, β and γ) but an analytical solution can still be provided.

[55] It is crucial to realize that the toll does not depend on the *actual* length of the queue at that particular time but rather on the length of the queue if the toll was zero not just at that particular time but throughout.

[56] This invariance of private-travel cost and schedule-delay costs in a tolling regime is specific to the bottleneck model and does not hold in the hydrodynamic model.

associated with bottlenecks and dynamic queuing, then the congestion impact of an additional vehicle depends on the location and time of entry of the vehicle into the transportation system. Measuring marginal social costs is much more difficult in these circumstances.

An issue that is completely ignored by the above analysis is the relationship between congestion and the variability of travel times. Road users value reliability, and hence the appropriate road charges should take into account the interaction between congestion and the variability of journey times. Such issues probably have to be resolved by relying on traffic simulation models. This is an important research topic for developing accurate estimates of the marginal social costs of vehicles entering a congested facility.

Another issue not addressed is the implications of vehicles with different performance characteristics.

2.10.1.4 Measuring and Interpreting the Costs of Congestion

The externality of congestion differs in some respects from most other examples of externalities. By definition, externalities refer to costs (or benefits) that are not priced in the market and accrue to third parties as a result of actions taken by individuals. Buyers and sellers in a market place will recognize the costs (and benefits) that they incur personally. But in the absence of property rights or legal frameworks that force individuals to consider such externalities, parties in a market transaction will not consider the costs imposed "externally" by their action. Pollution is a classic example of an externality since neither buyer nor seller of a polluting product has any incentive to consider the pollution costs they impose on others.

In their decision making process, motorists recognize the higher time costs they face during road congestion, but they do not recognize that they impose delay costs on other motorists on the road. Motorists do not perceive themselves a cause but rather a victim of congestion. Nonetheless, the collective delay costs are borne internally by all the motorists as a group; they are not imposed on a third party. In a sense, the externality is internalized in the aggregate, a form of collective internalization unlike most other externalities. The question arises whether congestion costs are part of the external social costs to be added to the private costs to arrive at the total social costs of transport, or whether such congestion costs are already internalized by motorists as a group?

There exists some confusion on the appropriate measure of the social costs of congestion as various alternative measures have been suggested in the literature (Newbery, 1990). If one is measuring the total social costs of transportation, the imputed value of total time spent traveling would certainly be part of the total costs. However, travel time costs exist even in the absence of congestion, but the existence of congestion causes these costs to be higher as users interfere with each other's travel. It is therefore appropriate to separate the costs of congestion from unavoidable time costs of transport, yet there is ambiguity in the proper way to do it.

The classic speed-flow relationship is used in Figure 2.10.1.4 to illustrate alternative interpretations of the social costs of congestion.

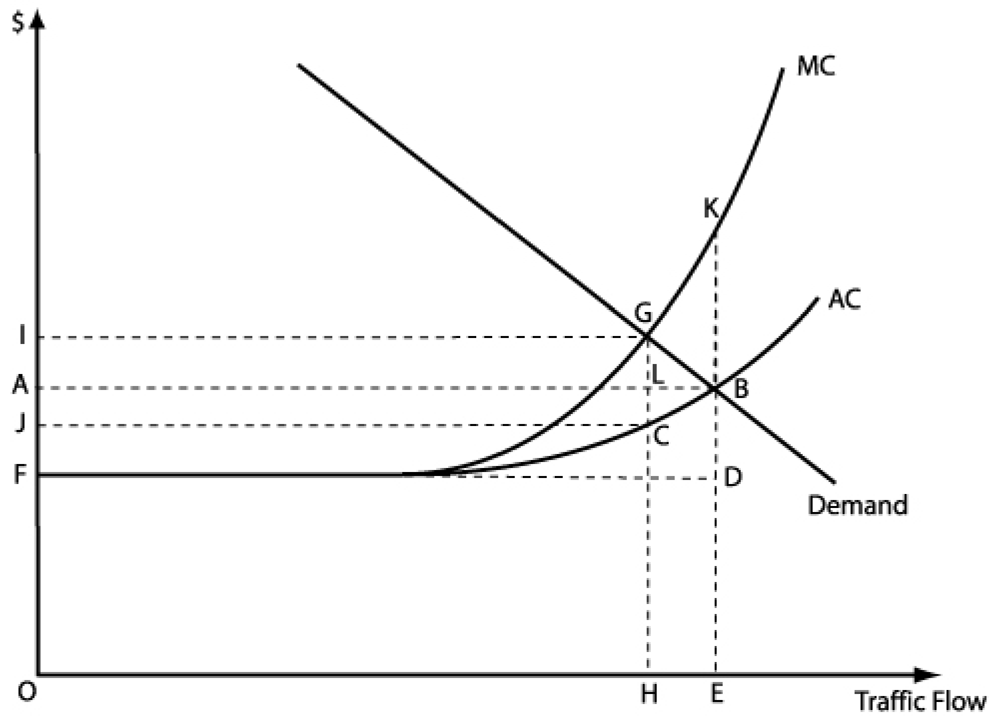


Figure 2.10.1.4: The Costs of Congestion

Ignoring the possibly backward-bending part of average costs, Figure 2.10.1.4 shows average and marginal social costs of travel for different traffic volumes relative to the demand for travel. In the absence of congestion pricing, all motorists whose willingness to pay (in time and money) exceed their costs will use the road and the market equilibrium occurs at the intersection of the average cost curve and demand, at point *B*. The traffic volume is equal to the distance *OE* with average costs of *OA* and total travel costs equal to the rectangle *OABE*.

One possible measure of the costs of congestion frequently cited is the extra cost involved in traveling on congested rather than uncongested roads, i.e. comparing the actual travel conditions with hypothetical free-flow conditions. In such a hypothetical scenario of zero congestion, the free-flow level of average costs *OF* would prevail for all traffic. Total travel costs would be *OFDE* and the difference to the market equilibrium *FABD* would be the costs identified with congestion versus non-congested conditions.

Defining congestion costs based on a comparison with hypothetical free-flow conditions is unrealistic and misleading. It would clearly be uneconomical to build road capacity up to a point at which congestion is completely absent (Newbery, 1990). Nonetheless, two arguments can be made in favor of defining the costs of congestion in relation to free-flow conditions. Koopmans and Kroes (2004) argue that diagnosis and therapy should not be mixed up and measuring the size of a problem is not identical to implying that this size could, or should be zero. The problem with this argumentation is that if congestion costs are not measured appropriately, the indicator is meaningless in directing strategic decisions on the congestion problem. The other argument in favor of the comparison with free-flow conditions is the fact that congestion costs can be calculated with knowledge of the values of time of motorists and the congestion technology without having to estimate travel benefits. Nonetheless, the above mentioned arguments are questionable. Congestion costs estimated based on comparisons to free-flow conditions are misleading and exaggerate the social costs of congestion.

Instead an alternate approach is to compare the extra costs of congestion in market equilibrium with the efficient situation in which motorists were forced to recognize the marginal social costs of travel. Under the optimal congestion toll, traffic volume is reduced to *OH* and motorists pay a toll equal to *CG* that raises their individual costs of travel up to the marginal social costs.

Total social costs of travel have fallen from market equilibrium *OABE* to *OJCH* as there are fewer motorists on the road and the costs to those who remain traveling are lower. The difference *ABCJ* + *HCBE* is the portion of total costs attributable to the congestion externality. This difference can alternatively be calculated as the area beneath the marginal social cost curve, area *HGKE*. Although it is still the case that motorists as a group bear the full social costs of congestion, it is conceptually useful to separate the costs into two components: the total costs under optimal congestion *OJCH* and the excess congestion costs *HGKE*.

Still another approach to define the social costs of congestion due to the externality problem is to limit the measure of social costs of congestion to the loss in social surplus associated with excessive road use. In the previous paragraph, the incremental congestion costs are represented by the area beneath the MC curve for the additional traffic volume *HE*. However, this incremental social cost is accompanied by a benefit of allowing more motorists to travel on the roads. The efficient total surplus under congestion pricing consists of the consumer surplus equal to the triangle formed by *IG* and the demand curve, plus the collected tax revenue from the congestion toll, *IJCG*. The total surplus associated with the market equilibrium is just the consumer surplus equal to the triangle formed by *AB* and the demand curve. The loss in social surplus due to excessive road use is then equal to the rectangle *AJCL* less the triangle *GLB*. This is also equal to the area of the standard deadweight loss triangle *GBK*. The social costs of congestion are then much less than the gross measure of costs associated with the additional traffic (*HGKE*).

It is the imposition of a congestion tax of amount *CG* that forces motorists to confront the marginal social costs of the decision to drive. This generates toll revenues which are a transfer from motorists to society via the government or tolling authority. There is a net social gain of *GBK*, but motorists will perceive themselves worse off because of tolling. In fact, assuming a constant value of time all types of road users - the tolled and the tolled off (those who avoid the road to shun the toll - are worse off.[57] With the exception of hyper-congested road conditions,[58] the major benefit of congestion pricing lies in the revenue collected.

"... although pricing certainly reduces congestion, the larger part of actual benefit from road pricing does not consist of this congestion relief. The benefit sits, 'locked-up', in the revenue collected, and it is only released when the revenue is used." (Goodwin, 1997).

Public support for road pricing measures will be low unless toll revenues are earmarked and motorists perceive that the money is channeled back in the form of reduced taxes, lower user charges or other transportation improvements (Hau, 1992).

A complication in computing the portion of total costs associated with excessive congestion is that the position and shape of the cost curves depend on the underlying road capacity. Expanding capacity shifts the curves down- and outwards. Conversely, if capacity has not kept pace with the growth of demand over time, congestion and delay costs will be higher. Hence, the level of congestion costs is not only a function of motorists' behaviour, but it is influenced by the actions (or inaction) by road authorities.

There are other complications to the above illustration of congestion costs. As noted earlier, the traditional diagrammatic presentation of speed-flow relationships of congestion implicitly assumes a constant value of time. If we allow for heterogenous values of time, the analysis has to be modified but the results are still quite intuitive.[59] Instead of the optimal congestion toll being based on the representative driver's VTTS, it is now based on a weighted average of different motorists' valuation of time, weighted by number of trips taken by those motorists using the facility (Hau, 1992). The constant value of time can therefore be re-interpreted as the weighted average value of time. In fact, motorists now can be better off after the toll is imposed if their value of time is sufficiently higher than average. Hence, allowing for heterogeneity in VTTS does not fundamentally alter the analysis.

The analysis is still a conceptual framework. Because travel demand relative to capacity differs from place to place and hour to hour, there is no single set of congestion cost curves. In order to estimate total social costs of congestion for society, one needs to know degrees of congestion for all locations and times of the day. One might propose a highly aggregative or overall average relationship and an average underlying VTTS. This would enable a very rough estimate of the average level of congestion costs.

---

[57] With heterogeneous valuation of time, primarily motorists with very high values of time are better off.
[58] In the presence of hyper-congestion, everyone is better off with congestion pricing.
[59] For a mathematical extension to heterogeneous values of time consult the appendix of chapter 4 in Mohring (1975).

2.10.1.5. Selected Estimates of Total Congestion Costs from Other Countries

Since previous studies have used various definitions for total congestion costs, it is essential to distinguish the different definitions in order to prevent comparing apples and oranges. However, we were unable to classify all the major studies and therefore the results should be considered and compared with the appropriate care.

Dodgson and Lane (1997) define congestion costs as the extra costs road users incur because the existing British road network is congested. Hence, they estimate total congestion costs based on the comparison to free-flow conditions. They estimate the total costs of congestion (including time and fuel) in Great Britain in 1996 based on the speed-flow model to be $14.6 billion, which is about 1% of GDP in 1996.

Table 2.10.1.5a: Total Congestion Costs (Dodgson and Lane, 1997)

Study	Country	Year	Costs	Cost/GDP
Dodgson and Lane (1997)	Great Britain	1996	$14.6 billion	1.0%

Source: Dodgson and Lane (1997).
All figures are in 2002 C$.

On the other side of the spectrum of congestion cost definitions, Infras/IWW (2000) define the total congestion costs as the total welfare loss caused by non-optimal pricing. This large study analyzes congestion in 17 European countries and estimated total congestion costs (including time but not fuel costs) based on the speed-flow model at around 1.9% of GDP in 1995. Although, the definition of congestion costs is less inclusive than in Dodgson and Lane (1997), the study finds significantly higher cost-GDP ratio estimates. However, the estimates exhibit large variation across countries that might be linked to the presence of large urbanized areas. The Infras/IWW (2000) estimates are presented in Table 2.10.1.5b.

Table 2.10.1.5b: Infras/IWW Estimates of Congestion Costs by Country

Study	Country	Year	Costs (billion)	Cost/GDP
Infras/IWW (2000)	Austria	1995	3.27	1.29%
	Belgium	1995	5.76	1.91%
	Denmark	1995	1.68	0.95%
	Finland	1995	1.09	0.83%
	France	1995	29.92	1.80%
	Germany	1995	44.53	1.83%
	Greece	1995	3.27	1.60%
	Ireland	1995	0.38	0.47%
	Italy	1995	29.08	2.01%
	Luxembourg	1995	0.35	1.95%
	Netherlands	1995	12.90	2.85%
	Norway	1995	1.17	0.78%
	Portugal	1995	1.61	0.95%
	Spain	1995	15.55	1.90%
	Sweden	1995	1.61	0.69%
	Switzerland	1995	5.08	1.61%
	UK	1995	30.89	2.75%

Source: Koopmas and Kroes (2004).
All figures are in 2002 C$.

There exist a few studies for which we have been unable to clearly identify the definition for total congestion costs, and hence these estimates presented in Table 2.10.1.5c should be used with caution.

Table 2.10.1.5c: Various Total Congestion Cost Estimates

Study	Country	Year	Costs (bill.)	Cost/ GDP	Cost Types[A]	M. [B]
BTE (1997)	Australia	1995	13.13 [C]	2.32%	TF	?
Schierhackl (1995)	Austria	1995	9.03	3.53%	TFAE	SF
Budget Ministry (2003)	Belgium	1995	1.57	0.51%	TF	?
AVV (1998)	Netherlands	1997	1.13	0.23%	TF	D
Infras (1998)	Switzerland	1996	0.64 [D]	0.3% [D]	TFAE	D
Delucchi (1998)	USA	1991	119.27 [D]	1.35% [D]	T	SF
TTI (2000)	USA	2000	83.54 [E]	0.70%	TF	?

Source: Koopmas and Kroes (2004).
All figures are in 2002 C$.
[A] Cost types included in the estimate: T - time, F - fuel, A - accidents, E - emissions.
[B] Measurement method for time cost: D - direct measurement, SF - speed-flow model.
[C] Six large urban areas.
[D] Figure represents mid-point of the range of estimates.
[E] 75 large urban areas.

2.10.2 Rail Congestion

The methodology of estimating rail congestion costs is quite different from road congestion costs. For rail, the volume of traffic is controlled by slots and capacity is therefore never exceeded. The main consequence of full utilization of rail capacity is that operators cannot get the capacity they want and when they want it (Nash and Sansom, 1999). They might have to run their trains at scheduled times (and possibly speeds) which are different from their preferred journey, or they may have to give up the journey altogether.

It is impossible to come up with a ready definition of capacity on a rail route. The mix of train speeds and the precise order in which the trains are run determines the maximum number of physical transport units that can use the link. On a predominantly high-speed (passenger) line, one more additional slow moving freight train may remove paths for several high-speed trains. Physical transport units are typically maximized by grouping trains of similar speeds, but this might conflict with providing good service of trains at regular intervals.

All these complications lead to the problem that the impact of an additional train of a particular type on other trains using the link differs enormously according to the mix and schedule of trains currently using the link. There is no hope of a general methodology to estimate the scarcity values of slots, i.e. it is the value of its next best use.

There are several ways in which scarcity values of slots could be obtained depending on circumstances. Competitive bidding for slots could reveal scarcity values, although such a bidding exercise will be very complex since there are so many options of mixing trains of different types, origin and destinations together to allocate rail system capacity. In addition, the value of a particular slot depends very much on what other slots the operator obtained in an attempt to offer its client an attractive service package.

There is essentially no theoretical literature on evaluating congestion costs for rail travel and therefore no guidance in estimating rail congestion costs. In addition, our belief is that rail congestion in the Canadian context is at best a minor issue compared to Europe. In terms of external congestion costs, if the owner of the rail infrastructure (network) is also running the majority of trains, a large part of the congestion costs will be internalized (if not all). This situation is equivalent to an airport with a monopoly airline: Since all delays affect own aircraft, the monopoly airline will internalize all congestion costs.

2.10.3 Air Congestion

Air congestion primarily occurs at airport hub and is costly for both passengers and airline companies. Costs take the forms of queuing cost, layover time cost and interchange-encroachment cost.[60] Eventually these costs are passed through to (and hence borne by) the individual passengers.

Models of congested transportation systems can be separated into three categories: standard peak-load pricing models, bottleneck models and queuing theoretic models.

Peak-load pricing models econometrically estimate the demand and/or the delay functions that vary by time of day. They have no structural specifications and generally do not incorporate inter-temporal traffic adjustments in response to congestion fees. Carlin and Park (1970) set up a time independent model of traffic congestion, from which delay functions are estimated using data from LaGuardia Airport (New York) in 1967-68. External congestion costs are defined as the marginal delay costs that one incremental aircraft operation imposes on other users.

Morrison (1983) as well as Morrison and Winston (1989) assume constant elasticity demand functions and then estimate the elasticity of demand and the delay cost function. The social cost of an aircraft operation is the average private delay cost, the additional delay costs imposed on the other aircraft plus any additional cost imposed on the airport authority. Imposing a tax equal to the difference between the social and private costs alleviates the problem of excess demand for airport operations, delay costs and congestion levels.

These peak-load pricing studies typically assume a specific value for air travel time based on which the congestion costs are calculated. Table 2.10.3 presents the results from some frequently cited studies.

Table 2.10.3: Estimates of Air Travel Congestion Costs

Study	**Congestion Cost per passenger hour**	
	Aircraft	*General Aviation*
Carlin and Park (1970)	$ 6 (1968US$)	$ 12 (1968US$)
Morrison and Winston (1989)[A]	$ 21	$ 21

Source: Carlin and Park (1970) and Morrison and Winston (1989).
All figures are in 2002 C$ unless otherwise indicated.
[A] The same numbers are cited by Daniel and Pahwa (2000) and Daniel (1995, 2001).

The deterministic bottleneck model is originally due to Vickrey (1969) and has been subsequently extended by Arnott, De Palma, and Lindsey (1993). The bottleneck model that has been discussed in the section on road congestion can similarly be used to model aircraft queuing at airports. These types of models are more sophisticated as they allow the traffic rate to adjust inter-temporally in response to congestion fees.

Stochastic bottleneck models extend pure queuing-theoretic models. Pure queuing models

[60] Interchange encroachment costs are defined as the costs incurred by the airline when delaying flights to accommodate connecting passengers.

such as Koopman (1972) capture the effects of stochastic arrivals on the evolution of queues, but assume exogenous arrival rates and do not allow for inter-temporal traffic adjustments. The stochastic bottleneck model due to Daniel (1995) incorporates both stochastic queuing and inter-temporal traffic adjustments. Daniel (2001) further incorporates elastic demand, heterogeneous operation time preferences as well as heterogeneous layover and queuing time values. Daniel and Pahwa (2000) compare these three models empirically based on a data set from the Minneapolis-St. Paul airport. They found the stochastic bottleneck model produces the best results among the three types of models.

The novelty of the stochastic bottleneck model by Daniel (1995) is to add uncertainty into the traffic rate. Although the aircraft operator doesn't know exactly what the time-varying arrival/departure rate is, the fact that the probability distribution of the traffic rate (and hence the queuing system) follows a Poisson process is known. The following paragraphs provide only a sketch of the main model idea since the details of the model are complicated. Nonetheless, the exposition theoretically identifies the external marginal cost imposed by an aircraft, which empirical studies aim to measure.

Assume an aircraft's most preferred arriving time is t^* (say 1000). The aircraft is scheduled to land at the airport at S_n (say 0925), but it is likely to actually arrive at time t (say 0930) with the probability $P_t^{S_n}$. If it arrives at time t thereby joining the queuing process, the queuing time for length k is $l(k)$, say 30 minutes. The probability for aircraft to wait $l(k)$ is $q_{tk}(s)$, where s is the state of the airport. An aircraft might be encountered with waiting time intervals of different length. While arriving earlier ($t + l(k) < t^*$) will increase layover time costs, arriving late ($t + l(k) > t^*$) will increase interchange-encroachment costs.[61]

Expected queuing cost at period t is the waiting time in the queue $l(k)$ weighted by its probability $q_{tk}(s)$ summed over all values of k. The expected total arrival cost for an aircraft joining the landing queue conditioned on landing at time t can then be written as

$$C_t^A(s) = c_q^A \sum_{l(k)} q_{tk}(s) l(k) + c_b^A \sum_{0 \le l(k) \le t^* - t} q_{tk}(s)\left[t^* - t - l(k)\right] + c_a^A \sum_{t^* - t \le l(k) \le K_t} q_{tk}(s)\left[t + l(k) - t^*\right]$$

assuming that the unit layover time cost is c_b^A, the unit interchange-encroachment cost is c_a^A and the unit queuing cost is c_q^A.

The unconditional expected total arrival cost for an aircraft which is scheduled arrive at S_n (but might actually arrive at t) is the sum over t of $C_t^A(s)$, weighted by the probability of arriving at t given schedule time S_n.

[61] The layover costs are defined as the time cost incurred by an aircraft at the airport after exiting arrival queues and before entering departure queues. The interchange-encroachment costs are defined as the risk of passengers missing connecting flights due to inadequate layover times.

$$\sum_t P_t^{S_n} C_t^A(s)$$

Suppose there are N aircrafts in the bank and the scheduled arrival time for the ith aircraft is S_i. A social planner who is minimizing costs would choose S_i to minimize the sum of expected costs of all aircraft:

$$\min_{S_i} \sum_N \sum_t P_t^{S_n} C_t^A(s)$$

The first order necessary condition for cost minimization is:

$$\sum_t \frac{\partial P_t^{S_n}}{\partial S_n} C_t^A(s) + \sum_i \sum_t \frac{\partial C_t^A(s)}{\partial S_n} = 0$$

The first term in the above equation represents the private cost minimizing solution to atomistic airlines. This is because the nth atomistic airline's private cost minimizing problem is

$$\min_{S_n} \sum_t P_t^{S_n} C_t^A(s)$$

The second term in the social planner's first order condition is the external marginal cost imposed by the nth aircraft on all other aircraft. The optimal congestion fee is equal to the second term. Typically however, airport authorities cannot directly observe schedule times and hence Daniel (1995) proposes a congestion fee contingent on the scheduled time of operation.

Daniel (2001) has criticized the current weight based pricing scheme (landing fee) employed in the US since it failed to alleviate the increasingly congested airport traffic situation. This practice calls for landing fees to depend on aircraft weight. The fee rates are approximately equal to the annual residual costs of an airport divided by the weight of all aircraft landing during the year.

Daniel argues that for uncongested airports such a pricing scheme might reflect the marginal cost of runway damage caused by aircraft landings. On the other hand it could be a form of Ramsey Pricing, using aircraft weight as a proxy for air-travel demand elasticity.[62] However, in the presence of congestion such a pricing scheme fails to build the right incentive to reduce the external congestion costs. More specifically, each individual aircraft operator regards costs in each period as parametric and ignores the effect of their own scheduling decisions on other aircraft operators. Under congestion, an increase in one aircraft's layover or queuing time will impose costs on all other airlines, costs that are external to the decision making process of the delaying aircraft operator.

[62] Ramsey Pricing calls for a tax on consumers that is inversely related to demand elasticity. Heavier aircraft might be a proxy for inelastic consumers and will therefore be subject to a higher landing fee.

2.10.4 Summary of Congestion Issues

Traditional congestion analysis is based on speed-flow diagrams. Modeling and estimating such speed-flow relationships is relatively straightforward. Combined with an appropriate measure of the value of time estimates of average and marginal congestion costs can be readily derived.

Although such speed-flow methods can serve as a first estimate, congestion is a more complicated phenomenon and cannot - in our view - be appropriately modeled through traditional analysis. In road networks, congestion often arises at bottlenecks in the form of dynamic queuing. The incremental congestion costs imposed by a vehicle become time-dependent: the location and the timing of entering or leaving the road network matters.

While the theory on dynamic bottleneck models has made significant progress, the empirical applications have been limited, most likely due to the high data requirements of dynamic models. Newbery and Santos (2002) have made an important contribution by moving past traditional link-based speed-flow relationships. Using the simulation software SATURN, they estimated congestion costs and optimal road charges in eight English towns when congestion primarily arises from delays at intersections (bottlenecks). Research efforts in this direction are highly valuable and more detailed data collections is strongly encouraged.

Even in the event that dynamic models cannot be directly applied to the data, they can guide the interpretation of results derived from traditional models. Bottleneck models with emphasis on schedule-delay costs show that a substantial portion of the gains from an optimal congestion toll results from the induced change in the time pattern of road use over the congested period (Arnott, et al., 1993). Hence, these findings can be used as a guide to interpret estimates ignoring schedule-delay as a lower bound of the actual congestion costs.

While road congestion has been explored in the literature, the analysis of congestion in air travel and (especially) rail travel has fallen short. While air congestion is usually studied as a side issue in the evaluation of airport expansion, the theoretical literature on rail congestion is simply non-existent. Theoretical and empirical investigations of air and rail congestion could be helpful even if the major issue in terms of social costs and public exposure remains congestion on roads.

Congestion costs have been defined in different ways. From an economic point of view the case is clear: Total congestion costs are measured by the typical deadweight loss resulting from any externality due to non-optimal pricing. Individual road users (rationally) do not take into account the delays imposed on others and hence there is too much traffic on the road (even though the congestion delays are borne by road users in the aggregate). However, there are time delays due to congestion even under optimal (efficient) pricing. For purposes other than economic efficiency, congestion costs have been defined solely based on the cost side (ignoring the benefits of a larger traffic volume) either relative to traffic flow under optimal pricing or relative to free-flow conditions.

2.11 Summary Research Recommendations:

Various suggestions of research needs have arisen throughout this chapter. Of course, almost any aspect of the subject could benefit from additional research, but in this section we try to identify research topics or themes that are especially important for Transport Canada's interests in environmental costing and possible pricing strategies. They are grouped in four categories: general, VTTS of passengers, VFTTS, and congestion.

2.11.1 General

Often there is ambiguity over whether externality unit costs are an average or marginal cost concept. This is often fairly well-defined for VTTS, but not for other externality categories. This calls for more attention and research on whether average or marginal externality costs are being estimated, *and* what is the mathematical relationship between them, i.e., how are total externality costs changing with increased volumes of transport activity? For several categories, we think the consensus is that total externality costs increase at an increasing rate, hence marginal costs exceed average costs. Given Transport Canada's interest in identifying what portions of externality costs are actually borne by transport user groups, and to calculate the total costs of transportation in Canada, it is necessary to know more about the mathematical relationship between average and marginal externality costs in order to link average and marginal cost measures.

2.11.2 Value of (passenger) travel time savings (VTTS)

VTTS is a composite value, affected by various quality attributes. The separation of value of time savings per se from correlated attributes of the journey is an on-going focus of VTTS studies. One that is particularly important is to separate the value of reliability (VOR) from time savings per se. Studies expressly on the value of reliability are needed.

The VTTS under stop/start or other congested conditions versus in-vehicle travel time valuation is especially important for evaluating urban projects and policies.

VTTS studies are dominated by roads. Research on VTTS for other modes would be helpful. Note that it is also important to include attribute differences between modes to better separate VTTS per se from trip and modal attribute values.

The distribution of VTTS is needed rather than just rely on average values. The skewedness of the distribution is important for predicting the response to pricing policies and their link with time savings/delays. Traditionally, VTTS studies have primarily focused on the average VTTS of the sample studied. More attention needs to be paid to the range, variance and skewedness of VTTS within the sample.

The valuation of small time savings remains an issue. It is compelling to use a constant VTTS regardless of the size of time savings for investment appraisal, but where behavioural responses are important (such as predicting the impact of pricing policies) it may be necessary to distinguish between large and small changes in time savings or delays. Hence research to learn more about behavioural responses to small time savings/delays is needed. This is also linked to the next research suggestion:

VTTS studies rarely discuss the underlying time horizon of people responding to changes in travel times. Research is needed on possible differences in short run and long run adjustments to time savings.

2.11.3 Value of freight travel time savings (VFTTS)

There is very limited research and data on the VFTTS. Yet the VFTTS (or the reliability) may be a major cost of increasingly congested cities. This topic should be a high priority. Research is needed on the variability of VFTTS depending on commodity, market type and other circumstances, i.e., we need to know more about the distribution of VFTTS across markets.

Research on VFTTS needs to separate the value of reliability/predictability of travel times from travel time savings per se.

2.11.4 Congestion Measurement

Research is needed on the link between the degree of congestion and its impact on reliability of travel times. This is a topic of considerable importance.

In order to estimate the total congestion costs in Canada or its regions, it is necessary to model (at least approximately) average measures of congested conditions and time delays. That is, Transport Canada needs some practical tools to estimate the amount and severity of congestion across Canada. Measures of congestion and associated time losses are needed both for large urban networks as well as for smaller community conditions.

Studies of congestion costs at airports are few in number. This is a candidate for further research.

APPENDIX A to Chapter 2. Time Allocation Theory

This appendix provides a formal discussion of the conceptual development of the valuation of travel time savings, particularly the contributions by De Serpa (1972). This discussion draws heavily from the summary provided by Jara-Diaz (2000).

The amount individuals are willing to pay for a travel-time reduction is not an isolated decision but rather a consequence of a general time allocation problem. The reassignment of time from one activity to another has been explored by researchers for decades from diverse perspectives. Different strands of the theory of time allocation deal with the issue of time valuation in various ways. As a result, different concepts of value of time emerged, depending on the way a period of time is treated: as a valuable resource, as something to be reassigned or as something to be reduced. This section introduces the various concepts and their evolution in the literature.

2.A.1 The Evolution of the Theory of Time Allocation

Three important aspects differentiate the different theories of time allocation: First, the role of time in the utility function, second, the time constraints and third, the relationship between time and goods consumption. In its most basic form, Becker's (1965) theory of the allocation of time considered a set of final commodities Z_i (e.g. prepared meal) which directly produce satisfaction to the consumer. On the other hand, market goods and preparation time are necessary inputs for these final commodities. Work time is then the total amount of time minus preparation and consumption time. It follows that consuming has a time cost, the cost of not working and earning money. In Becker's model, the value of time is equal to the individual wage rate irrespective of the individual assignment of time to the various activities as additional time can be assigned to work to increase income.

Implicitly, Becker's model assumes that a unit of the final good Z_i requires market goods and preparation time in fixed proportions. Under this model, time enters the utility function indirectly as a necessary input for final goods. The model incorporates a time constraint that can subsequently be replaced by the income constraint.

The reason for the equality between the value of time and the wage rate is that working time does not influence utility directly. The time spent working is utility neutral, i.e. neither pleasant nor unpleasant. Johnson (1966) then subsequently extends Becker's basic model by including work time in the utility function. As a result, the value of time is now equal to the wage rate plus the ratio between the marginal utility of work and the marginal utility of income - the subjective value of work. Johnson claimed that the wage rate plus the subjective value of work is the value of leisure, which in turn is equal to the value of travel time. Any reduction in travel time could be either reassigned to leisure or work, but an optimizing consumer has chosen a time allocation at which these to values are equal.

Oort (1969) subsequently raised the issue that travel time itself should also be added into the utility function for the same reason as work time should be included: it can be (un-) pleasant in itself. Hence a third term is added in the utility function, the direct perception of travel time. This is an attractive feature of the model as now a reduction in travel time not only increases the time available that can be reassigned to leisure or work, but it also provides a direct utility benefit if travel is an unpleasant activity.

A simple model similar to Oort (1969) incorporates the models of Becker (1965) and Johnson (1966) as special cases: Denote aggregate consumption in monetary units by C, time assigned to leisure by L, time assigned to work by W and exogenous travel time by T. The consumer maximizes utility

$$\max_{C,L,W,T} U(C,L,W,T)$$

subject to the income constraint (λ)

$$wW - C \geq 0$$

and the time constraint (μ)

$$\tau - (L + W + T) = 0$$

where w is the wage rate and τ is the total time available. Becker's model is a special case of this version in which working time W and travel time T are not part of the utility function. Similarly, Johnson's model is a special case in which (only) travel time T is not a component of the utility function. The first-order conditions are

$$\frac{\partial U}{\partial C} - \lambda = \frac{\partial U}{\partial L} - \mu = \frac{\partial U}{\partial W} + \lambda w - \mu = 0$$

from which the following results can be derived:

$$\frac{\mu}{\lambda} = \frac{\frac{\partial U}{\partial L}}{\frac{\partial U}{\partial C}} = w + \frac{\frac{\partial U}{\partial W}}{\frac{\partial U}{\partial C}}$$

In words, the monetary value of leisure is equal to the wage rate plus the marginal utility of spending time at work in monetary terms (the value of work). Furthermore we have

$$-\frac{\frac{dU}{dT}}{\lambda} = w + \frac{\frac{\partial U}{\partial W}}{\frac{\partial U}{\partial C}} - \frac{\frac{\partial U}{\partial T}}{\frac{\partial U}{\partial C}}$$

where dU/dT is the total utility effect of an exogenous change in travel time. In words, the value of a reduction in the minimum necessary travel time is equal to the value of leisure minus the monetary value of travel time in the utility function. Becker and Johnson's results are special cases as the value of a reduction in travel time would be equal to the wage rate only if both working time and travel time do not enter the utility function directly.

De Serpa (1971) made an important contribution to the theory of time allocation by explicitly introducing a set of technical constraints relating time and goods. In his model, the utility function is dependent on all goods and all activities, including work and travel time. The technical constraints establish minimum assignments of time for the consumption of each good. Consumers maximize utility

$$\max_{C,T,W} U\left(C_1,\ldots,C_N,T_1,\ldots,T_N,W\right)$$

where C_i denotes the consumption of good i, and T_i is the time assigned to activity i. Utility is maximized subject to the income constraint (λ)

$$\sum_{i=1}^{N} p_i C_i = wW$$

and the following technical constraints (λ, K_i)

$$\sum_{i=1}^{N} T_i + W = \tau$$

$$T_i \geq a_i C_i \qquad i = 1,\ldots,N$$

where p_i is the price of good *i* and a_i denotes the minimum time requirement for the consumption of one unit of good *i*. The following results can be obtained from the first-order conditions

$$\frac{\mu}{\lambda} = \frac{\frac{\partial U}{\partial L}}{\lambda}$$

$$\frac{K_i}{\lambda} = \frac{\mu}{\lambda} - \frac{\frac{\partial U}{\partial T_i}}{\lambda}$$

De Serpa subsequently defines three different concepts of the value of time. First, there is the *value of time as a resource*, which is the value of extending the total time available. This concept is equivalent to the ratio of the marginal utility of total time and the marginal utility of income, or μ/λ. The second concept is *the value of time as a commodity*, which is the value of time allocated to a specific activity. It is given by the rate of substitution between that activity and money, which is equal to μ/λ only if the individual assigns more time to an activity than the minimum required through the technical constraints. The third concept is *the value of saving time in activity* i defined by the ratio K_i/λ, where K_i is the multiplier of the corresponding technical constraint. It is clear from above that the value of saving time in activity i is equal to the difference between the value of time assigned to an alternative use (resource value) and the value of time as a commodity.

Leisure is defined by de Serpa as all the activities to which more time is assigned than the necessary minimum time. For leisure activities, the value of time savings is zero and the value of time allocated to such an activity is the same for all leisure activities and equal to μ/λ the resource value of time.

Specifically on the issue of travel time and savings thereof, the contribution by Small (1982) is relevant. The development of this strand of time allocation theory was motivated by the *fundamental law of traffic congestion* first stated by Downs (1962). It is the tendency of urban highways to reach a peak level of congestion relatively independent of supply and demand conditions. It indicates that theories of time allocation that exclude scheduling considerations applied to transportation and congestion phenomena are flawed.

Building on the previous literature, Small adds scheduling considerations to both the utility function and the constraints. The consumer maximizes the utility over consumption (C), leisure time (L), work time (W), and "consumption" time (T). The consumption activity involves a monetary cost $R(S)$ and must be carried out at a specific time of day (S).

$$\max_{C,L,W,S} U(C,L,W,S)$$

subject to the income constraint (λ)

$$C + R(S) = wW$$

and the time constraint (μ)

$$L + T(S) + W = \tau$$

where "consumption" time $T(S)$ and cost $R(S)$ depend on S. The last constraint (γ) added relates the schedule S and working time W to exogenous parameters:

$$F(S,W;w) = 0$$

Given this setup the value of leisure time can be derived as

$$\frac{\mu}{\lambda} = w + \frac{\frac{\partial U}{\partial W}}{\lambda} - \gamma \frac{\frac{\partial F}{\partial W}}{\lambda}$$

If the scheduling constraint is binding, the value of leisure time is modified by a term that indicates the extent to which additional working time aggravates scheduling difficulties. This term is likely to be important if the activity under consideration is transportation as scheduling considerations play an important role.

2.A.2 Discrete Travel Mode Choice Models and the Subjective Value of Time[63]

Disaggregate discrete choice models are the most popular travel demand model from which the value of time can be inferred. It is important to relate the empirical estimates

[63] This section draws heavily from Jara-Diaz (2000).

back to the theory of time allocation to insure proper interpretation. This section relates the subjective value of travel time (SVTT) estimated from discrete-choice models back to the de Serpa's theoretical concepts of value of time.

In discrete travel choice models, the utility of alternative i is specified as a function of parameters including cost and travel time of alternative i, where R_i denotes the travel cost of mode i and Q is a set of other characteristics.

$$\overline{V}_i = F(R_i, T_i, Q)$$

Utility maximizing consumers pick the alternative that provides them with the greatest utility. The subjective value of time (SVTT) can then be derived to be the rate of substitution between time and cost:

$$SVTT = \frac{\frac{\partial \overline{V}_i}{\partial T_i}}{\frac{\partial \overline{V}_i}{\partial R_i}}$$

More specifically, the term "utility" in discrete choice models in is fact a conditional indirect utility function representing the optimum over all other variables but travel. The discrete choice models relies on the existence of such a conditional indirect utility function, which can be derived from a microeconomic foundations that emphasize the characteristics of such a measure. Take again a simple time allocation model in which the consumer maximizes

$$\max_{C,L,W,T} U(C, L, W, T)$$

subject to the income constraint

$$C + R_i = wW\ ,$$

the time constraint

$$L + W + T_i = \tau\ ,$$

and the minimum time requirement a per unit of consumption

$$L \geq aC\ .$$

Substituting the equality constraints into the objective function, the rewritten maximization problem is

$$\max_{W} U[(wW - R_i), (\tau - W - T_i), W, T_i]$$

subject to

$$\tau - W - T_i - a(wW - R_i) \geq 0$$

Solving for the optimal amount of work gives

$$W^*(R_i, T_i) = \frac{\tau - T_i + aR_i}{1 + aw}$$

Substituting the optimal amount of work back into the utility function we get the conditional indirect utility function:

$$V_i \equiv U\left[\left(\frac{w(\tau - T_i) - R_i}{1 + aw}\right), \left(\frac{a(w(\tau - T_i) - R_i)}{1 + aw}\right), \left(\frac{\tau - T_i + aR_i}{1 + aw}\right), T_i\right]$$

The subjective value of time can then be shown to be equal to

$$SVTT = \frac{\frac{\partial V_i}{\partial T_i}}{\frac{\partial V_i}{\partial R_i}} = w + \frac{\frac{\partial U_i}{\partial W}}{\frac{\partial U_i}{\partial C} - a\kappa} - \frac{\frac{\partial U_i}{\partial T_i}}{\frac{\partial U_i}{\partial C} - a\kappa}$$

where κ denotes the multiplies on the constraint of the rewritten (direct utility) maximization problem. A property of all discrete-choice models is that $\partial V_i / \partial R_i$ is equal to the marginal utility of income λ. Hence, the subjective value of travel time (SVTT) is indeed equal to DeSerpa's concept of the value of saving time in the travel activity K_i / λ.

$$SVTT = \frac{\frac{\partial V_i}{\partial T_i}}{\frac{\partial V_i}{\partial R_i}} = w + \frac{\frac{\partial U_i}{\partial W}}{\lambda} - \frac{\frac{\partial U_i}{\partial T_i}}{\lambda} = \frac{\frac{\partial U_i}{\partial L}}{\lambda} - \frac{\frac{\partial U_i}{\partial T_i}}{\lambda} = \frac{\mu}{\lambda} - \frac{\frac{\partial U_i}{\partial T_i}}{\lambda} = \frac{K_i}{\lambda}$$

The equation shows that the rate of substitution between travel cost and travel time calculated from model discrete-choice models gives the difference between the value of leisure (value of time as a resource) and the value of travel time in direct utility (value of travel time as a commodity). Hence, discrete-choice models of travel demand do in fact allow the estimation of travel time savings based on solid microeconomic foundations.

Chapter 2 References

AASHTO (1978): *A Manual on User Benefit Analysis of Highway and Bus-Transit Improvements*, Washington, DC: American Association of State Highway and Transportation Officials.

AASHTO (2003): *User Benefit Analysis for Highways*, Washington, DC: American Association of State Highway and Transportation Officials.

Abay, Georg, Kay W. Axhausen and Arnd König (2003): "Time Is Money: The Valuation of Travel Time Savings in Switzerland," paper presented the 3rd Swiss Transport Research Conference 2003, Ascona.

AHCG Accent Marketing & Research and Hague Consulting Group (1995) "Value of Travel Time Interim Report," HCG, The Hague.

AHCG Accent Marketing & Research and Hague Consulting Group (1999) "The Value of Travel Time on UK Roads," The Hague, Netherlands.

Arnott, Richard, André de Palma and Robin Lindsey (1988): "Schedule Delay and Departure Time decisions With Heterogeneous Commuters," *Transportation Research Record*, No. 1197, pp. 56-67.

Arnott, Richard, André de Palma and Robin Lindsey (1993): "A Structural Model of Peak-Period Congestion: A Traffic Bottleneck With Elastic Demand," *American Economic Review*, 83(1), March, pp. 161-79.

Bates, John (1988) "Economic Issues in Stated Preference Analysis," *Journal of Transport Economics and Policy*, 22(1), pp. 59-69.

Bates, John and Stephen Glaister (1990), "The Valuation of Time Savings for Urban Transport Appraisal for Developing Countries: A Review", *World Bank Working Paper*, World Bank, Washington D.C.

Bates, John, John Polak, Peter Jones and Andrew Cook (2001) "The Valuation of Reliability for Personal Travel," *Transportation Research Part E*, 37(2-3), p. 191-229.

Bates, John, and Gerard Whelan (2001a) "Size and Sign of Travel Time Savings," *ITS Working Paper*, 561, Institute for Transport Studies, University of Leeds.

Bates, John, and Gerard Whelan (2001b) "Market Segmentation Analysis," *ITS Working Paper*, 565, Institute for Transport Studies, University of Leeds.

Beca Carter Hollings & Ferner Ltd (1991): "The Value of Travel Time Savings" Working Paper No. 2 by I.H. Bone, prepared for Transit New Zealand.

Becker, Gary S. (1965): “A Theory of the Allocation of Time,” *Economic Journal*, 75, pp. 493-517.

Beesley, Michael E., T.M. Coburn and J.G. Reynolds (1959): "The London-Birmingham Motorway: Traffic and Economics" *Road Research Laboratory, D.S.I.R.* Technical paper No.46, August.

Beesley, Michael E. (1965): "The Value of Time Spent Travelling: Some New Evidence," *Economica*, 32(126), May, pp. 174-185.

Blackburn Anthony J., Michael E. Beesley and C. D. Foster (1963): "Urban Transport Models and Motorway Investment," *Economica*, 30(119), August, pp. 243-261.

Brown, S. L. and W. Watkins (1971): "Measuring Elasticity of Air Travel from New Cross-Sectional Data," Civil Aeronautics Board Staff Paper.

Brownstone, David, Arindam Ghosh, Thomas F. Golob, Camilla Kazimi and Dirk van Amelsfort (2002): “Drivers' Willingness-to-Pay to Reduce Travel Time: Evidence form the san Diego I-15 Congestion Pricing Project,” Working Paper, University of California, Irvine.

Brownstone, David and Kenneth A. Small (2003): “Valuing Time and Reliability: Assessing the Evidence From Road Pricing Demonstrations,” Working Paper, University of California, Irvine.

Brownstone, David and Seiji S.C. Steimetz (2003): “Heterogeneity in Commuters' Value of Time with Noisy Data: A Multiple Imputation Approach,” Working Paper, University of California, Irvine.

Bruzelius, Nils (1979): *The Value of Travel Time: Theory and Measurement*, Croom Helm: London.

Calfee, John and Clifford Winston (1998) “The Value of Automobile Travel Time: Implications for Congestion Policy,” *Journal of Public Economics*, 69, p. 83-102.

Calfee, John, Clifford Winston and Randolph Stempski (2001) “Econometric Issues in Estimating Consumer Preferences From Stated Preference Data: A Case Study of the Value of Automobile Travel Time,” *Review of Economics and Statistics*, 83(4), p. 699-707.

Carlin, Alan and Rolla E. Park (1970): "Marginal Cost Pricing of Airport Runaway Capacity," *American Economic Review*, 60, pp. 310-319.

Carlton, Dennis W., William M. Landes and Richard A. Posner (1980): **"**Benefits and Costs of Airline Mergers: A Case Study." *The Bell Journal of Economics*, 11(1), Spring, pp. 65-83.

Cherlow, Jay R. (1981): **"**Measuring Values of Travel Time Savings." *Journal of Consumer Research*, 7(4), Spring, pp. 360-371.

Cole, Sherman Inc. (1989): *New York State Rail Ridership Study*.

Cole, Sherman Inc. (1990): "Attitudinal Survey: Tradeoff Analysis," Excerpt from Draft Report prepared for VIA Rail Canada.

Coleman, R. R. (1961): "A Study of Urban Travel Times in Pennsylvania Cities," *Highway Research Board Bulletin*, 306, pp. 39-63.

Daniel, Joseph I. (1995): "Airport Congestion Pricing: A Bottleneck Model with Stochastic Queues," *Econometrica*, 63, pp. 327-370.

Daniel, Joseph I. and Munish Pahwa (2000): "Comparison of Three Empirical Models of Airport Congestion Pricing," *Journal of Urban* Economics, 47, pp. 1-38.

Daniel, Joseph I. (2001): "Distributional Consequences of Airport Congestion Pricing," *Journal of Urban* Economics, 50, pp. 230-258.

De Jong, Gerard, M.A. Gommers and J. Kloosters (1992) "Time Valuation in Freight Transport: Method and Results," Proceedings of 20^{th} PTRC Summer Annual Meeting. Manchester.

De Jong, Gerard (2000): "Value of Freight Travel-Time Savings," in David A. Hensher and Kenneth J. Button (eds.): *Handbook of Transport Modelling,* Vol. 1, Elsevier Science, Oxford, pp. 553-563.

De Serpa, Allan C. (1972): "A Theory of the Economics of Time," *Economic Journal*, 81, pp. 828-846.

De Vany, Arthur (1974) The Revealed Value of Time in Air Travel," *Review of Economics and Statistics*, 56(1), pp. 77-82.

Downs, Anthony (1962): "The Law of Peak-Hour Expressway Congestion," *Traffic Quarterly*, 16, July, pp. 393-409.

Evans, Alan W. (1972): "On the Theory of the Valuation and Allocation of Time," *Scottish Journal of Political* Economy, 19, pp. 1-17.

Fowkes, A. S. and Mark Wardman (1988): "The Design of Stated Preference Travel Choice Experiments, with Special Reference to Interpersonal Test Variation," *Journal of Transport Economics and Policy*, 22(1), pp. 27-44.

Fowkes, A. S. (2001a): "Principles of Valuing Business Travel Time Savings," *ITS Working Paper*, WP 562, Institute of Transport Studies, University of Leeds.

Fowkes, A. S. (2001b): "Values of Time for Road Commercial Vehicles," *ITS Working Paper*, WP 563, Institute of Transport Studies, University of Leeds.

Guilbault M., F. Piozin and C. Rizet (2000) "Preparation d'une nouvelle enquete aupres des chargeurs, resultants de l'enquete test Nord-Pas de Calais," INRETS, Septembre 2000.

Goodwin, Phil (1997): "Solving Congestion", Inaugural Lecture for the Professorship of Transport Policy University College London, 23rd October, 1997.

Gronau, Reuben (1970): "The Value of Time in Passenger Transportation," *NBER Occasional Paper*, No. 109, National Bureau of Economic Research: New York.

Gunn, Hugh and C. Rohr (1996): "The 1985-1996 Dutch Value of Time Studies," paper presented at PTRC International Conference on the Value of Time.

Gunn, Hugh , J.G. Tuinenga, Y.H.F. Cheung and H.J. Kleijn (1999): "Value of Dutch Travel Time Savings in 1997," in H. Meersman, E. Van de Voorde and W. Winkelmans (eds.) *World Transport Research: Proceedings of 8th World Conference on Transport Research*, vol.3, Pergamon: Amsterdam.

Gunn, Hugh (2001): "Spatial and Temporal Transferability of Relationships between Travel Demand, Trip Cost and Travel Time," *Transportation Research Part E*, 37, pp. 163-189.

Haight, Frank A. (1963): *Mathematical Theories of Traffic Flow*, Academic Press: New York.

Hau, Timothy D. (1992): "Economic Fundamentals of Road Pricing: A Diagrammatic Analysis", *Policy Research Working Papers*, WPS 1070, Transport Division, The World Bank.

Hau, Timothy D. (1998): "Congestion Pricing and Road Investment", in Kenneth J. Button and Erik T. Verhoef (eds.) *Road Pricing, Traffic Congestion and the Environment*, Edward Elgar Publishing Limited, Cheltenham, England, pp. 39-78.

Hauer, Ezra, and J. C. Greenough (1982): "A Direct Method for Value of Time Estimation," *Transportation Research*, 16A (1), pp. 163-172.

HCG Hague Consulting Group (1990): *The Netherlands Value of Time Study: Final Report*, Report to Rijkswaterstaat, The Hague.

Hensher, David. A. (1977): *The Value of Business Travel Time*, Pergamon Press: Oxford.

Hensher, David. A. (2001a): “The Valuation of Commuter Travel Time Savings for Car Drivers: Evaluating Alternative Model Specifications,” *Transportation*, 28, pp. 101-118.

Hensher, David. A. (2001b): “The Sensitivity of the Valuation of Travel Time Savings To The Specification of Unobserved Effects,” *Transportation Research Part E*, 37, pp. 129-142.

Highway Research Board (1965): *Special Report 87: Highway Capacity Manual*, Washington.

Jara-Diaz, Sergio R. (2000): “Allocation and Valuation of Travel Time Savings,” in David A. Hensher and Kenneth J. Button (eds.) *Handbook of Transport Modelling*, Elsevier Science: Oxford.

Jara-Diaz, Sergio R. (2003): “On the Goods-Activities Technical Relations in the Time Allocation Theory,” *Transportation*, 30, pp. 245-260.

Johnson, M. Bruce (1965): “Travel Time and the Price of Leisure," *Western Economic Journal*, 4, pp. 135-145.

Kawamura, Kazuya (2000): "Perceived Value of Time for Truck Operators", *Transportation Research Record*, 1725, pp. 31-36.

Keeler, Theodore E. and Kenneth A. Small (1977): “Optimal Peak-Load Pricing, Investment, and Service Levels on Urban Expressways,” *Journal of Political Economy*, 85(1), pp. 1-25.

Koopman, Bernard O. (1972): "Air-Terminal Queues under Time Dependent Conditions," *Operations Research*, 20(6), pp. 1089-1114.

Koopmans, Carl and Eric Kroes (2004) “Estimation of Congestion Costs in the Netherlands,” *SEO Amsterdam Economics Discussion Paper*, No. 28.

Kurri, Jari, Ari Sirkiä, and Juha Mikola (2000): "Value of Time in Freight Transport", *Transportation Research Record*, 1725, pp. 26-30.

Lam, Terence C. and Kenneth A. Small (2001) “The Value of Time and Reliability: Measurement from a Value Pricing Experiment,” *Transportation Research Part E*, 37(2-3), p. 231-251.

Lighthill, James and Gerald B. Whitham (1955): “On Kinematic Waves II: A Theory of Traffic Flow on Long Crowded Roads”, *Proceedings of the Royal Society, London, Series A*, 229, pp. 317-345.

Lindsey, Robin and Erik Verhoef (2000): “Congestion Modelling”, in David A. Hensher and Kenneth J. Button (eds.) *Handbook of Transport Modelling*, Vol. 1, Elsevier Science, Oxford, pp. 353-373.

Moses, Leon N. and Harold F. Williamson Jr. (1963): "Value of Time, Choice of Mode, and the Subsidy Issue in Urban Transportation," *Journal of Political Economy*, 71(3), June, pp. 247-64.

Mackie, P. J., Sergio Jara-Diaz and A.S. Fowkes (2001) “The Value of Travel Time Savings in Evaluation,” *Transportation Research Part E*, 37, pp 91-106.

Mackie, P. J., Mark Wardman, A.S. Fowkes, G. Whelan, J. Nellthorp and John Bates (2001): "Values of Travel Time Savings in the UK: A Report on the Evidence," *ITS Working Paper*, WP 567, Institute of Transport Studies, University of Leeds.

Mackie, P. J., Mark Wardman, A.S. Fowkes, G. Whelan, J. Nellthorp and John Bates (2003): “Values of Travel Time Savings in the UK – Summary Report,” Report to the Department of Transportation.

Massiani, Jerome (2003) “Can we Use Hedonic Pricing to Estimate Freight Value of Time,” paper presented at the 10th International Conference on Travel Behavior Research, Lucerne.

May, Adolf D. (1990): *Traffic Flow Fundamentals*, Prentice Hall; Englewood Cliffs, NJ.

Miller, Ted R. (1989): *The Value of Time and the Benefit of Time Saving*, prepared for the National Road Board, New Zealand and the Federal Highway Administration of the US Department of Transportation, Urban Institute: Washington DC.

Mohring, Herbert D. (1976): *Transportation Economics*, Ballinger Press; Cambridge, MA.

Morrison, Steven A. (1987): "The Equity and Efficiency of Runway Pricing," *Journal of Public Economics*, 34, pp. 45-60.

Morrison Steven A. and Clifford Winston (1989): "Enhancing the Performance of the Deregulated Air Transportation System," *Brookings Papers on Economic Activity*, 0(0), Special Issue, pp. 61-112.

MVA Consultancy, Institute of Transport Studies University of Leeds, and Transport Studies Unit University of Oxford (1987) "The Value of Travel Time Savings," *Policy Journals*, Newbury, Berks, U.K.

Nash, Chris and Tom Sansom (1999): "Calculating Transport Congestion and Scarcity Costs", Final Report of the Expert Advisors to the High Level Group on Infrastructure Charging (Working Group 2).

Newbery, David M. (1990): "Pricing and Congestion: Economic Principles Relevant to Pricing Roads," *Oxford Review of Economic Policy*, 6, pp. 22-38.

Newbery, David M. (2002): "Road User and Congestion Charges," Working Paper.

Newbery, David M. and Georgina Santos (2002): "Estimating Urban Road Congestion Charges," CEPR Discussion Paper, DP3176.

Oort, Conrad J. (1969): "The Evaluation of Traveling Time," *Journal of Transport Economics and Policy*, 3, pp. 279-286.

Pigou, Arthur C. (1920): *Wealth and Welfare*, Macmillan: London.

Quarmby, David A. (1967): "Choice of Travel Mode for the Journey to Work," *Journal of Transport Economics and Policy*, 1, pp. 273-314.

Ramjerdi, F.L. Rand, A.F. Saetermo and Kjartan Saelensminde (1997) *The Norwegian Value of Time Study*, Report no. 379/1997, Institute of Transport Economics, Oslo.

Richards, Paul I. (1956): "Shock Waves on the Highway," *Operations Research*, 4, pp. 42-51.

Saelensminde, Kjartan (2002) "The Impact of Choice Inconsistencies in Stated Choice Studies," *Environmental and Resource Economics*, 23, p.403-420.

Small, Kenneth A. (1982): "The Scheduling of Consumer Activities: Work Trips," *American Economic Review*, 72, pp. 467-79.

Small, Kenneth A. (1992a): *Urban Transportation Economics*, Harwood Academic Publishers: Chur.

Small, Kenneth A. (1992b): "Using the Revenues From Congestion Pricing," *Transportation*, 19(4), pp. 359-81.

Small, Kenneth, Robert Noland, Xuehao Chu and David Lewis (1999): *Valuation of Travel-Time Savings and Predictability in Congested Conditions for Highway User-Cost Estimation,* Report 431, National Cooperative Highway Research Program, Washington, D.C.

Small, Kenneth A., Clifford Winston and Jia Yan (2002) "Uncovering the Distribution of Motorists' Preferences for Travel Time and Reliability: Implications for Road Pricing," Working Paper.

Steer Davies Gleave (2004): New Fraser River Crossing: Traffic and Revenue Forecasts (Executive Summary Report), prepared for Greater Vancouver Transportation Authority.

Steimetz, Seiji S.C. (2003) "Defensive Driving and the External Costs of Accidents and Driving Delays," Working Paper, Department of Economics, University of California – Irvine.

Transmode Inc. (1981): *Illinois Inter-City Rail Passenger Upgrading Study - Market Analysis*, prepared for the Illinois Department of Transportation.

Transmode Inc., Market Analysis of High Speed Rail Services in Ohio, prepared for Ohio Dept. of Transportation, April 1985.

TTI Texas Transportation Institute (1990): *Value of Time and Discomfort Costs, Progress Report on Literature review and Assessment of Procedures and Data*, Technical Memorandum for NCHRP Number 7-12.

TTRL Transport and Road Research Laboratory (1980): *The Demand for Public Transport*, Report of the International Collaborative Study of the Factors Affecting Public Transport Patronage, Crowthorne: Berkshire.

U.S. Department of Transport (1997): "The Value of Travel Time: Departmental Guidance for Conducting Economic Evaluations" U.S. Department of Transportation: Washington D.C.

U.S. Department of Transport (2003): "Revised Departmental Guidelines: Valuation of Travel Time in Economic Analysis" U.S. Department of Transportation: Washington D.C.

Vickrey, William S. (1969): "Congestion Theory and Transport Investment," *American Economic Review*, 59(2), May, pp. 251-61.

Vickrey, William S. (1973): "Pricing, Metering, and Efficiently Using Urban Transportation Facilities," *Highway Research Record*, No. 47, pp. 36-48.

Walters, Alan A. (1961): “The Theory and Measurement of Private and Social Cost of Highway Congestion,” *Econometrica*, 29(4), pp. 676-697.

Wardman, Mark (1998): "The Value of Travel Time - A Review of British Evidence," *Journal of Transport Economics and Policy*, 32(3), pp. 285-316.

Wardman, Mark (2001a): "A Review of British Evidence on Time and Service Quality Valuations," *Transportation Research Part E*, 37, pp. 107-128.

Wardman, Mark (2001b): "Public Transport Values of Time," *ITS Working Paper*, WP 564, Institute of Transport Studies, University of Leeds.

Wardman, Mark (2001c): "Inter-Temporal Variations in the Value of Time," *ITS Working Paper*, WP 566, Institute of Transport Studies, University of Leeds.

Waters, W. G. II (1992a): *The Value of Time Savings for the Economic Evaluation of Highway Projects in British Columbia*, UBC Centre for Transportation Studies: Vancouver.

Waters, W. G. II (1992b): “Values of travel time savings used in road project evaluation: a cross country/jurisdiction comparison,” *Proceedings* Australasian Transport Research Forum, 1992, Bureau of Regional and Transport Economics, Canberra, Australia.

Waters, W. G. II (1994) “The Value of Travel Time Savings and the Link with Income: Implications for Public Project Evaluation," *International Journal of Transportation Economics* Vol.21, No.3 (Oct., 1994) 243-53.

Waters, W. G. II, C.Wong and K Megale (1995): “The Value of Commercial Vehicle Time Savings for the Evaluation of Highway Investments – a Resource Savings Approach *Journal of the Transportation Research Forum* 25(2) pp.

Waters, W. G. II (1996): “Values of Travel Time Savings in Road Transport Project Evaluation,” in David A. Hensher, Jenny King and Tae Hoon Oum (eds.) *World Transport Research: Proceedings of 7th World Conference on Transport Research*, vol.3, Pergamon: Oxford.

Welch, Michael and Huw Williams. (1997) “The Sensitivity of Transport Investment Benefits to the Evaluation of Small Travel-Time Savings,” *Journal of Transport Economics and Policy*, 31(3), pp. 231-254.

Wigan, Marcus, Nigel Rockcliffe, Thorolf Thoresen and Dimitris Tsolakis (2000): "Valuing Long-Haul and Metropolitan Freight Travel Time and Reliability," *Journal of Transportation and Statistics*, 3(3), December, pp. 83-89.

Wynter, Laura M. (1995) "The Value of Time in Freight Transport in France: Estimation of Continuously Distributed Values from a Stated Preference Survey," *International Journal of Transport Economics*, 22(2), pp. 151-165.

Chapter 3: The Value of Statistical Life [64]

3.1 Introduction

Valuing life is a contentious subject. Unfortunately, though, travel is somewhat risky and deaths cannot be eliminated entirely. Travel accidents are noteworthy and are invariably reported in the press and on the evening news. Sometimes, travel accidents result in multiple deaths and are newspaper headlines. Attempting to reduce such deaths is a legitimate goal of transportation policy. But, in order to make efficient allocation of resources one should ask: at what cost? In order to answer such questions one needs an estimate of the value of life.

Economists have attempted to estimate the value of life for many years using many different methods. The value of life is one of the most frequently researched topics in policy analysis and has been the subject of a number of recent reviews and meta-analyses (Mrozek and Taylor, 2002; de Blaeij et al., 2003; Viscusi and Aldy, 2003; Jones-Lee and Loomes, 2003). Despite this research, recent estimates still vary widely from just over $1 million (Hammitt and Graham, 1999) to $ 33 million (Arabsheibani and Marin, 2000), where all figures are expressed in 2002 C$.

Section 3.2 discusses the concept of the value of a statistical life (VSL) and some of its properties. Section 3.3 critically reviews the major methods used to value a statistical life, focussing on wage-risk studies. Section 3.4 presents a summary of the empirical evidence of the VSL as of the early 1990s, based on Boardman et al. (2001). A major focus of this chapter is Section 3.5 which reviews the recent academic literature. Section 3.6 reviews the value of life used for policy purposes by government agencies in developed countries. Section 3.7 briefly reviews two studies that summarise the recent literature and suggest VSLs for policy purposes in Canada and Australia. Section 3.8 presents our range of the VSL and our best estimate for Canada based on the previous research and government policy. These estimates implicitly adjust for the income differences between Canada and other countries. Section 3.9 presents a range and a best estimate for the VSL based exclusively on US studies and then explicitly adjusts these estimates for use in Canada based on the difference in average income between Canada and the US. Section 3.10 raises the issue of the whether the VSL in Canada should be adjusted for the level of risk associated with the particular policy issue under consideration. It also discusses adjusting for age and income within Canada. Section 3.11 offers potential areas for further research activity.

This chapter provides important foundations for Chapter 4 on the cost of accidents and the Chapter 6 on the cost of air pollution. The issue of internalised costs versus externality costs are addressed in these chapters.

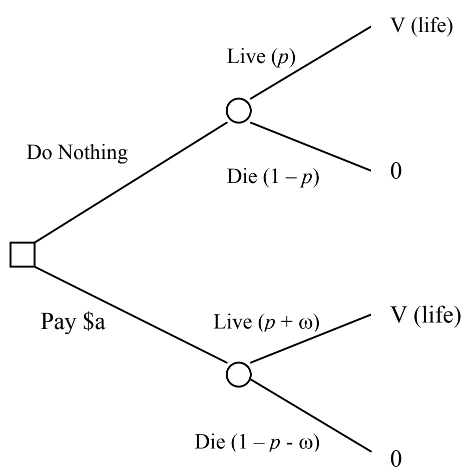
[64] The authors would like to thank Transport Canada and, in particular, John Lawson for many helpful comments and suggestions on drafts of this Chapter.

Estimating the value of life to use for policy purposes is an extremely difficult task. The evidence is extraordinarily uncertain and the estimated VSLs vary enormously. At the same time, it is important to emphasise that the VSL has probably been studied in more depth than any other "plug in" number.

3.2 The Value of a Statistical Life, VSL

Early methods to value life were based on a person's foregone earnings.[65] Earnings provide a measure of the value of a person's lost output. In 1968, Schelling (1993) pointed out that a major problem with this measure is that it does not reflect an individual's willingness to pay to reduce his or her own death. Furthermore, Schelling recognized that there is an important distinction between the deaths of identifiable individuals and statistical deaths. A safety improvement to a highway, for example, does not lead to the saving of the lives of a few individuals who can be identified ex ante, but rather to the reduction in the risk of death (or injury) to all users of the highway. In order to value the benefit of proposed safety improvements, analysts should ascertain how much people are willing to pay for reductions in their risk of death that are of the same order of magnitude as the reduced risk that would result from the proposed safety improvements. Since Schelling's important article, the value of life used in cost-benefit analyses has increased considerably.

The VSL reflects what individuals are willing to pay for an increase in the probability of living (reduction in the probability of dying). Suppose that currently the probability that an individual will live is p. Also suppose that through an action, which costs \$a, this person can increase the probability of living by ω. Should the individual take the action, assuming that the only effect is to increase the probability of living and it is identical to the status quo in all other respects? This problem is laid out as a decision tree in Figure 3.1. If the individual is willing to pay more than \$a, then s/he will take the lower branch, otherwise s/he will maintain the status quo.



[65] For an overview of early methods to value life see Lawson (1989).

Figure 3.1: A Decision Tree to Determine the VSL

Suppose that $\omega = 1/5,000 = 0.0002$; that is, if 5,000 people took the same action, then one statistical life would be saved. Also suppose an individual's maximum willingness to pay to take the action is $ 800. This implies that if we set $a = $ 800 in Figure 3.1, then this individual would be indifferent between the upper and lower branches. Consequently, his/her VSL would be given by:[66]

$$V(life) = \$\ 800/(0.0002) = \$\ 4 \text{ million.}$$

Thus, the value of life is based on a linear extrapolation. In practice, such estimates are based on many individuals and result in a collective VSL of the group.

It should be clear that the VSL reflects what people in a particular sample are willing to pay for small increases in the probability of living. The VSL is generally not appropriate to assess policies or projects that make large changes to the probability of living, including in the extreme, what someone would pay to avoid their death. Furthermore, the estimated VSL represents the preferences of the people in the particular sample.

The VSL depends on the level of risk, measured by the probability of survival, *p*.[67] Like most goods, there are diminishing marginal returns to safety; put simply, demand curves for safety slope down. More accurately, it is reasonable to expect a convex relationship between the WTP for safety and the level of safety, as shown in Figure 3.2. When the level of safety is very high, for example at S_1, individuals are willing to pay relatively little for an increase in the level of safety. However, as the level of risk increases, for example to S_2, individuals will be willing to pay more for the same increase in safety. When the level of risk is very high, for example at S_3, individuals would be willing to pay very large amounts for the same increase in safety.

[66] In general if an individual is indifferent between the two branches, then $(p + \omega)V(life) - \$a = pV(life)$, which implies $(p + \omega)V(life) - pV(life) = \$a$, and $\omega V(life) = \$a$. Consequently, $V(life) = \$a/\omega$.
[67] For more discussion on the shape of the cost curve for risk see Gollier and Eeckhoudt (2001).

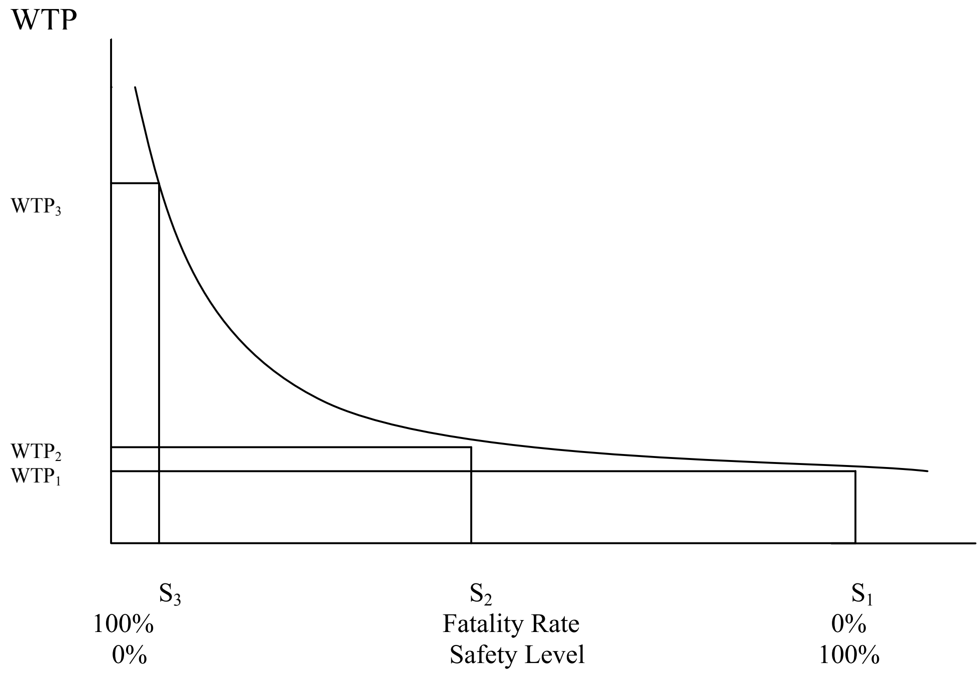


Figure 3.2: Hypothetical (Convex) Relationship between the Willingness to Pay for Increased Safety and the Level of Safety (and Fatality Risk)

There are two immediate, important implications of this discussion. First, the estimated VSL depends on the level of risk—it will be higher for high levels of risk. Second, given that different modes of travel have different levels of safety, the VSL should differ across different modes of transportation. For example, as air travel is generally safer than car travel, the VSL for air travel should be less than the VSL for car travel.

In addition to varying with the level of risk, an individual's WTP for safety will vary with income. Safety is a normal good with a positive income elasticity of demand: individuals with high incomes (or wealth) are willing to pay more for an improvement in safety than people with low incomes (or wealth).

A positive income elasticity of demand implies that the VSL of people in rich countries is higher than the VSL of people in poor countries. One implication is that the VSL calculated based on the WTP in one country should be adjusted for income differences before it is applied to another country. *In particular, estimates of the VSL obtained from the US should be adjusted downwards before they are applied to Canada.*

The positive income elasticity also raises the issue of whether one should use different VSLs within a country to reflect the different income levels of people who use different modes of transportation. If people who fly have higher average incomes and more wealth than people who take the train, one might conclude that analysts should use a higher VSL for policies pertaining to airplane safety than for policies pertaining to train travel safety.

Using a different VSL for different transportation modes due to different average income levels raises ethical and practical issues. Certainly, it would be simpler to use one and only one VSL.[68] This gives the appearance of being fair, although a counter-argument is that this would be inconsistent with economic theory. Cost-benefit analysis determines the value of benefits based on the concept of WTP. If, for example, analysts value the saved time of high income people more than that of low income people because high income people are willing to pay more for time saved, analysts should also use a higher VSL for rich people if they are willing to pay more for safety improvements.

Nonetheless, many people are uncomfortable with the idea of spending resources to save a few lives of rich people when the same level of resources would save more lives of poor people. Some analysts have argued for weighting poor people more than rich people. The key reason is that while cost-benefit analysis treats all dollars equally, the marginal utility of income is higher for a poor person than for a rich person: a dollar is worth more to a poor person than to a rich person. Consequently, benefits accruing to poor people might be weighted more than the same dollar benefits accruing to rich people. These normative issues cannot be resolved in this chapter, but they should be taken into consideration when making a final recommendation about the VSL.

This discussion ignores what happens to the wealth of the deceased upon their death. Wealth is often transferred to a person's heirs, thus enabling the heirs to consume more. Increasing the probability of survival increases utility but survivors receive fewer transfers. When individuals indicate their maximum WTP, it is important to know whether they take into consideration transfers to their descendents.[69]

---

68 Another issue is that, given the difficulty in deriving a single "average" VSL, to apply different VSLs across different modes might imply greater certainty than would be warranted.

69 Johansson (2002) presents a theoretical model of the VSL where $V^E = \pi V[W]$ represents the expected utility, *W* denotes wealth, π is the probability of survival, and $V[\cdot]$ is the utility function. As in Rosen (1988), the VSL is defined as the marginal rate of substitution between wealth and risk, $VSL' = \frac{\partial V^E / \partial \pi}{\partial V^E / \partial W} = \frac{V[W]}{\pi V_W[W]}$, where dividing utility by the marginal utility of income converts the expression to monetary units. Rosen (1988) shows that this equation is equal to the WTP for a small reduction in risk divided by the risk reduction, $VSL = dW / d\pi$. As this model includes only wealth and risk, it ignores what happens to the wealth of the deceased. Johansson (2002) suggests that this wealth may be transferred to surviving people, Rosen (1988) shows that the VSL would then be defined as the marginal rate of substitution between wealth and risk with consumption *c* deducted, $VSL'' = \frac{V[W/\pi]}{\pi V_W[W/\pi]} - c$. In Rosen's (1988) model, after a person dies, all the survivors share equally in the remaining assets of the deceased. If wealth from a deceased is transferred, saving a life still yields utility, but survivors will receive fewer transfers as the probability of survival increases. The VSL can then be calculated by $VSL = dW / d\pi$, where unlike in the above model *dW* is the WTP for a measure increasing the survival probability by $d\pi$. If there is a bequest function in the deceased's utility function, the VSL estimate would be reduced since the deceased would "live on" through the survivors (Rosen 1988).

Johansson (2002) notes that since the calculation for VSL is the same for both models, it is not possible to infer which model lies behind the estimate for VSL; it is not possible to determine if the

In summary, this discussion has raised three important conceptual issues/problems associated with the VSL and its measurement:

1. Studies measure the WTP for small changes in the probability of living (or dying) and extrapolate to impute a valuation per life.
2. The VSL depends on the level of risk—the higher the risk, the higher the VSL. Since some models of transportation are safer than others (e.g. air is safer than road, per mile), a strong case can be made that the VSL on some (safer) modes would be less than the VSL on other modes.
3. Safety is a normal good. Consequently, the VSL in a rich country is higher than in a poor country. Furthermore, one can argue that there are within-country differences. Specifically, if the income of passengers on one mode is higher on average than on another mode, a case can be made that the VSL of riders on the former mode should be higher than on the latter. However, ethical and practical reasons also have to be considered.

Other conceptual issues are discussed later. Practical issues relating to measuring the VSL are discussed in the following section on estimation.

3.3 Methods of Estimating the VSL

Most recent estimates of the VSL are based on one of three methods: wage-risk studies, consumer purchase studies and contingent valuation method (CVM) studies. The first two methods are based on revealed preferences, while the latter is based on stated preferences. One recent study surveys the implicit value of life in jury awards.

There are many methodological concerns with all of these estimation methods. As economists generally prefer to use revealed preference estimates when they are available, we focus on these estimates. However, CVM studies appear to be becoming more reliable than previously. There is little reason to base policy decisions on jury awards, but they are included for completeness and out of interest.

3.3.1 Wage-Risk Studies

Wage-risk studies examine the amount needed to compensate individuals for taking more risk in the labour market. Sometimes they are called labour market studies. This section begins with a brief discussion of simple wage-risk studies and then turns to hedonic wage regressions. The discussion of simple wage-risk studies allows us to discuss some fundamental issues that pertain to all wage-risk studies.

---

consumption *c* has been subtracted already in the calculation of VSL. However, when people are asked about their WTP, they may or may not take into account the fact that their descendants will receive their assets or life-insurance payments. The fact that the respondents care about their descendants or they would think about it when asked may modify the WTP value which cannot be determined afterwards. To improve the information on this issue, questions should explicitly ask in the survey.

Simple Wage-Risk Studies
The most simple form of wage-risk study can be explained in terms of Figure 3.3, a slightly revised version of Figure 3.1. Suppose there are two jobs that are similar in all respects except that workers are safer in one job than the other job—safer in the sense that they have a lower risk of dying due to the nature of the work. For example, one job might entail performing a construction task on a skyscraper while the other job might entail performing similar tasks on the ground. The top branch in Figure 3.3 represents the safer job while the bottom branch represents the more risky job. Suppose that the probability of dying in the riskier job exceeds that in the safer job by ω. Economic theory suggests that workers in the more risky job would be paid more; they would receive a wage premium to compensate them for the greater risk. Suppose that the market wage premium is \$a, that is, in equilibrium the market compensates workers, on average, \$a to take more risk. As before, the wage-risk study would compute the VSL = \$a/ω.

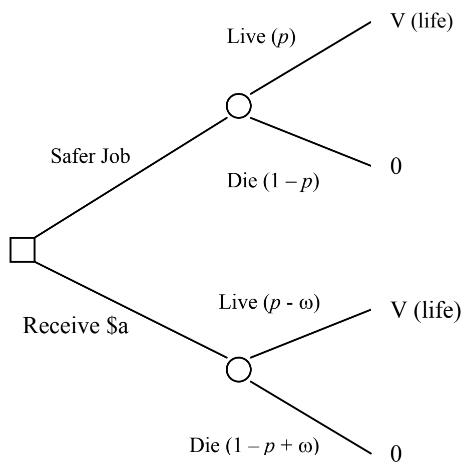


Figure 3.3: Determining the VSL Using a Simple Wage-Risk Study

For a simple wage-risk study to give a satisfactory VSL, three conditions must be met. First, the researcher must have an accurate assessment of the difference in fatality risk, ω. In practice, many U.S. wage-risk studies use data from the Bureau of Labor Statistics, which are aggregated to the industry level.[70] These data do not reflect the actual difference in risk faced by workers in different occupations within the same industry. For example, a coal miner and a secretary in a coal mining company have quite different fatality risks.

---

[70] Early studies used actuarial data which tended to overestimate on-the-job risk which biased the estimated VSLs downward (Viscusi, 1993).

Second, workers must have full information; specifically, they must have an accurate perception of the actual difference in fatality risk, ω. In practice, workers make decisions based on perceived risks not actual risks.[71] If they underestimate the risk of the more risky job, then they will accept a lower risk premium to perform that job and the estimated VSL will be lower than appropriate.

There is fairly strong evidence that people underestimate the occurrence of low-probability "bad" events.[72] People often think that a bad outcome is so unlikely that it could never happen to them. When people suffer from such cognitive biases, labour market studies will tend to underestimate the VSL. However, people may over-estimate job-market risks. More problematically, people may over-estimate the risk level of riskier jobs more than they over-estimate the risk level of safer jobs. The marketing arms of safety equipment manufacturers have a vested interest in ensuring people are "sensitive" to the risks. Where corporations fail to take adequate safety measures, there may be well-publicized court cases. If people systematically overestimate the riskiness of more risky jobs, then this would bias estimates of the VSL downwards.

A third assumption is that no other factors affect wages or, put simply, there is no omitted variables problem.[73] This means that the wage premium must reflect only the different risk levels and not other characteristics of the job, characteristics of the market or characteristics of the workers. In practice, as Adam Smith (1776, p. 12) noted "The wages of labour vary with the ease or hardship, the cleanliness or dirtiness, the honourableness or dishonourableness of employment." It is necessary to control for such differences in job characteristics. Also, it is important to control for labour market characteristics. Wages may not be set in a competitive market. Labour unions may help to make the market more competitive by ensuring that their members are well informed about the relevant risk data or by negotiating on their members' behalf. However, a strong labour union may be able to negotiate "over-compensation" for its members, which would result in overestimating the VSL.[74] Finally, the workers in the different jobs should have similar characteristics. If all of the high risk takers end up in the high risk jobs and all of the low risk-takers end up in the low-risk jobs, the wage premium would really reflect the preferences of the high risk takers, not the population as a whole. Simple wage-risk studies may produce biased estimates of the VSL due to omitted variables or self-selection problems.

One might think that wage-risk studies provide a measure of willingness to accept (WTA) and that this is problematic because, in general, WTA measures are larger than

[71] As Miller and Guria (1991) note, individuals utilize heuristics rather than true understanding of risk in evaluations that they make, thinking not of all potential risky situations but only those within their scope of experience. For more discussion of this issue see Frankel and Linke (1992).
[72] For a discussion of these issues and some evidence see Camerer and Kunreuther (1989) and Viscussi (1989).
[73] It would not be problematic if they were equal across the two alternatives or were uncorrelated with fatality risk.
[74] For example, Lawson (1982) found that UK construction workers were paid "danger money" for risks that were objectively lower than those encountered crossing the street

willingness to pay (WTP) measures. Indeed, Figure 3.3 implies that the safer job is the reference point (the upper branch) and workers have to ask themselves how much they would be willing to accept to take a more risky job (the lower branch). However, nothing in the description of the problem in the paragraph above Figure 3.3 suggests that the safer job is reference point. Indeed, one could treat the lower branch in Figure 3.3 as the reference point and ask how much a worker would be willing to pay (WTP) or forego in order to have a safer job (the upper branch). Put another way, the top branch in Figure 3.1 could pertain to a risky job while the bottom branch in this figure would pertain to the safer job. In practice, some workers are on the top branch asking themselves if they should switch to the bottom branch while others are on the bottom branch asking if they should switch to the top branch. In equilibrium, the lowest WTA equals the highest WTP or, put simply, the VSL estimates are a combination of WTA and WTP measures.

Hedonic Wage Studies

One potential way to overcome the omitted variables problem is to use the hedonic wage method which includes fatality risk and some control variables in a regression model. Control variables usually include other important job quality characteristics (such as injury risk and job flexibility), individual characteristics (such as education and age) and labour market variables (such as unionization). For example, a researcher might estimate the following hedonic wage equation:

$$\text{Wage} = ß_0 + ß_1 * \text{fatality risk} + ß_2 * \text{injury risk} + ß_3 * \text{flexibility} + ß_4 * \text{education} + ß_5 * \text{age} + ß_6 * \text{union} + e \qquad (1)$$

The purpose is to obtain an unbiased estimate of $ß_1$, the coefficient of fatality risk. The magnitude of this coefficient reflects the size of the wage premium required to compensate workers for taking on additional fatality risk, formally ∂wage/∂fatality risk. For example, if wage is the hourly wage, fatality risk is measured as the number of deaths per 10,000 workers and $ß_1 = 0.3$, then VSL = 0.3 x 2,000 hours/year x 10,000 = $ 6 million.

There are many variations on equation 1. Analysts typically use linear or semi-logarithmic functional forms. They may use after-tax income instead of wages, and may include different explanatory variables. Some models include interaction terms involving fatality risk and personal characteristics.

There is an important distinction between fatality risk and non-fatality risk. Thus far we have been discussing fatality risk i.e. the risk of dying on a job. However, wages also differ due to non-fatality risks, such as the risk of a non-fatal injury, of being fired or of being sued for poor workmanship.[75] Such factors should be taken into account. However, some studies do not include a non-fatal risk variable to avoid multicollinearity problems. In this case the fatality risk variable picks up the effects of non fatal risks too. If there is a positive correlation between fatality risk and non-fatality risk, then failing to control for non-fatality risk will lead to over-estimates of the VSL—all of the salary differential will be attributed to fatality risk when it should not be. Similarly, if there is a negative

[75] Dillingham, et al. (1996) point out that the classification of different risks is often arbitrary.

correlation between the fatal and non-fatal risk, then the simple wage-risk approach will under-estimate the VSL. In practice, as exemplified in equation 1, wage-risk studies generally take a narrow approach to non-fatal risk and focus on non-fatal injury risk, ignoring other non-fatal risks.

Age and experience are often included as an explanatory variable because older and more experienced workers are generally paid more. Some studies include individual productivity measures.

The hedonic wage approach assumes that markets work reasonably well (i.e. are efficient) and that wage differentials are due to fatality risks and other controllable factors. In practice, labour market institutions and the regulatory environment can have substantial effects on the size of wage differentials. Unionization, the strength of the union, the ability to engage in collective action, government arbitration and changes in worker's compensation programs may affect risk premia.[76] Including variables to reflect such institutional factors helps to reduce biases that would occur if they were omitted.

A final version of the omitted variables problem is that the WTP to reduce fatality risk may depend on the type of fatality and how it comes about. Put simply, some ways of dying are preferable to others. Most of us would prefer to die quickly and without pain. Thus WTP may vary depending on whether potential death is due to an accident or say occupational disease. Also, our WTP to reduce risk depends on the extent to which we feel we have control over the outcomes. People are willing to pay more for risk reductions when they are not in control (someone else is flying the plane) than when they are in control (they are driving the car).[77]

Another problem in wage-risk studies is measurement error, particularly of fatality risk.[78] In practice, fatality risk is based on several years of industry-specific or occupation-specific risk data. Such historical estimates may not provide an accurate estimate of ex ante fatality risk. Note first that as we are dealing with very small probabilities: one or a few greater or fewer deaths may have a large percentage impact on the estimate of fatality risk and the resultant $\tilde{VSL}$. Our initial example assumed that $\omega = 0.0002$. With \$a = \$ 800, then VSL = \$ 4 million. Suppose now that there were one more death among 5,000 people, then $\omega = 2/5{,}000 = 0.0004$, and VSL = \$800/0.0004 = \$ 2 million. The estimate of the VSL has been halved.

---

[76] For example, Kim and Fishback (1993) show that unionization and government arbitration in the US railroad industry lead to a decline in risk premia paid for fatalities in that industry. In a recent examination of the Korean labour market, Kim and Fishback (1999) were able to follow the effect of two substantial labour market reforms, the first being relaxation of prior restrictions on inter-firm and inter-industry ties that allowed increased collective action, and the second being an increase in worker's compensation benefits paid for fatalities by 30%.

[77] Jones-Lee et al. (1998) find that the average WTP to reduce the risk of death on the London underground is 50 percent higher than to reduce road fatalities.

[78] For more discussion of measurement error in wage-risk studies, see Sandy et al. (2001). They also note that miscoding may be a problem.

It is also important to point out that the risk levels of jobs used in wage-risk studies are actually quite low, in effect at or to the right of S_1 in Figure 3.2. Jennings and Kinderman (2003) observe that the rate of occupational fatalities in most industries has fallen roughly 95% since 1920, and is now one third of the rate of accidental deaths in the home.[79] This has two important implications. First, the risk level in wage-risk studies may be significantly lower than the risk level of transportation. Second, as Jennings and Kinderman (2003) maintain, "the current fatality rates are so low and their individual causes so often random that statistical attempts to measure how fatalities affect wages are unlikely to meet with success".

Measurement problems also arise because jobs tend to become safer over time, implying that historical estimates of fatality risk are biased upwards. Even if the estimates of fatality risk were accurate in the past, they might no longer be so. In a linear model, this would not affect the estimate of the VSL if the fatality risk of all jobs were over-estimated by the same amount. However, it would be problematic if, as seems likely, the risk of riskier jobs were over-estimated more than the risk of safer jobs.

As mentioned above, a major measurement problem is using industry-specific data which might be too broad to provide an accurate estimate of the risk of an individual's job within that industry. Using an industry average might be very inaccurate. For example, a coal miner and a secretary in a coal mining company have quite different fatality risks.

Some studies use all-cause fatality risk rather than workplace fatality risk. This would artificially underestimate the VSL.

Thus far we have discussed omitted variables problems and measurement error problems. There are some additional potential problems with hedonic wage studies.

The hedonic wage approach assumes that workers face a continuum of wage-risk combinations; see, for example, Figure 1 in Viscusi and Aldy (2003, 8). In practice, however, some worker's choice set may consist of only one or two options. The wage-risk combination that would maximize their utility may be unavailable.

Part of the reason that occupational fatality rates have fallen is increasingly stringent government safety regulations. Such labour market characteristics can be included as explanatory variables in hedonic wage regressions. However, this may be insufficient. More seriously there may be a truncation bias problem: some workers would prefer to take high risk-high paying jobs, but they do not exist.

Finally, the occupations used in wage-risk studies may not be representative of the population as a whole. As shown in Table 3.14, the risk level in most VSL studies ranges between about 4 in 100,000 to about 22 in 100,000 with an average of about 10 in 100,000. Viscusi (1993) states that the average risk in the U.S. workplace is also 10 per 100,000, which indicates that wage-risk studies are representative. However, according to

[79] See also Table 3.10 which is discussed later.

the BLS, the average US fatality rate for all occupations is 4 in 100,000 people; see Table 3.10.[80] Thus, wage-risk studies may under-represent risk-averse individuals.

In summary there are a number of potential problems associated specifically with wage-risk studies:

1. Workers may not have full information and may be subject to cognitive biases.
2. There may be an omitted variables problem. Studies assume that all relevant variables are controlled for in the regression. This includes non-fatality risk, other job quality characteristics, individual characteristics and labour market characteristics.
3. There may be a measurement error problem. An extreme version of this argument is that fatality rates are random so that it is impossible to measure the relationship between wages and risk.
4. Workers may not have the option of selecting the wage-risk combination that maximises their utility.
5. Low occupational risk levels may lead to truncation bias.
6. Risk-averse individuals may be under-represented.

These problems are in addition to those mentioned at the end of Section 3.2.

3.3.2 Consumer Market and Time Cost Studies

Consumer market studies examine consumers' willingness-to-pay to accept certain risks in markets for commodities that embody risks. For example, through the purchase of such goods as air bags, bicycle helmets, smoke detectors and fire alarms, consumers reveal the value they place on the reduction in risks that these products offer. Similar to wage-risk studies, analysts usually use hedonic regressions to control for non-fatality risk factors. For example, they may regress the price of a car on a variable reflecting the fatality risk of that make of car and various other factors that consumers consider when purchasing a car (such as performance and maintenance costs). These studies suffer from the same problems as wage-risk studies, including misperception of the risks and omitted variables.

Somewhat more problematically, consumer purchase choices represent discrete choices rather than a continuum of choices. Individuals buy the smoke detector or they don’t; there are not any intermediate possibilities. This makes it is difficult to obtain reasonable estimates of the VSL from simple consumer market studies. Analysts estimate hedonic price coefficients using discrete choice methods instead of multiple linear regression.

The control variables are likely to be more important in consumer market studies than hedonic wage studies. Wage premia are probably determined primarily by safety issues, but car purchase decisions are not.

---

[80] For more information see Table 3.10. The fatality rate varies enormously ranging from 1 in 100,000 for jobs in finance, insurance and real estate to more than 27 per 100,000 for construction labourers.

Time cost studies examine the trade-off between the time individuals take to do something (such as fasten a seat belt) and their safety.

3.3.3 Contingent Valuation Methods

An increasing number of studies are based on contingent valuation surveys where members of a representative sample of a population are asked how much they are willing to pay for a hypothetical reduction in risk.[81] Sometimes, these studies are called stated preference studies. One way or another, most of the problems that pertain to wage-risk studies and consumer preference studies also pertain to CVM studies. Respondents may not understand the probabilities or the effect of small changes in probabilities, they may not treat the given probabilities as applicable to them but may be relying on prior beliefs to determine risk estimates or they may not value changes in risk consistently with expected utility theory. There is some evidence that the questioning process sensitizes people to risks leading them to under-perceive the consequences. Thus, there are hypotheticality problems, informational problems and cognitive biases. A major problem is scope effects or embedding bias which refers to when the WTP of a group of goods is similar to the WTP of a subset of those goods. This is analogous to measurement error in wage-risk studies. In addition, CVM studies may be inadequately sensitive to changes in the amount of risk reduction offered and depend on the presentation and framing of questions, the starting point for bidding, and question order (sequencing effects).[82] As CVM estimates are based on surveys, they suffer from all of the problems with surveys including sample selection bias, non-response bias and interviewer bias. For a review of the problems associated with contingent valuation studies see Boardman et al. (2001), Ch 14. For negative or polemical views on CVM see Hausman (1993) and the debate in the *Journal of Economic Perspectives* (Autumn 1994) between Portney, Hanemann, and Diamond and Hausman.

3.3.4 Meta-analyses

Meta-analyses attempt to explain the reason for different VSL estimates across different studies. Put another way, they can determine whether certain factors have a significant impact on VSL estimates. These factors typically include the baseline level of risk, demographics of the sample, the source of the data, model specification, etc. Using the estimated regression coefficients one can perform "what if" analyses. In particular, one can ask what the estimated VSL from a particular study would have been under

---

[81] Overviews of contingent valuation include Cummings et al. (1986), Mitchell and Carson (1989), Hanley (1989), and Bishop and Heberlein (1990).

[82] Beattie et al.'s (1998) CVM results showed evidence of extensive and persistent insensitivity to the sequencing and scope of the safety improvements specified even though respondents were given the opportunity to discuss various safety issues and key concepts in group meetings held in advance of individual interviews. In undertaking a market research approach to estimating the VSL in New Zealand, Miller and Guria (1991) were careful to construct a survey with both realistic and relatively large risks. They state "We believe the limit of understanding (risk) probably is around 1 in 10,000."(p. 9) and note that the risk must be realistic.

alternative circumstances, for example, if the data were not from the BLS. In general, though, meta-analyses do not provide "best estimates": they summarize existing estimates and explain the reasons for the differences.

3.3.5 Conclusion on Methods of Estimation

There are four or five major potential problems associated with wage-risk studies. Consumer market studies might suffer from the same problems and are subject to some additional concerns—the problem of discrete dependent variables and the issue that safety is not the primary explanatory variable. Contingent valuation studies may contain hypotheticality bias, noncommitment bias, order bias, embedding (scope) bias and strategic bias. They also suffer from the problems associated with any survey, such as sample selection bias, non-response bias and outliers.

Despite their limitations, economists prefer revealed preference methods to survey methods. Thus, they tend to prefer labour market studies and consumer purchase studies to CVM. Indeed, in the past 10 years there have been far more labour market studies than CVM studies.

3.4 Estimates of the VSL Circa Early 1990s

Boardman et al. (2001) concluded that the "best" estimates of the VSL in the early 1990s for use in developed countries ranged from $ 3.1 million to $ 4.8 million (in 2002 C$). This was based primarily on Miller's (1989, 1990) review of 49 studies. Miller dropped 20 of the 49 studies because of insufficient sample size, poorly designed surveys, or failure to include appropriate risk variables. Using a consistent real discount rate of 2.5 percent across all studies, Miller estimated the mean value of life for the remaining 29 studies at C$ 3.724 million in 2002 after-tax dollars, with a range of C$ 1.931 million to C$ 8.138 million and a standard deviation of C$ 0.952 million.[83] Miller argued that these VSL estimates are sufficiently consistent with one another that one can have some confidence in them. He also concluded that the consistency among the findings implies that individuals appear to value life similarly whether the risk is largely voluntary (for example, accepting a dangerous job) or involuntary (the risk of a nuclear accident) and whether the potential death is slow and painful or sudden and quick.

Two other surveys of VSL studies at that time suggested a much greater range of estimates than did Miller's survey and imply that the upper bound of C$ 4.8 million may have been low. For example, after reviewing estimates from 21 studies, Fisher et al. (1989, p. 96) concluded that the most defensible empirical results indicate a range for the VSL of 2002 C$ 3.0 million to 2002 C$ 15.9 million. However, they go on to state that

[83] Miller (1990, p. 18) states: "...the value of a life equals the value of a life year times the discounted sum of the remaining life years. At a discount rate between 2 percent and 5 percent, each year of difference in mean age (and roughly, in life expectancy) in the 37- to 40- year age range leads to a 1 to 2 percent difference in the value of life." Thus, the values of life estimates are not very sensitive to the discount rate.

"[o]n balance, we place more confidence in the lower end of the range" (p. 98). By far the greatest range of value of life estimates -- $ 0.11 million to $ 24.8 million in 2002 dollars -- are exhibited by the 38 studies reviewed by Viscusi (1993). In Viscusi's view, most of the reasonable estimates of the VSL are clustered in the 2002 C$ 4.7 million – 2002 C$ 10.9 million range.

At that time there were few Canadian studies. The first labour market study was conducted by Meng (1989) who obtained estimates of the VSL in the range of 2002 C$ 4.84 million + or – 2002 C$ 422,000.

3.5 Recent Estimates from Individual Studies and Meta-Analyses

This section reviews VSL studies since the early 1990s. It begins with a review of wage-risk studies, followed by consumer market and time cost studies, then contingent valuation studies. Court awards are included in the consumer market studies. Meta-analyses are discussed where they fit best.

3.5.1 Wage-Risk Studies

The estimated VSLs from wage-risk studies published in the last ten years are summarized in Table 3.1. This table shows a great deal of variation. At the upper end, Arabsheibani and Marin (2000) generate a VSL of C$ 33.333 million. Dorman and Hagstrom (1998) use four different measures of fatal risk with results that imply a VSL between C$ 10.767 and C$ 25.124 million. Siebert and Wie (1994) generate a VSL of C$ 22.680 million for unionized workers and approximately 20% less, C$ 18.557 million, for non-unionized workers in the United Kingdom. At the lower end, Sandy and Elliot (1996), who also study the United Kingdom, report a range of C$ 0.405 million to C$ 0.890 million for VSL for union and non-union workers respectively. Furthermore, it is important to note that at least 16 studies report some results that show no statistically significant relationship between the risk of death and workers' wages (Mrozek and Taylor, 2002).

Dillingham et al. (1996) emphasize the importance of controlling for non-fatal risk and include broad characteristics of non-fatal risk as well as fatal risk in their estimated model. Their risk measures include different severities of non-fatal risk, fatal risk, and the extent of non-fatal loss. The VSL implied in their analyses range from C$ 3.791 to C$ 5.832 million.

In Mrozek and Taylor's (2002) meta-analysis of VSL estimates from labour market studies, the authors propose that the VSL estimates over C$ 2-3 million reflect the lack of attention in the previous literature to control for unobserved determinants of wages at the industry level. As well as including the usual labour covariates in their analysis of 33 labour market studies with 203 VSL estimates, the authors also include seven broad industry classification dummy variables (based on SIC codes) to capture the effect of inter-industry wage differentials separately from the effect of risk. Imposing these specifications on the studies that did not include them, Mrozek and Taylor generate a VSL of C$ 2.564 million. Mrozek and Taylor (2002) also find that the effect of not including non-fatal risk in wage-risk analyses is negligible.

In their meta-analysis, Viscusi and Aldy (2003) report that half of the U.S. labour market study estimates of the VSL fall between 2002 C$ 6.188 and 2002 C$ 14.851 million with a median value of about 2002 C$ 8.663 million. They also say that the median is "in line with estimates from the studies that we regard as most reliable" (p. 18). Estimates of the VSL from other countries are generally lower. Viscusi and Aldy (2003, p. 29) find that most Canadian labour market VSLs are within the range of 2002 C$ 3.71-$ 7.43 million, with the exception of Lanoie, Pedro and Latour (1995) who obtain a much higher number.[84]

Viscusi and Aldy (2003) duplicate Mrozek and Taylor's (2002) specification with their own wage-risk sample, but note that with many explanatory variables and 41 observations, the specification generates imprecise estimated coefficients. Viscusi and Aldy's (2003) meta-analysis used various OLS and robust regression with Huber weights specifications. Explanatory variables reflect whether or not union membership was included in the original study, as well as educational attainment, income, mean risk, type of risk measure, and labour market variables. Using the estimated coefficients from the regressions, they generate VSL estimates for each study in their meta-analysis. The mean predicted VSL based on all studies ranges from C$ 6.19 to C$ 7.67 million (p. 42). In the US population, the mean predicted VSL ranges from C$ 6.81 to C$ 9.41 million. The authors note that for most of the models the 95% confidence interval upper bounds are roughly double or greater than double the 95% confidence interval lower bounds.

Recently, Jennings and Kinderman (2003) use Bureau of Labour Statistics data from the period 1992-1999 to examine the correlation between changes in occupational mortality rates and changes in the hourly wages of workers. Their hypothesis is that during the more recent period, when fatality rates have been declining, there should be evidence of a decline in wage rates. Fatality data were taken from the Census of Fatal Occupational Injuries, and employment data were obtained from the Occupational Employment Statistics Survey. Injury and illness data were gathered from the Survey of Occupational Injuries and Illnesses. During this time period the rate of illness and injury dropped in the manufacturing and construction sectors by roughly 30%, while the rate of fatalities to injuries was approximately 1/700. Using these data they regressed the overall trend in the percentage change in rates of wages for each year on the rate of change per year in fatalities and injuries. This allowed them to detect if industries with the fastest rates of decrease in injury and fatality had the fastest rates of decrease in wage rates.

Their results showed no significant evidence of support for the hypothesis of compensating wage differential due to risk. None of their findings reached statistical

[84] Lanoie, Pedro and Latour (1995) is discussed in more detail in the section on CVM. It is worth noting immediately that it was not based on a representative sample (Dionne and Lanoie, 2004).

significance and while they did find a positive coefficient on the rate of change in fatalities, which in consistent with theory, they found a larger and negative coefficient for injuries and illness, implying that wages were falling fastest in those industries with increases in risk.

While such evidence appears damaging to the use of wage-risk studies, it is important to identify some problems with this study. Jennings and Kinderman are interested in determining the value of a life, not the VSL. Thus, they object strongly to interpolations from wage-risk studies in which the probability of dying is very small to estimates of the value of a human life. They appear more interested in the value of a life for court awards than in determining the appropriate VSL to use as a guide to policy concerning small increases or decreases in risk, relative to the status quo.

There are also some methodological issues with their study. The authors themselves point out that the failure to find a statistically significant relationship is not surprising. Based on a hypothetical industry with 40 per million fatalities per year, and a \$ 200 per year wage differential, the implied VSL is \$ 5 million. If this industry were to become 25 % safer and the fatalities were to drop to 30 per million, the risk payment should drop to \$ 150. Spread over the year, this results in an hourly wage reduction of only 2.5 cents given a 2000 hour work period, a very small change in wage for a large reduction in risk. Another problem is that wages were measured in real wages but nominal wages are notoriously sticky downwards. Reaching the new appropriate equilibrium may take some time. Furthermore, they use data from the Bureau of Labor Statistics, which are aggregated to the industry level, and may not accurately reflect the risks to workers.

3.5.2 Consumer Market and Time Cost Studies

Some researchers examine consumption decisions to estimate the VSL. Through the purchases of goods that affect safety, purchasers reveal their value for reduced risk. VSL estimates obtained from recent consumer market and time cost studies are summarized in Table 3.2.

Jenkins et al. (2001) studied the market for bicycle helmets assuming that the helmets provide protection to a single user as opposed to other safety devices, such as smoke detectors, and likely do not have any other benefit from use. The VSL implied by Jenkins et al.'s study for adults ages 20-59 is \$ 5.195 million (costs throughout this section are in 2002 C\$). In their 1995 study, Dreyfuss and Viscusi estimate the VSL using price-risk tradeoffs for automobiles purchases. Their estimates of vehicle price as a function of vehicle attributes such as size, power, reliability and safety imply a VSL of \$ 4.290 to \$ 6.110 million.

Blomquist et al. (1996) look at the time and disutility costs of using safety goods to determine the VSL. The user's safety is traded off with the cost in terms of time of putting a helmet on, buckling a seat beat, or putting a child in a child safety seat, and the disutility associated with the activity, discomfort for example. The value of time is assumed to be 0.6 of the wage rate. The mean VSL implied by seat belt use is $ 5.759 million, the VSL implied by child safety equipment is $ 4.267 million, and the VSL implied by motorcycle helmet use is $ 1.969 million.

3.5.3 Studies using the Contingent Valuation Method (CVM)

Estimates from recent CVM studies are summarized in Table 3.3. Interestingly, CVM studies tend to be quite critical of other CVM studies. For example, Hammitt and Graham (1999) suggest previous CVM studies may be poorly designed to estimate changes in WTP valuation due to changes in the magnitude of risk. Similarly, Beattie et al. (1998) suggest that conventional CVM procedures may not be reliable or valid.

Lanoie et al. (1995) compare the two main approaches used to estimate the VSL, the contingent valuation approach and the revealed preference approach. The authors conducted a survey in Montreal where respondents were asked CVM questions and questions needed to gather pertinent information for a wage-risk study and then compared the VSL implied by each method. The CVM questions asked the respondents about risk reduction in the workplace and risk reduction in cars. The questions used to gather information for the wage-risk studies dealt with safety in the workplace only. Using the wage-risk approach, Lanoie, Pedro, and Latour find a significant VSL for unionized manual workers only. Under different specifications the estimated coefficient for risk of death was generally positive but not significant. The implied VSL for the unionized manual worker from the different specifications of the wage-risk analyses ranged from $ 24.679 million to $ 27.389 million. The contingent valuation estimates of VSL in the workplace ranged from $ 31.384 to $ 38.516 million.

Lanoie, Pedro and Latour show that the VSLs from the wage-risk study are lower than the VSLs implied by the CVM estimates due to the inclusion of risk-averse workers, a group that is more likely to assign a higher value to safety. The authors also suggest that the risk-averse workers may be concentrated in jobs where an explicit risk premium is unlikely or difficult to detect with a regression, causing their valuation for safety obtained by a survey to be higher. This claim is supported by de Blaeij, Florax, Rietveld, and Verhoef's (2003) meta-analysis that showed the magnitude of VSL estimates depends on whether the study is a revealed preference or contingent valuation study and that revealed preference studies lead to lower estimates than contingent valuation studies. The contingent valuation estimates of VSL implied by the potential purchase of airbags were much lower and ranged from $ 2.240 to $ 3.994 million. The reason for the difference in the VSL implied by reductions in risk of death on the job and in a car is unclear and Lanoie, Pedro and Latour suggest that workers may be less reluctant to die from a car accident than an accident at work.

Using telephone surveys in the United States to estimate the WTP for risk reductions from dying in auto accidents where respondents are asked their WTP for airbags, Hammitt and Graham (1999) find the VSL to be from $ 1.026 to $ 2.727 million. Beattie et al. (1998) CVM survey results showed evidence of extensive and persistent insensitivity to the sequencing and scope of the safety improvements specified even though respondents were given the opportunity to discuss various safety issues and key concepts in group meetings held in advance of individual interviews. The authors used CVM and relative valuations to determine the WTP based values of safety for various contexts in the United Kingdom (such as nuclear power, the workplace, domestic fires, and road traffic). With respect to reductions in risk of road accidents, they find that the VSL is $ 21.258 million or $ 9.979 million depending on whether the respondents were asked about a 1 in 100,000 or a 3 in 100,000 reduction in annual risk of death respectively. These results however were judged by the authors to be unreliable due to embedding, scope and sequencing effects. A second phase of their study incorporated changes: emphasizing the different magnitudes of risk reduction offered by the various safety improvements, emphasizing that the WTP is needed rather than the amounts the respondents can afford, and the avoidance of sequencing effects by focusing just on fatal injuries. In the second phase of their study, Beattie et al. (1998) find that the VSL is $ 18.872 million or $ 8.395 million depending on whether the respondents were asked about a 1 in 100,000 or a 3 in 100,000 reduction in annual risk of death respectively. However, these showed less sensitivity to scale in responses and not more as the authors had hoped. The VSL implied by reduction in risk of death for a house fire was 0.67 times that of the mean VSL for roads based on the 1 in 100,000 death reduction responses indicating that house fires were seen as more the responsibility of the inhabitants and more under the control of the inhabitants than a road crash.

Krupnick et al. (2002) determine the WTP for mortality risk reductions in people of different ages using a CVM survey in Canada. 930 respondents from Hamilton, Ontario aged 40 to 75 in 1999 were surveyed. Respondents were asked how much they were willing to pay for a product that reduced baseline risk by 5 in 1,000 over a 10 year period, and 1 in 1,000 over a 10 year period. The VSL implied by the survey is approximately $ 1.2 million (2002 C$ 1.27 million) for a 1 in 10,000 annual risk reduction and $ 3.8 million (2002 C$ 4.03 million) for a 5 in 10,000 annual risk reduction. The authors find that the VSL is constant to 70 years of age but falls 30 % for those over 70 years. Also, physical health status has no impact on WTP, but mental health does. People with fewer symptoms of psychological distress are willing to pay more to reduce their chance of dying.

3.5.4 Jury Awards and Government Decisions

Recent estimates of the VSL using jury awards or government decisions are summarized in Table 3.4. Cohen and Miller (2003) examine the willingness to award non-monetary damages in over 1200 cases of consumer product related injuries and intentional assaults. From the awards which are to compensate for injury, pain, suffering, shock, discomfort, and make the plaintiff “whole”, Cohen and Miller derive a VSL of $ 2.568 to $ 5.135 million. The authors looked at jury cases involving physical assaults and consumer product related injuries. Punitive damages and medical costs are excluded in their analyses. In each case the mean award was approximately $ 869,000. Looking at jury awards without considering other factors, the median VSL ranges from $ 1.4 for assaults to $ 1.7 million for consumer products. When the cases are evaluated by severity, the median VSL estimates range from $ 0.815 to $ 4.400 million. The authors note a small downward trend in VSL estimate as impairment increases. When Cohen and Miller include other factors in their analysis, such as demographics, legal and institutional characteristics, culpability, the implied VSL is $ 5.135 million for assault cases, and $ 2.568 million for consumer product cases.

3.5.5 Multi-Method Meta-analyses

Estimates of the VSL based on meta-analyses or summaries of original studies are presented in Table 3.5. Meta-analyses that pertain to only one estimation method were discussed above, including Mrozek and Taylor's (2002) and Viscusi and Aldy's (2003) meta-analyses of wage-risk studies. The two policy-oriented (summary) articles in Table 3.5 are discussed in Section 3.7.

Desvousges, Johnson, and Banzhaf's (1998) meta-analysis of 28 wage-risk studies and 1 CVM study includes only two explanatory variables, the fatality risk rate and a dummy variable if the data is not from the Bureau of Labour Statistics. They generate a VSL of $ 5.070 million. Like most meta-analyses, this study does not attempt to correct for the issues raised earlier and is just a calculation of a simple mean while controlling for the data source of the original study.

Miller's (2000) meta-analysis of international studies includes explanatory variables for whether the study is CVM or wage-risk study, the inclusion of occupational dummies, whether the wage-risk study used actual risk rather than perceived risk, and whether or not the study used all mortality risk by occupation rather than risk of work related mortality. Regression results confirm that studies that do not use occupational mortality risk or occupational dummy variables overestimate VSL and that using all cause mortality risk under-estimates VSL. Applying the regression estimates to individual studies for Canada used in the meta-analysis with the CVM indicator set to zero, the VSL is between $ 2.162 and $ 3.514 million in North America and between $ 3.378 and $ 4.865 million for the European Union. Specifically for Canada, Miller (2000) generates a range for VSL between $ 2.838 and $ 4.189 with a best estimate of $ 3.432.

Miller's (2000) estimate of the value of a statistical life at $ 3.432 million is almost the same as the upper end of Mrozek and Taylor's (2002) suggested plausible range of $ 1.628 to $ 3.436 when the BLS data set is used. When the NIOSH data set is used, the estimated VSL ranges from $ 2.564 to $ 5.128 million but Mrozek and Taylor (2002) suggest that these figures derived from the NIOSH data may be misleading as their risk data are aggregated to a 1 digit SIC code. Viscusi and Aldy's (2003) meta-analysis present estimates of VSL when the meta-regression includes dummy variables for industry effects, inclusion of morbidity risks, and inclusion of risks beyond workplace risk of $ 7.302 million for the United States. The VSL estimates are calculated by using the estimated coefficients in the meta-regression to predict a VSL for each study, then averaged to generate a mean VSL estimates. Viscusi and Aldy's (2003) VSL estimate is more than double Miller (2000) and Mrozek and Taylor's (2002) estimates but it is not clear that the biases concerning inter-industry wage differentials, perceived versus actual risk, and the exclusion of non-fatal risks are removed.

3.6 VSL Values Used by Government Agencies in Different Countries

The VSLs used by US government agencies are summarized in Table 3.6. It shows a generally increasing trend over time. However, the United States Department of Transportation has been remarkably consistent at about 2002 C$ 3.6 million. In contrast, the EPA recommends 2002 C$ 7.8 million.

The VSLs used in developed countries other than the United States are summarized in Table 3.7. Clearly, these figures are much lower than those used in the US. France, Australia, Britain and Sweden use low VSLs -- all less than 2002 C$ 2 million. Of the other countries in the table, Belgium has the highest VSL, equal to 2002 C$ 6.4 million. VSLs in Canada are in-between these two ends, but vary considerably among departments with Health Canada using a much higher VSL (2002 C$ 4.6 million) than Transport Canada (2002 C$ 1.8 million).

Fourteen European countries estimated the VSL from traffic accidents at the request of the Commission of the European Communities in the 1990s. The cost estimates ranged from 2002 C$ 0.170 to 2002 C$ 3.744 million (Trawen et al., 2002).

This section first discusses the US, then other countries and ends with a discussion of Canada.

United States

In 1994, Federal United States Department of Transportation, Federal Highway Administration (FHWA) updated their method of evaluating the comprehensive costs of motor vehicle traffic accidents (Technical Advisory, T 7570.2, 1994). When calculating the motor vehicle accident costs they used a VSL of $ 2.2 million (USD 1988), based on a study by The Urban Institute (1991). The FHWA updated this amount to $ 2.6 million based on use of a recommended GDP implicit price deflator, which increased the value by roughly 18%.

Recently, the US Department of Transportation has reevaluated this recommendation. Although there have been a large number of studies performed in the past decade, they consider there to be little convergence in the value or range of the VSL that would necessitate modifying their existing standard. In a memorandum sent to his agencies on January 29, 2002, the Secretary of Transportation recommend the use of a value of a statistical life of $ 3.0 million (2001US$) in all DOT analyses (OST, 2002). This translates to a value of 2002 C$ 3.63 million.

United Kingdom

The British Department of Transport has undertaken more detailed analysis of the VSL for use in preparing reports and analysis of transportation issues (DOT 1997, 2001). This Department has undertaken to develop proposals on a common methodological approach to cost benefit analysis in order to reduce the variety of appraisal methods. Their method treats accident risks as a cost of travel that is unperceived, and so accident rates are assumed to have no role in forecasting travel patterns or modal choice. All accidents are treated as negative externalities and there is no differentiation between users of transportation and non-users. The total costs include the loss of output by those fatally injured, the medical and support costs and the "human costs" of pain and suffering, as outlined by Hopkin and Simpson (1995). The department has disaggregated these three cost components and thus it is possible to determine the Human Capital component of a VSL at 2001 UK £410,540 (2002 C$ 0.781 million) and the willingness to avoid pain and suffering at 2001 UK £783,000 (2002 C$ 1.49 million). Because the willingness to pay estimate contains some valuation to avoid risk, the 2002 C$ 1.49 million is the more appropriate figure.

This standard protocol extends between the different divisions of the British Department of Transport, and the Aviation Group also utilizes a similar protocol when evaluating third party deaths from accidents that occur during take off and landing in the lands at the end of the runways of Great Britain's busiest airports. In this analysis the Department has chosen to utilize the VSL from road accidents and therefore uses a value of 2002 C$ 1.788 million (1996 VSL £0.847580).

Australia

Australia has also attempted to look at disaggregated values of Human Capital included with some component of willingness to pay to avoid pain and suffering (BTRE, 2002). In an examination of rail accident costs in Australia the Department of Transport and Regional Services looked closely at all of the cost components of accidents under this mode. Here Human Capital productivity losses are considered for both formal (paid employment) and informal (home and volunteer) production. From their analysis they have determined an average value of productivity losses of AU$ 1.2 million due to rail accidents in 1999 (2002 C$ 1.17 million). Again as described above this does not capture any element of risk, only creating an accounting model of the lost productivity to society. Therefore they updated the methodology employed in reports on aviation and road accidents (BTRE, 1998, 2002) to include an estimate reflecting the lost quality of life. Based on (BTE 2000), this was estimated to be AU$ 327,000 (2002 C$ 0.306 million), similar for both rail and road accidents. Thus, the sum of the Human Capital and the Quality of Life lost due to fatality equals AU$ 1.527 million (2002 C$ 1.476 million).

New Zealand

In 1990, the Land and Transport Safety Authority in New Zealand hired Ted Miller to conduct a market research study on road safety to estimate the value of statistical life. Miller and Guria (1991) asked families how much, in resource terms, they would be willing to forgo to avoid a risk of death. They evaluated the willingness to pay from several directions of questioning and found relatively consistent VSL estimates, whether they examined the trade off in the value of time for reducing speed in bad weather, the willingness to pay for a safer car or the willingness to increase taxes to fund roadway and pedestrian safety improvements.

In 1990 the VSL was found to be roughly NZ$ 2 million for evaluations specifically involving transport projects, which is equal in current Canadian dollars (2002 C$ 2 million). This valuation has been accepted for use in other departments of the New Zealand Government, demonstrating some confidence in this measure. The Health Research Council of New Zealand has considered this figure in examining tobacco and alcohol misuse (Easton, 1997).

Other findings from New Zealand include the finding that VSL does not vary systematically with sex or race but that it does vary with age. The elderly have been found to have lower VSL, with the value declining roughly 1% per year beyond age 60. It has also been noted that WTP for safety improvements and risk reductions rises with incomes and is positively correlated with residence in urban areas. Urban residents will generally pay 25% more for safety, partially reflecting increased incomes in urban areas. WTP increased by about 1 – 2 % for each increase in income of NZ$ 1000. However willingness to pay declines with family size, dropping between 10 and 25% for each additional family member beyond two members, depending on their method of assessment, suggesting that a family's financial situation affects its demand for safety. The authors note that families are also willing to pay to reduce risk for the general public, partially reflecting altruism, and a value on friends and relatives, but partially reflecting the gains from public safety including reduced tax payments to cover public costs. They also note that their survey was cast in the context of highway safety, where the respondents feel that they have some control. This allows for extrapolation of these results to other contexts where the individuals may have similar control, such as consumer safety, and occupational choice. They do not feel that these results should be extrapolated to situations where the risks are perceived to be outside of the public's control, such as environmental exposures, and air and public transportation. In these applications, higher values are suggested to be more suitable.

Belgium

Belgium has estimated the VSL in examining the external costs of interurban freight traffic (Beuthel et al., 2002). When estimating the effects of deaths from transport pollution, they examined both the direct emissions as well as the emissions of nitrous oxide, sodium dioxide and other pollutants by applying an appropriate mortality rate of the concentration of pollutant multiplied by the population. This provided a loss of life per gram of pollutant that could be used when multiplied by a value of life to arrive at a monetary value for the total effect of one gram of pollutant. The value of a statistical life chosen was from De Borger et al. (1996) with a measure of ECU 4.453 million, which has a Canadian value of 2002 C$ 6.425 million. This result is in line with the expectations from New Zealand, with the value being relatively high for a risk over which there is little individual control.

France

In 1993 the French Government financed a CVM study to determine the value of a human life for road accidents (Desaigues and Rabl, 1995). Understanding that road safety is a public good, their interest was in determining individuals' willingness to trade off consumption of private goods and improvements in road safety. They sought to create a hypothetical but readily understandable market for the purchase of differing levels of road safety. They asked the willingness to pay (in terms of increased taxes) on a per household basis per year for saving specific numbers of lives from road accidents, between 50 and 5000. The VSL is computed as the number of households in France multiplied by the stated willingness to pay divided by the number of lives saved. The authors recommend a value of FF 5.5 million (2002 C$ 1.182 million), based on a reasonable goal of reducing traffic deaths by 10% in the near future, or 1000 lives saved per year. They note that this corresponds closely with the values recommended in Sweden by Persson (1989) and Miller and Guria (1991) in New Zealand.

Sweden and Norway

Trawen, Maraste and Persson (2002) revisited the methods used in evaluating the costs of fatality from road accidents in selected countries taken from the respondents to COST 313 (1994), and other contact persons in Australia, Canada, New Zealand, South Africa and the US. Their purpose was partially to evaluate the changes in methodologies used for evaluating accident costs in the studied countries over the period between 1990 and 1999. Their analysis identifies two further European countries that report an official value of statistical life used within their jurisdictions. Sweden reports a VSL of SEK 13 million (1999), or 2002 C$ 1.759 million and Norway reports a measure of NOK 15.919 million (1999), or 2002 C$ 2.184 million. The other countries that were identified by the authors as using an official value have already been presented here and include Great Britain, New Zealand, and the US. They also note two countries that although still using an official value based on a Human Cost approach, are considering switching to an official VSL: Austria and Finland.

Canada

For a number of years, Transport Canada has been using a VSL in the region of 2002 C$ 1.8 million. In 1994, they used $ 1.5 million in 1991 C$, equivalent to 2002 C$ 1.762 million.[85] This estimate was based on a willingness to pay approach as has been

[85] Somewhat contradictorily, the Treasury Board of Canada Secretariat (July 1998: 31) states that Transport Canada had used 1986 C$2.5 million (2002 C$3.57 million). It turns out that this was for aviation projects and Transport Canada used a much lower value for road safety projects (Lawson, 1989, B2-B7). Subsequently, Transport Canada's Benefit-Cost Analysis guide recommended a consistent VSL for all transport analysis.

recommended in the Guide to Benefit Cost Analysis in Transport Canada (1994) and an evaluation of international studies and best practices. It recommends this amount as the value of a fatality avoided in all modes of transportation, however it also recommends sensitivity analysis in a range between 1991 C$ 0.5 million and 1991 C$ 2.5 million, due to the difficulty in establishing the value of a fatality avoided with precision, or objectivity. Recently, based on a review of the regulations that establish access control to railway right of ways, the Railway Safety Consultative Committee used a slightly higher estimate of $ 1.79 million in 2001 C$, equivalent to 2002 C$ 1.808 million (Transport Canada, 2002).

The VSL used by Transport Canada is lower than that used by Health Canada, reported by Krupnick et al. (2002), and by Environment Canada, which is based on a study by Chestnut et al. (1999) and is reviewed below.

3.7 Other Studies: Policy Suggestions

Canadian consultants, such as HLB Decision Economics, have relied on US data such as Technical Advisory, T 7570.2 (US DOT 1994) when they prepared cost benefit analysis of transportation issues in Canada (HLB, 2002). HLB is a consulting firm that has conducted studies for a variety of Canadian governmental bodies, from the municipal to the federal level, on transportation issues including rail, aviation and highway modes. They specialize in risk and economic analysis for transportation and infrastructure, among other areas. HLB has utilized the updated American estimate without alteration for country differences, adjusting the VSL to Canadian currency levels. Valued at today's Canadian dollar the VSL used by HLB is C$ 3.586 million.

Chestnut et al. (1999) in a report to Environment Canada on the Air Quality Valuation Model (AQVM) reviewed the literature on WTP for changes in risk of death and estimated a VSL to be used in the economic evaluation of environmental issues. They concluded that the VSL of people over 65 years of age is 1996 C$ 3.9 million (2002 C$ 4.24 million) with a high of $ 7.8 million and a low of $ 2.3 million. For people under 65 years of age, they concluded that the VSL should be 1996 C$ 5.2 million (2002 C$ 5.7 million), with a low of 1996 C$ 3.1 million (2002 C$ 3.4 million) and a high of 1996 C$ 10.4 million (2002 C$ 11.3 million).[86] Taking a weighted average of these estimates and assuming that 85% of air particulate related deaths are to those members of the population aged 65 and older, Environment Canada recommends a central age-weighted estimate of 1996 C$ 4.1 million (2002 C$ 4.5 million) with a high of 1996 C$ 8.2 million and a low of 1996 C$ 2.4 million.

Abelson (2003) reviews the basic concepts pertaining to VSL, QALYs and the value of a life year (VOLY). He reviews a few VSL studies and current government practice in Australia. He notes that although the VSL may rise over age until about age 40 and then decrease, single values for VSL are generally recommended for policy use. The U.S.

[86] These recommended values are based a review of international studies, which provides slightly lower estimates than Canadian studies alone.

Environmental Protection Agency recommended 2002 C$ 7.712 million, the UK Department of Transport used 2002 C$ 1.793 million, the European Union recommended the range of 2002 C$ 1.2 to $ 4.67 million with a best estimate of 2002 C$ 1.867 million and $ 1.333 million for elderly people. For Australia, Abelson notes that there is no single VSL estimate for government use. However, in 2002 the NSW Roads and Traffic Authority (2002) recommended a VSL of 2002 C$ 1.109 million. Since there is a lack of original research on the VSL for Australia, Abelson draws from international VSL studies. Noting also that European government VSLs are lower than standard US ranges, and given the similarity between European and Australian incomes, Abelson suggests that a VSL of 2003 AU$ 2.5 million (approximately 2002 C$ 2.2 million) should be used for public policy.

Dionne and Lanoie (2004) present an up-to-date survey of more than 85 papers on the VSL. They argue that Canadian Federal and Provincial transport authorities should use a VSL of 2000 C$ 5 million (technically 2002 C$ 5.1 million but for simplicity we will continue to refer to the $ 5 million figure). They suggest a range of $ 3 million to $ 7 million. Their conclusion is based primarily on seven "best" studies in the transport sector, four of which are from the US. Five of these studies are CVMs and two are consumer market studies. They note that the average VSL of only Canadian studies is also around $ 5 million.

3.8 Our Initial Suggestion

As mentioned previously estimates of the VSL vary widely depending upon the method employed for estimation. Generally, the VSL from consumer market studies are lower than those from wage-risk studies, which are lower than those from CVM studies.

Based on previous studies summarized in Tables 3.1 through 3.5 and our review of methodologies and estimates, we suggest that the appropriate VSL to use in Canada ranges between 2002 C$ 1.0 million and 2002 C$ 7.5 million. The main studies that we draw on are summarized in Table 3.8. Some of these studies pertain directly to Canada (Krupnick et al., 2002; Chestnut et al. (1999), Dionne and Lanoie (2004)). Both meta-analyses by Miller (2000) and Viscusi and Aldy (2003) contain recommendations specifically for Canada. These Canadian-specific numbers are used where possible.

The top end of our range includes Viscusi and Aldy's (2003) range of Canadian wage-risk studies of 2002 C$ 3.71-$ 7.43 million. It also includes most of their mean predicted range of the VSL based on 49 international studies from 2002 C$ 6.19- 2002 C$ 7.67 million. At the bottom end, the range includes Mrozek and Taylor's (2002) estimate based on "best practices" of 2002 C$ 2.56 million and their range of $ 1.6 million - $ 3.4 million, and it includes Krupnick et al.'s (2002) estimates which ranged from 2002 $ 1.3 million- $ 4.0 million. Recommendations by Boardman et al. (2001), Miller (2000), Devousges et al. (1998), Chestnut et al. (1999) and Dionne and Lanoie (2004) are well within the $ 1.0 million - $ 7.5 million range.

The $ 1.0 million - $ 7.5 million range is too large for practical purposes. Selecting a "best" point estimate is necessarily somewhat arbitrary. *In our opinion, we believe that a reasonable point estimate of the VSL for policy purposes in Canada is 2002 C$ 4.25 million. This figure is at the mid point of the $ 1.0 million to $ 7.5 million range*. It is between the estimates recommended by Chestnut et al. (1999) and Dionne and Lanoie (2004) and it fits within Viscusi and Aldy's (2003) range.

The $ 4.25 million figure is more than twice the figure currently used by Transport Canada ($ 1.76 million). However, it is slightly lower than figures used by Environment Canada ($ 4.46 million) and Health Canada ($ 4.47 million). It is slightly higher than the US Office of the Secretary of Transportation (OST, 2002) which recommends 2002 C$ 3.63 million.

Many scholars would argue that the $ 4.25 million is on the low side. In particular, it is well below Viscusi and Aldy's (2003) suggestion of 2002 C$ 8.7 million. Although the Viscusi and Aldy's study is probably the most authoritative study, we prefer a lower estimate for a number of reasons:

1. The 2002 C$ 8.7 million is based largely on evidence from the US where incomes are higher.
2. Much of the evidence is based on wage-risk studies which suffer from numerous problems which were discussed earlier. It seems reasonable to err on the side of caution and use lower estimates.
3. It seems appropriate to give some weight to Mrozek and Taylor (2002) paper which obtains much lower "best" estimates than Viscusi and Aldy (2003).[87]
4. Governments have to make decisions under budget constraints. Note that $ 4.25 million x 31 million people = $ 131 trillion, which is more than 100 times larger than Canada's GDP. The $ 4.25 million estimate is above the net wealth of most individuals and the NPV of their earnings. One might think this is inconsistent, but it is not. As mentioned earlier, the VSL measures the marginal WTP for small reductions in risk. However, as Abelson (2003, S6) points out it "does raise the issue of whether society can afford to base all its resource allocation decisions for health and safety on marginal WTP values."

Of course, other scholars would argue that the $ 4.25 million estimate is on the high side. In particular it is just outside Krupnick et al.'s (2002) range of $ 1.27 to $ 4.03 million and it is higher than Mrozek and Taylor's (2002) $ 2.6 million. Our main rejoinder to this is that by far the weight of the evidence is a much higher number (Viscusi and Aldy, 2003; Dionne and Lanoie, 2004). Despite the problems with wage-risk studies and other revealed preference methods, they are probably generally superior to stated preference methods.

[87] It is worthwhile noting that when Viscusi and Aldy (2003) duplicate Mrozek and Taylor's (2002) specification with their own wage-risk sample, they find that with many explanatory variables and 41 observations, the specification generates imprecise estimated coefficients.

The $ 4.25 million estimate implicitly takes account of income differences between Canada and the US. However, it does not take account of cultural differences between the countries. Nor is it adjusted for age or any other factor.

3.9 Transferring Estimates of the VSL from US Studies to Canada

An alternative way to estimate the VSL in Canada is to obtain a reasonable estimate of the VSL in the US and then adjust for income differences between Canada and the US using the income elasticity of demand. This method requires an estimate of the income elasticity of safety. Unfortunately, there is not agreement on the magnitude of this estimate.

Jones-Lee et al. (1998, p. 29) suggest on a priori grounds that health and safety is a luxury (its income elasticity is greater than one). They say: "common observation suggests strongly that people and nations with increasing material prosperity over time are willing to pay an increasing percentage of their income to achieve a given improvement in the quality of life in such fields as environmental quality and health." However, the evidence from most wage-risk studies suggests otherwise, at least for safety. Miller (2000) finds a range of income elasticity from 0.85 to 0.96. Mrozek and Taylor (2002) find very inelastic income elasticity estimates of 0.46 to 0.49. In contrast, in their meta-analysis of wage-risk studies, Bowland and Beghin (2001) find a median income elasticity of 1.95, and a range of income elasticity from 1.7 to 2.3, and de Blaeij et al. (2003) find an income elasticity of VSL of 1.67. Viscusi and Aldy (2003) replicate the meta-analyses undertaken by Miller (2000), Bowland-Beghin (2001), and Mrozek and Taylor (2002) with their own wage-risk dataset and find income elasticities between 0.52 and 0.61[88]. Under various specifications, Viscusi and Aldy (2003) note that the 95% confidence interval's upper bound never exceeded 1.0. As Jones-Lee et al. (1998) note, the low estimated income elasticities may be a result of the studies being based on cross-sectional data that provide smaller estimates than would time series data. While this latter point may be correct, we are not so convinced as Jones-Lee et al. (1998) that safety is a luxury and are more inclined to believe that its income elasticity lies between 0.5 and 1.0.

Drawing exclusively on US studies suggests the VSL in the US is in the range of 2002 C$ 1.5 million – 2002 C$ 8.5 million.[89] As above, we select a point estimate at the mid-point of this range, specifically 2002 C$ 5.0 million.

By definition, the income elasticity of safety is given by:

$$e = \frac{\%\Delta V}{\%\Delta I},$$

[88] Although the income elasticity of 0.52 calculated using Mrozek and Taylor's (2002) specification is not statistically significant at the 5% level, both estimates using Miller's (2000) and Bowland and Beghin's (2001) specifications are significant at the 5% level, and are 0.53 and 0.61 respectively.
[89] Viscussi and Aldy (2003) prefer US$ 7 million (2002 C$ 8.36 million).

where $\%\Delta V$ represents the percentage change in VSL and $\%\Delta I$ represents the percentage change in income. Consequently, to convert a VSL based on US data to an appropriate figure for use in Canada, we use the following formula:

$$V_{CAN} = V_{US} + eV_{US}(I_{CAN} - I_{US})/I_{US}$$

Adjusting for purchasing power, Canadian incomes are approximately 15 percent lower than US incomes and have maintained this average difference over the past 30 years.[90] Setting $(I_{CAN} - I_{US})/I_{US} = -0.15$, the equivalent Canadian VSLs for a range of US-based VSLs under different income elasticities are given in Table 3.9.

If the appropriate VSL for the US equals 2002 C$ 5.0 million, then the appropriate VSL for use in Canada after adjusting for income differences is 2002 C$ 4.25 million, 2002 C$ 4.44 million and $ 4.63 million, depending on whether the income elasticity is 1.0, 0.75 or 0.5, respectively. These estimates are very close to, but slightly higher, than the 2002 C$ 4.25 million figure suggested above.

If the VSL in the US ranges between 2002 C$ 1.5 million – 2002 C$ 8.5 million, then the VSL in Canada should range between 2002 C$ 1.3 million and 2002 C$ 7.9 million (allowing for the possibility that the income elasticity of safety may vary between 0.5 and 1.0. This range is very similar to the range suggested above of 2002 C$ 1.0 million to 2002 C$ 7.5 million.

Based on this method, we conclude that the VSL in Canada ranges between 2002 C$ 1.3 million and 2002 C$ 7.9 million, with a best point estimate of about $ 4.44 million. This serves to confirm the results obtained in the previous section.

As mentioned above, Dionne and Lanoie (2004) suggest a VSL of $ 5.0 million for use in evaluation of Transportation projects in Canada. They maintain "(t)he discussion was conducted in the context of Quebec, but most of it could easily apply to the rest of Canada, or to any other jurisdiction (p. 266)." However, their $ 5 million value is based primarily on the average VSL of seven "best" transportation studies. The authors did not adjust for income differences between Canada and the countries used in these studies.[91] Dionne and Lanoie (2004, 264-265) argue: "Four of the studies are American in origin, two are from Sweden, and the last one comes from the UK, all countries with a standard of living similar to that of Canada." In a footnote (p. 265), they recognize "(s)trictly speaking…if all of the studies were American, we would like to make adjustments to account for the higher income and initial risk in the US but, given that three out of the

[90] Currently, Canadian incomes are about 14 percent lower than US incomes when adjusted for purchasing power. Over the past 45 years Canadian incomes have varied between 80 percent and 90 percent of US incomes (Centre for the Study of Living Standards, 2003).

[91] Another problem is that Dionne and Lanoie (2004) appear to over-estimate the VSL obtained from some studies when converted into 2000 C$. For example, Persson et al. (2001) suggest the VSL equals SEK 22.3 million in 1998 currency units. Converting 1998 Swedish Krone into 2000 Canadian $ based on PPP (Purchasing Power Parity) yields 2000 C$ (22.3/7.382)*.98 million = $2.96 million. However, Dionne and Lanoie (2004, p. 264) present an estimate of $3.22 million, almost 9 percent higher.

seven studies are coming from countries that are more similar to Quebec, we do not feel an adjustment would make a large difference. Furthermore, such an adjustment would not be straightforward." In fact, adjusting for income differences is straightforward. When one does so, it explains most of the difference between our point estimate of $ 4.25 million and Dionne and Lanoie's estimate of $ 5 million.

3.10 Adjusting for Other Factors

Thus far we have focused on an "average" VSL for use in Canada. Considerable evidence suggests that the VSL varies according to individual characteristics and transportation mode (or policy dimension) characteristics.[92] Important individual characteristics are income (or wealth), age, and culture. Mode characteristics include risk level and individual degrees of control. The question arises whether the "average" VSL should be adjusted for such factors. For example, should the VSL for Concorde passengers be higher than that for bicycle riders because their average income is higher, the risk is higher and they have less direct control over their safety?

Traditional economic theory indicates that one should make such adjustments as it would lead to more efficient allocation of resources. However, ethical, political and pragmatic arguments can be put forward to suggest that one should not. Furthermore, there are some fundamental problems with traditional economic arguments. These concern the rationality of some people, especially young high risk-taking people, and how to deal with addictive behaviour, such as smokers.

There is some merit to the argument that one should use a single VSL figure for all policy purposes in Canada and, specifically for all modes of transportation in Canada. Currently, Transport Canada adopts this approach. In our view, some legitimate reasons why one should use a single VSL are:

1. A single number has the virtue of consistency. Of course it might be consistently wrong, but it is hard to argue for the use of one figure one day for one purpose and another figure on another day for another purpose.
2. A single number is simple and reduces the cost of analysis. Thus, it might lead to more analysis and ultimately to more efficient allocation of resources.
3. Attaching different VSLs to different groups within a society based on income fits implies a form of distributionally-weighted cost-benefit analysis (Boardman et al., 2001). Typically, cost-benefit analysis assumes that the marginal utility of a dollar is equal across all members of society, i.e., a dollar is worth the same to a rich person as to a poor person.

[92] Dionne and Lanoie (2004) discuss the issues that determine the transferability of estimates of VSL for road safety to the Quebec context. They point out that even within societies that have the same traffic-risk parameters and similar insurance plans there may be differences in the personal preferences of individuals in different countries. The differences due to religious, cultural and demographic factors would be captured by individual's utility index and may be justification for conducting independent studies in individual countries.

Distributionally-weighted cost-benefit analysis weights poor people more than rich people on the grounds of equity. What are the appropriate distributional weights? This issue is highly subjective. It depends on one's philosophical and political views. Economics can provide little guide to selection of these weights. Resolution of this issue is beyond the scope of this paper.

4. In order to use VSLs that differ across individuals or modes we need to be more certain of the accuracy and appropriateness of the magnitudes of the differences—the functional form(s).

Nonetheless, there are arguments for using different VSLs for people with different ages and different incomes, and for different modes of transportation due to different risk levels and differences in the degree of control.

3.10.1 Age

It is generally agreed that at some age the VSL declines but the value of a life year increases. Whether this occurs at age 40, 60, or 70 remains disputed. Chestnut et al. (1999) suggest the VSL is, on average, about 30 percent lower for people over 65 than for people under 65 (2002 C$ 4.24 million versus 2002 C$ 5.7 million). While adjusting for age might make sense in some policy contexts, it does not seem an obvious adjustment to make for transportation. It is not obvious that people who use different modes of transportation (air, rail, car) are significantly different in age from people who use other forms of transportation. Even if they did differ in age, it is not clear that this is grounds to use a different VSL for different transportation modes.

3.10.2 Income

Earlier we argued for using a lower VSL for Canada than the US due to lower average incomes in Canada. Consistency would suggest using a lower VSL for people with lower incomes and for the mode of transportation most frequently used by such people. However, this is not an entirely compelling argument. In the past there might have been some legitimate argument for using a higher VSL for people who fly because they are willing to pay more for safety improvements than people who take the bus or use other forms of transportation. However, it is not clear at this time that there is a significant difference in the average incomes of people who use one mode of transportation over another.

3.10.3 The Level of Risk

There are four issues:

1. When estimating the VSL for Canada and drawing on US studies, should one adjust for the different level of work risk in Canada vs. the US?

2. When estimating the VSL for Canada and drawing on US studies, should one adjust for the lower level of transportation risk in Canada?
3. Should one adjust the VSL for transportation because it is more or less risky than the risk level in the studies used to estimate the VSL?
4. Should one adjust the VSL according to the mode of transportation in accordance with the arguments in Section 3.2 on the grounds that different modes have different levels of risks?

One might think that US jobs are more risky than Canadian jobs. If this were true and Canadian incomes were the same as US incomes one might further conclude, consistent with Figure 3.2, that the VSL from US wage studies would be higher than the VSL obtained from Canadian wage studies. This would be incorrect. In fact, Canadian jobs are more risky than US jobs; see Table 3.10.[93] Indeed this is what one would expect given that Canadian incomes are lower than US incomes and safety is a normal good. Furthermore, the VSL based on Canadian studies is less than the VSL based on US studies, which is also what one would expect given lower incomes. The main implication of this discussion is that when applying US data to Canada one should only adjust for income differences between the two countries, not the difference in job risk levels, which are also a function of income differences.

The answer to the second question is "No". The estimated VSL is based on wage-risk studies and CVM studies. Transportation safety rates are rarely used to impute the VSL. Thus, they are not relevant, although they do affect the 3rd question. Furthermore, the presumption that transportation risk is lower in Canada is incorrect. Comparison of column 3 of Table 3.11 and Table 3.12 indicates that motor vehicle fatalities per person are about 50 percent higher in the US than in Canada. Similarly comparison of column 2 of Table 3.11 and column 5 of Table 3.12 shows that the average number of fatalities per vehicle is much higher in the US than in Canada. However, the much more appropriate comparison is fatalities per vehicle mile traveled (VMT). In fact, according to this measure, Canadian and US fatality rates are quite similar. Basic data from the International Road Traffic and Accident Database (OECD, 2004) show the road fatality rate is 0.93 per hundred million vehicle km in Canada and 0.94 per 100 million vehicle km in the US. Further, the rate of injury accidents is larger in Canada at 0.51 per million vehicle km over 0.46 per million vehicle km in the US.

The third question is more important. In theory, the VSL for a particular application should reflect the risk level of that particular application as per Figure 3.2. Contrary to some views, transportation risks are higher than work risks. Dionne and Lanoie (2004, 260) claim "most individuals covered by studies based on the job market face higher risks at work than on the road." This is incorrect. As shown in Table 3.10 the average US fatality rate for all occupations is 4 in 100,000 people, although it ranges considerably from 1 in 100,000 for jobs in finance, insurance and real estate to 20 or more per 100,000

[93] Part of the reason for the higher Canadian fatality rates is that the Canadian data are measured in terms of 100,000 worker years while the US data are in terms of 100,000 workers. If a worker does not work a full worker year, s/he will be less likely to be killed on the job than someone who does work a full worker year. Even controlling for this, Canadian jobs appear to be more risky.

for some other occupations. In contrast, road fatalities per 100,000 vehicles or per 100,000 people are generally higher. In 2000 in the US, for example, there were approximately 15 deaths per 100,000 people and approximately 22 deaths per 100,000 licensed drivers. When one realizes that most workers spend considerably more time working than driving, it is quite clear that the risk of a fatality while driving is considerably higher than the fatality risk while working. Suppose that conservatively a worker spends 4 times as many hours working as driving. This implies that the chance of being in a fatal accident in a year is 22 per 100,000 licensed drivers x 4 times the time spend working as driving / 4 deaths per 100,000 people if working = 22 times higher while driving than working (on an hourly basis); roughly 88 in 100,000 for the year. We can check this ratio by examining the occupational fatality rate of truck drivers. Table 3.10 indicates that truck drivers are 25/4 = 6.25 times more likely to be involved in a fatal accident while working than people in other occupations.[94] Furthermore, passenger car occupants are 3.5 times more likely to be involved in an accident (per mile) than a large truck occupant; see Table 3.13. Thus, we come to a similar conclusion that, on an hourly basis, one is 22 times more likely to have a fatality while driving than working.

The main conclusion is that, on average, people who drive face risks that are 22 times greater than the risk while working. Following Figure 3.2, one could argue that the VSL used in transportation policy should be higher than the VSL estimated by wage-risk studies.[95]

Furthermore, the VSL should vary with the mode of transportation. Different transportation modes have different fatality risks. Table 3.13 presents fatalities by vehicle type in the United States. It shows that fatalities per VMT are highest for motorcycles, followed by passenger cars, light trucks, then large trucks. It is also clear that on a per passenger mile basis, air carrier fatality rates are more than 100 times safer than motor vehicles (Waters and Wu, 2003). This suggests that the VSL for air travel should be significantly less than the VSL for road travel.

In order to determine an appropriate VSL for different modes based on different risk levels, analysts need an empirical estimate of Figure 3.2. Mrozek and Taylor (2002) generate VSL estimates using different baseline risks ranging from 2.5 deaths to 20 deaths per 100,000 worker years. Their results, which are summarized in Table 3.15 and Figure 3.4 show a nonlinear relationship between baseline risks and the estimated value of statistical life. However, there are three problems using this relationship for policy purposes. First, it is not monotonic: it "dips down" at high risk values, contrary to a priori expectations. Second, it does not cover the relevant range. We suggested above that the risk of a fatality while driving is more than 20 times the risk while working, on average, which corresponds to approximately 88 in 100,000. Third, empirical estimation of such

[94] The risk is higher for pilots and navigators who are 70/4 = 17 times more likely to be involved in a fatal accident while working than people in other occupations.
[95] One might expect that the estimated VSL would be much greater in transportation studies than in wage risk studies. However, this does not obtain a figure of 2002 C$ 7 million (Dionne and Lanoie, 2004). It may be because their transportation studies are based on CV and market studies than on wage-risk studies.

graphs is relatively rare. Attention is generally focused on the mean VSL, not on the whole distribution.

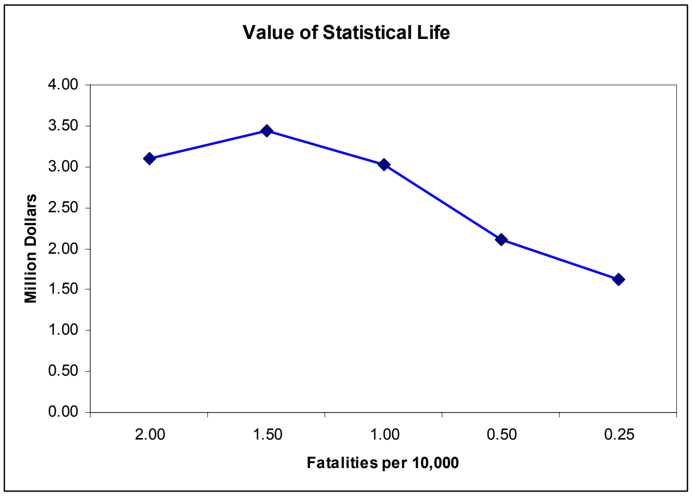


Figure 3.4 Mrozek and Taylor's (2002) Estimates of the Relationship between the VSL and the Risk level

Clearly, more research is needed on this topic before adjusting the VSL for risk.

3.10.4 Sense of Control

The voluntariness, control, and responsibility an individual has in a particular mode also affects his VSL. People may feel in less control in rail or air crashes and therefore be more willing to pay for safety improvements, ceteris paribus. CVM studies can try to capture these effects.

Chilton et al. (2002) estimated the VSL of rail travel relative to road travel. Using a "matching" question (where respondents are asked the number of fatalities prevented in one context needed to be as good as the prevention of fatalities in another context) to estimate VSL relativity ratios for the United Kingdom, they find that low rail users (respondents who traveled 200 miles or less in the last 12 months) had a relative ratio of VSL_{RAIL}/VSL_{ROAD} = 0.933 and that high rail users (respondents who traveled more than 200 miles in the last 12 months) had a relative ratio of VSL_{RAIL}/VSL_{ROAD}=1.157. This would lead to a VSL for low rail users of $ 3.97 million and $ 4.92 million for high rail users, given our point estimate of the VSL of $ 4.25 million.

Jones-Lee et al. (1998) find that the average WTP to reduce the risk of death on the London underground is 50 percent higher than to reduce road fatalities. Part of this may be due to lack of control on the underground. Part is also probably due to over-estimating the risk on the underground. People also over-estimate road fatalities. In Jones-Lee's

(1982) survey, people thought that road fatalities were eight times more numerous than they are in reality and people thought they were worsening when in reality they were improving substantially.

To determine an estimate for the VSL for air travel, Carlsson, Johansson-Stenman, and Martinsson (2004) note that people's willingness to pay for a risk reduction of a fatality when traveling by air is more than two times the willingness to pay for travel by taxi. Using a contingent valuation survey, Carlsson et al. (2004) determine the willingness to pay for a common reduction in fatal risk when taking a taxi versus traveling by air. To avoid complications of the effect of control, the authors compare a trip between two locations by taxi and airplane, versus driving oneself and taking an airplane. Willingness to pay for risk reductions may be higher for air travel if consumers perceive and suffer differently from the same objective risk as traveling by taxi, or if it is expected to be more traumatic to die in a plane crash (Carlsson et al., 2004). In their survey, respondents were asked how much they were willing to pay for a risk reduction of 1 in a million to 0.5 in a million for either a taxi or plane trip with the same price. Carlsson et al. (2004) note that the implied VSLs from their surveys are high and the surveys do not correct for scale effects where the willingness to pay does not increase proportionately to the risk reduction, and they do not recommend their figures for public policy. However, their study does indicate that the VSL for air travel is more than double the VSL for travel by taxi, and this difference is statistically significant. According to their study, the estimated VSL for air travel is approximately 2.9 times that for a trip by taxi. This would imply a VSL for air travel of $ 12.32 million. Considering that being in control of the car, that is driving oneself versus taking a taxi, should decrease the VSL, the VSL for air travel may be higher. Carlsson et al. (2004) suggest that an important reason for the differences in willingness to pay by these two modes of transportation is the individual subjectively suffers more from the risk and therefore is willing to pay more to reduce the mental suffering.

3.11 Potential Future Research Activities

Cost benefit analysis (CBA) and the decisions arrived at for policy development from CBA rely on accurate estimates of the economic costs included. Measurement of VSL in the academic setting shows wide variance, reducing the reliability of decisions based on CBA that includes VSL. Thus it is possible that the wrong policy decisions could be made if the VSL used is not a good point estimate of the true WTP for risk reduction.

Following from the discussion in this chapter, there are a number of factors that determine the VSL estimate. They include, most importantly, the design of the study used to assess the magnitude of the WTP of a population, the magnitude of the risk reduction proposed, and the ability of respondents to understand the probabilities involved. In this report we have suggested that a single figure for VSL of 2002 C$ 4.25 million be used for all transportation costing that requires valuation of health impacts. Again this figure has been recommended in order to increase the ability to compare across interventions, and to reduce the cost of analysis into transportation issues. We also feel that this somewhat addresses the ethical issues associated with there being variation in WTP between different income brackets and therefore choice of mode.

Problems exist with attempting to transfer estimates from other jurisdictions due to differing underlying risks, cultural differences and income differences. Also the estimates here are judgments based on a wide variety of study designs. Both Viscusi and Aldy's study and Mrozek and Taylor's study are based on wage risk studies and do not specifically test the WTP for reduction in transportation related risk. Both of these studies heavily influence the value suggested in this report, but their applicability can still be called into question. It is possible that individuals perceive the risk of transportation to be lower than they are actually exposed to due to hedonic adaptation. Or they may feel that the impacts of environmental damage are greater than the true risk due to heuristic evaluations.

These implications suggest that it may be prudent for Transport Canada to undertake an investigation into the Canadian VSL for a wide range of transportation issues, including those entailed in this full report. This study should be of a contingent valuation design such as was conducted in New Zealand by the Land and Transport Safety Authority (Miller and Guria, 1991). If cast in a wider manner than was done in New Zealand, it would be possible to capture the VSL inherit in transportation risk for Canada specifically and could shed further light on Transportation Canada's costing project as it is being undertaken currently.

3.12 Conclusion

This chapter reviews many of the important issues analysts and policy makers have to consider when determining the appropriate VSL for policy purposes. It also recommends a VSL for use in Canadian transportation policy. In our view, the appropriate VSL ranges between 2002 *C$ 1.0 million to 2002 C$ 7.5 million. A reasonable point estimate is 2002 C$ 4.25 million, the mid point of this range.*

These estimates were based primarily on existing studies that had significant Canadian content (Krupnick et al., 2002; Mrozek and Taylor, 2002; Boardman et al., 2001; Miller, 2000; Chestnut et al., 1999; Dionne and Lanoie, 2004; and Viscusi and Aldy, 2003). We checked these numbers by obtaining a best estimate and range for the US and then adjusting for lower Canadian incomes. This resulted in a point estimate of 2002 C$ 4.4 million and a range of 2002 C$ 1.3 million and 2002 C$ 7.9 million. This point estimate and range are very similar to previous estimates, thus providing more confidence in them.

We are very confident that the VSL for Canada ranges between 2002 C$ 1.5 million and 2002 C$ 7.5 million. However, this range is too large for sensitivity analysis in policy analyses. Using a VSL of $ 4.25 million and sensitivity analysis of plus or minus $ 2 million would be reasonable, although we cannot attach confidence intervals.

This chapter discussed whether the VSL should be adjusted for individual characteristics or for mode of transportation. In theory the VSL should be adjusted for both types of factors. However, we believe that the VSL should not be adjusted for individual characteristics because of pragmatic reasons (it makes the analyses more complicated) and because it is not clear that it is ethically and politically justifiable. A much stronger theoretical case can be made for adjusting the VSL based on mode. However, in order to make such adjustments one would need to know:

1. The risk levels of different forms of transportation.
2. The relationship between the risk level and WTP as shown hypothetically in Figure 3.2
3. Whether individuals have good assessments of the risk levels.

In practice, we do have reasonable data on the different risk levels of different modes. However, we do not have good estimates of Figure 3.2. One set of relationships is presented in Figure 3.4. In practice, such graphs are not very precise and may not even include the "relevant range." Finally, individual assessments of the risks can be very poor. Under the circumstances and valuing simplicity, it does not seem reasonable to adjust the VSL across mode or across broad application. In our opinion all departments in government should use the same "average" VSL.

Chapter 3 References

Abelson, P. (2003): "The Value of Life and Health for Public Policy", *The Economic Record,* 79(Special Issue), pp. 2-13.

Arabsheibani, G. and Marin, A. (2000): "Stability of Estimates of the Compensation for Danger", *Journal of Risk and Uncertainty,* 20(3), pp. 247-269.

Beattie, J., Covey, J., Dolan, P., Hopkins, L., Jones-Lee, M., Loomes, G., Pidgeon, N., Robinson, A. and Spencer, A. (1998): "On the Contingent Valuation of Safety and the Safety of Contingent Valuation: Part 1 – Caveat Investigator", *Journal of Risk and Uncertainty,* 17, pp. 5-25.

Beuthel, M., Degrandsart, F., Geerts, J.F. and Jourquin, B. (2002): "External Costs of the Belgian Interurban Freight Traffic: A Network Analysis of Their Internalization 1", *Transportation Research, D, 7*(4), pp. 285–301.

Bishop, R.C. and Heberlein, T.A. (1990): "The Contingent Valuation Method", in Johnson, R.L. and Johnson, G.V. (eds.), *Economic Valuation of Natural Resources: Issues, Theory, and Application,* Boulder, CO: Westview Press, pp. 81-104.

Blomquist, G.C., Miller, T.R. and Levy, D.T. (1996): "Values of Risk Reduction Implied by Motorist Use of Protection Equipment", *Journal of Transport Economics and Policy,* 30(1), pp. 55-66.

Boardman, A.E., Greenberg, D.H., Vining, A.R. and Weimer, D.L. (1997): "Plug-In Shadow Price Estimates for Policy Analysis", *Annals of Regional Science,* 31(3), pp. 299-324.

Boardman, A.E., Greenberg, D.H., Vining, A.R. and Weimer, D.L. (2001): *Cost-Benefit Analysis: Concepts and Practice*, 2nd Ed., Prentice Hall: New Jersey, Chapter 14.

Bowland, B. and Beghin, J. (2001): "Robust Estimates of Value of a Statistical Life for Developing Economies: An Application to Pollution and Mortality in Santiago", Journal *of Policy Modelling,* 23(4), pp. 385-396.

Bureau of Transport Economics (BTE) (1999). *Cost of Civil Aviation Accidents and Incidents,* Report 98, Canberra: AGPS.

Bureau of Transport Economics (BTE) (2000). *Road Crash Costs in Australia*, Report 102, Canberra: Bureau of Transport Economics.

BTRE (Bureau of Transport and Regional Economics) (2002): *Rail Accident Costs in Australia,* Report 108, Canberra: Bureau of Transport and Regional Economics.

Carlsson, F., Johansson-Stenman, O. and Martinsson, P. (2004): "Is Transport Safety More Valuable in the Air", *Journal of Risk and Uncertainty,* 28(2).

Camerer, Colin F. and Howard Kunreuther (1989) "Decision Processes for Low Probability Events: Policy Implications*," Journal of Policy Analysis and Management*, 8(4): 565–592,

Centre for the Study of Living Standards, Table 3, 2003. www.csls.ca/data/ipt8.pdf. (accessed June 23, 2004).

Chestnut, L.G., Mills, D. and Rowe, R.D. (1999): "Air Quality Valuation Model Version 3.0 (AQVM 3.0) Report 2: Methodology", prepared for Environment Canada, *Health Canada by Status Consulting Inc*., Boulder, CO.

Chilton, S., Covey, J., Hopkins, L., Jones-Lee, M., Loomes, G., Pidgeon, N. and Spencer, A. (2002): "Public Perceptions of Risk and Preference-Based Values of Safety", *Journal of Risk and Uncertainty,* 25(3), pp. 211-232.

Cohen, M. and Miller, T. (2003): "'Willingness to Award' Non-monetary Damages and the Implied Value of Life from Jury Awards", *International Review of Law and Economics,* 23(2), p.165.

COST 313 (1994): *Socio-Economic Costs of Road Accidents,* Commission of the European Communities, Brussels, Belgium.

Cummings, R.G., Brookshire, R.G. and Schulze, W.D. (1986): *Valuing Environmental Goods: An Assessment of the Contingent Valuation Method*, Rowman & Allanheld: Totowa, New Jersey.

De Blaeij, A., Florax, J.G.M.R., Rietveld, P. and Verhoef, E.T. (2003): "The Value of Statistical Life in Road Safety: A Meta-Analysis", *Accident analysis and Prevention,* 35, pp. 973-986.

De Borger, B., Ochelen, S., Proost, S. and Swysen, D. (1996): "Alternative Transport Pricing and Regulation Policies: a Welfare Analysis for Belgium in 2005", *Transportation research, D*, 12(3), pp. 177–198.

Department of Transport, *Public Safety Zones: A Consultation Document.* Aviation, 1997 http://www.dft.gov.uk/stellent/groups/dft_aviation/documents/page/dft_aviation_503312.hcsp

Department of Transport, *Highways Economics Note No.1: 2001*, Road Safety, 2001 http://www.dft.gov.uk/stellent/groups/dft_rdsafety/documents/page/dft_rdsafety_507642.hcsp

Department of Transport, *Multi-modal Transport Appraisal Investment*, Transportation Strategy, 2002 http://www.dft.gov.uk/stellent/groups/dft_transstrat/documents/page/dft_transstrat_504897.hcsp

Desaigues, B. and Rabl, A. (1995): "Reference Values for Human Life: An Econometric Analysis of a Contingent Valuation in France", In Schwab-Christe, N.G. and Soguel, N.C. (Eds.) *Contingent Valuation, Transport Safety and the Value of Life*, Boston: Kluwer.

Desvousges, W., Johnson, F.R. and Banzhaf, H.S. (1998): *Environmental Policy Analysis with Limited Information*, Edward Elgar: Northampton, MA.

Diamond, P.A. and Jerry A. Hausman (1994): "Contingent Valuation: Is Some Number Better Than No Number?" *Journal of Economic Perspectives*. 8(4): 45-64

Dillingham, A., Miller, T. and Levy, D.T. (1996): "A More General and Unified Measure for Valuing Labour Market Risk", *Applied Economics,* 28, pp. 537-542.

Dionne, G. and Lanoie, P. (2004): "Public Choice about the Value of a Statistical Life for Cost Benefit Analyses: The Case or Road Safety", *Journal of Transport Economics and Policy*, 38(2), pp. 247–274.

Dorman, P. and Hagstrom, P. (1998): "Wage Compensation for Dangerous Work Revisited," *Industrial and Labor Relations Review*, 52(1), pp. 116-135.

DOT (Department of Transport), (1997): *Public Safety Zones: A Consultation Document. Aviation*, United Kingdom, available at: http://www.dft.gov.uk/stellent/groups/dft_aviation/documents/page/dft_aviation_503312.hcsp

DOT (Department of Transport) (2001): *Highways Economics Note No.1: 2001*, Road Safety, United Kingdom, available at: http://www.dft.gov.uk/stellent/groups/dft_rdsafety/documents/page/dft_rdsafety_507642.hcsp

DOT (Department of Transport) (2002): *Multi-modal Transport Appraisal Investment*, Transportation Strategy, United Kingdom, available at: http://www.dft.gov.uk/stellent/groups/dft_transstrat/documents/page/dft_transstrat_504897.hcsp

Dreyfus, M. and Viscusi, K. (1995): "Rates of Time Preference and Consumer Valuations of Automobile Safety and Fuel Efficiency", *Journal of Law and Economics,* 38(1), pp. 79-105.

Easton B. (1997): "The social costs of tobacco use and alcohol misuse", *Public health Monograph*, No. 2, A report prepared for the Alcohol Advisory Council of New Zealand, the Health Research Council of New Zealand, and the Public Health Commission, Department of Public Health, Wellington School of Medicine.

Economist (2003): *Pocket World in Figures*, 2003 Edition, London: Profile Books, 2002.

European Union (2001): *Recommended Interim Values for the Sake of Preventing a Fatality in DG Environment Cost Benefit Analysis.* Available at: http://europa.eu.int/comm/environment/enveco/others/recommended_interim_values.pdf.

Fisher, A, Chestnut, L.G. and Violette, D.M. (1989): "The Value of Reducing Risks to Death: A Note on New Evidence", *Journal of Policy Analysis and Management*, 8(1), pp. 88-100.

Frankel, M. and Linke, C. (1993): "The Value of Life and Hedonic Damages: Some Unresolved Issues", *Journal of Forensic Economics*, 6(2), pp. 93-98.

Gollier, C. and Eeckhoudt, L. (2001): "Which Shape for the Cost Curve of Risk?" *Journal of Risk and Insurance*, 68(3), pp. 387-401.

Hammitt, J.K. and Graham, J.D. (1999): "Willingness to Pay for Health Protection: Inadequate Sensitivity to Probability?" *Journal of Risk and Uncertainty,* 8, pp. 33-62.

Hanemann, W.M. (1994): "Valuing the Environment through Contingent Valuation", Journal of Economic Perspectives. 8(4): 19-43

Hanley, N.D. (1989): "Valuing Non-Market Goods Using Contingent Valuation", *Journal of Economic Surveys,* 3(3), pp. 235-252.

Hausman, J.A. (1993): "Contingent Valuation: A Critical Assessment", *Contributions to Economic Analysis*, 220, Elsevier Science, Amsterdam; London and Tokyo: North-Holland

HLB Decision Economics Inc. (2002): "Cost Benefit Framework and model for the evaluation of transit and highway investments", Final Report, *Sustainable Development Branch*, Prepared for Transport Canada.

Hopkin J.M. and Simpson, H.F. (1995): "Valuation of Road Accidents", *Transport Research,* Laboratory Report, p. 163.

Jenkins, R., Owens, N. and Wiggins, L.B. (2001): "Valuing Reduced Risks to Children: The Case of Bicycle Safety Helmets", *Contemporary Economic Policy,* 19(4), pp. 397-408.

Jennings, W.P., and Kinderman, A. (2003): "The Value of a Life: New Evidence of the Relationship between Changes in Occupational Fatalities and Wages of Hourly Workers, 1992-1999", *The Journal of Risk and Insurances*, 70(3), pp. 549-561.

Johansson, P.-O. (2002): The Value of Statistical Life: Theoretical and Empirical Evidence", *Applied Health Economics and Policy*, 1: 33-42.

Jones-Lee, M. and Loomes, G. (2003): "Valuation of Safety", in Hensher, D.A. and Button K.J. (Eds.) *Handbook of Transport and the Environment, 4,* Elsevier, Amsterdam.

Jones-Lee, M.W., Loomes, G., Jones, S., Rowlatt, P., Spackman, M. and Jones, S. (1998): "Valuation of Deaths from Air Pollution", *NERA and CASPAR*. Report prepared for the Department of the Environment, Transport and the Regions and the Department of Trade and Industry, London.

Kim, S.W. and Fishback, P.V. (1993): "Institutional Change, Compensating Differentials, and Accident Risk in American Railroading, 1892 - 1945", *Journal of Economic History,* 53, pp. 796-823.

Kim, S.W. and Fishback, P.V. (1999): "The Impact of Institutional Change on Compensating Wage Differentials for Accident Risk: South Korea, 1984-1990", *Journal of Risk and Uncertainty*, 18, pp. 231-248.

Krupnik, A., Alberini, A., Cropper, M., Simon, N., O'Brien, B., Goeree, R. and Heintzelman, M. (2002): "Age, Health and the Willingness to Pay for Mortality Risk Reductions: A Contingent Valuation Survey of Ontario Residents", *Journal of Risk and Uncertainty,* 24(2), pp. 161-186.

Lanoie, P., Pedro, C. and Latour, R. (1995): "The Value of a Statistical Life: A Comparison of Two Approaches", *Journal of Risk and Uncertainty,* 10, pp. 235-257.

Lawson, J.J. (1989): "The Value of Transport Safety", Final Report. *Transport Canada,* Report No. 10569.

Lawson, Tony. (1982): "On the Stability of the Inter-Industry Structure of Earnings in the UK, 1954 – 1978", *Cambridge Journal of Economics*, 6(3):249-66.

Miller, T.R. (1989): "Narrowing the Plausible Range around the Value of Life", *The Urban Institute*, Washington D.C.

Miller, T.R. (1990): "The Plausible Range for the Value of Life – Red Herrings among the Mackerel", *Journal of Forensic Economics*, 3(3), pp. 17-39.

Miller, T.R. (1991): "The Costs of Highway Crashes", *The Urban Institute*, Washington, D.C.

Miller, T.R. (2000): "Variations between Countries in Values of Statistical Life", *Journal of Transport Economics and Policy,* 34(2), pp. 169-188.

Miller, T. and Guria, J. (1991): "The value of Statistical Life in New Zealand: Market Research on Road Safety", *Land Transport Division*, Ministry of Transport.

Miller, P., Mulvey, C. and Norris, K. (1997): "Compensating Differentials for Risk of Death in Australia", *Economic Record,* 73, pp. 363-372.

Mitchell, R.C. and Carson, R.T. (1989): "Using Surveys to Value Public Goods: The Contingent Valuation Method, *Resources for the Future*, Washington, DC.

Mrozek, J. and Taylor, L. (2002): "What Determines The Value of Life? A Meta-Analysis", *Journal of Policy Analysis and Management*, 21(2), pp. 253-270.

NSW (New South Wales) Roads and Traffic Authority (2002), *Economic Analysis Manual*, RTA, Sydney.

OECD (2004): *Selected Risk Values for the Year 2002*. International Road Traffic and Accident Database (irtad). Available at http://www.bast.de/htdocs/fachthemen/irtad//english/we2.html.

OST (Office of the Secretary of Transportation), (2002): "U.S. Department of Transportation: Memorandum", January 29 2002, Available at: http://ostpxweb.dot.gov/VSL_2002_Guidance.pdf

Persson U. (1989): *Cost of Road Traffic in Sweden*, Department of Traffic Planning and Engineering, Lund Institute of Technology, University of Lund, Sweden.

Persson, U., Norinder, A., Hjalte, K. and Gralen, K. (2001): "The Value of a Statistical Life in Transport: Findings from a New Contingent Valuation Study in Sweden", *Journal of Risk and Uncertainty*, 23(2) pp. 121-134.

Portney, P, R. (1994): "The Contingent Valuation Debate: Why Economists Should Care", *Journal of Economic Perspectives*. 8(4): 3-17.

Rosen, S. (1988): "The Value of Changes in Life Expectancy", *Journal of Risk and Uncertainty,* 1, pp. 285-304.

Sandy, Robert and Robert F. Elliott (1996): "Unions and Risk: Their Impact on the Level of Compensation and Fatal Risk", *Economica*. 63:291-309.

Sandy, Robert, Robert F. Elliott, W. Stanley Siebert, and Xiangdong Wei. "Measurement Error and the Effects of Unions on the Compensating Differentials for Fatal Workplace Risks", *Journal of Risk and Uncertainty*. 23(1): 33-56, 2001.

Schelling, T.C. (1993): "The Life You Save May Be Your Own," in *Economics of the Environment: Selected Readings,* 3rd ed., eds. Dorfman R. and Nancy S. New York, pp. 388 - 408.

Siebert, W.S. and Wei, X. (1994): "Compensating Wage Differentials for Workplace Accidents: Evidence for Union and Nonunion Workers in the UK", *Journal of Risk and Uncertainty,* 9, pp. 61-76.

Smith, A. (1776 reprinted 1937): "*The Wealth of Nations",* Modern Press, New York.

Transport Canada (1994): "Guide to Benefit-Cost Analysis in Transport Canada", Transport Canada Report, TP11875E, September 1994.

Transport Canada (2002): "RIAS Background Document (Railway Right of Way Access Control Regulations) Draft Report", Rail Safety Consultative Committee, August 2002, Available at: http://www.tc.gc.ca/railway/RSCC/RIAS.htm

Trawen, A., Maraste P. and Persson, U. (2002): "International Comparison of Costs of a Fatal Casualty of Road Accidents in 1990 and 1999", *Accident Analysis and Prevention,* 34, pp. 323-332.

Treasury Board of Canada Secretariat (1998): "Benefit-Cost Analysis Guide*"*, Draft, Ottawa.

US EPA (United States Environmental Protection Agency), (2000): "Regulatory Impact Analysis for the Proposed Ground Water Rule," *Federal Registry,* Washington, DC.

US DOT (United States Department of Transportation), (1994): "Motor Vehicle Accident Costs", Federal *Highway Administration*, Technical Advisory, T 7570.2.

Viscussi, W.K. (1989): "Perspective Reference Theory: Toward an Explanation of the Paradoxes", *Journal of Risk and Uncertainty,* 2(3), pp.235-64.

Viscusi, W.K. (1993): "The Value of Risks to Life and Health", *Journal of Economic Literature,* 31(4), pp. 1912-1946.

Viscusi, W.K. and Aldy, J. (2003): "The Value of a Statistical Life: A Critical Review of Market Estimates Throughout the World", *Journal of Risk and Uncertainty,* 27(1), pp. 5-76.

Table 3.1 Recent Estimates of the VSL Obtained Using Wage-risk Studies

Study	Study Type	Country	VSL (2002 C$)	VSL in Original Currency
Arabsheibani and Marin (2000)	Wage-Risk	UK	$33.333 million	£9.7 million (1985 UK£)
Dorman and Hagstrom (1998)	Wage-Risk	US	$10.767 - $25.124 million	$8.7 - $20.3 million (2000 U$)
Miller, Mulvey and Norris (1997)	Wage-Risks	Aus	$11.841 - $20.452 million	$11 - $19 million (1991 AU$)
Dillingham, Miller and Levy (1996)	Wage-Risks	US	$3.791-$5.832 million	$1.3-$2 million (US 1977$)
Sandy and Elliot (1996)	Wage-Risk	UK	Non-Union: at work risk $116.409, all cause risk $0.890 Union: at work risk $115.842, all cause risk $0.405	Non-Union: at work risk £33.875, all cause risk £0.259 Union at work risk £33.710, all cause risk £0.118 (1985 UK£)
Lanoie, Pedro and Latour (1995)	Wage-Risk	Can	$24.679 - $27.389 million-Job Safety	$17.3 - $19.2 -job safety (1986 C$)
Siebert and Wei (1994)	Wage-Risk	UK	$22.680 million (union) $18.557 million (nonunion)	£8.8 million (union) C7.2 million (nonunion) (1990 UK£)

Table 3.2 Recent Estimates of the VSL Obtained Using Consumer Market and Time Cost Studies

Study	Study Type	Country	VSL (2002 C$)	VSL in Original Currency
Jenkins, Owens, and Wiggins (2001)	Consumer Market	US	Bicycles: ages 5-9: $3.506 million, ages 10-14: $3.377 million, ages 20-59: $5.195million	Bicycles: ages 5-9: $2.7 million, ages 10-14: $2.6 million, ages 20-59: $4 million (1997 US$)
Blomquist, Miller and Levy (1996)	Time Costs	US	Car (seatbelt): $3.269, $11.514, $2.493 million Car (all child safety equipment): $4.267 million Motorcycle: $1.969 Million	Car (seatbelt) $2.213, $7.795, $1.688 million Car (all child safety equipment) $2.889 million Motorcycle $1.333 Million (1991 US$)
Dreyfuss and Viscusi (1995)	Consumer Market	US	Car: $4.290 - $6.11 million	Car: $2.6 - $3.7 million (1988 US$)

Table 3.3 Recent Estimates of the VSL Obtained Using Contingent Valuation Studies

Study	Study Type	Country	VSL (2002 C$)	VSL in Original Currency
Krupnick, Alberini, Cropper, Simon, O'Brien, Goeree, Heintzelman (2002)	Contingent Valuation	Can	$1.274-$4.034 million	$1.2-$3.8 million (1999C$)
Persson et al. (2001)	Contingent Valuation	Sweden	$3.021 million	SEK 22.3 million = US$2.6 million (1998)
Hammitt and Graham (1999)	Contingent Valuation	US	Car (airbag): $1.026-2.727 million	Car (airbag): $0.8-2.1 million (1998 US$)
Beattie et al. (1998)	Contingent Valuation	UK	Road fatality: $8.395 - $18.872 million	Road fatality: £3.87 million - £8.7 million 1995 dollars.
Lanoie, Pedro and Latour (1995)	Contingent valuation	Can	Job safety: $31.384 -$38.516 million Cars safety: $2.240-$3.994 million	Job safety: $22 -$27 million Car safety: $1.57-$2.8 million (1986 C$)

Table 3.4 Recent Estimates of the VSL Based on Jury Awards and Government Decisions

Study	Study Type	Country	VSL (2002 C$)	VSL in Original Currency
Cohen and Miller (2003)	Jury Awards	US	$2.568-$5.135million	$1.9-$3.8 million (1995 US$)
Ashenfelter and Greenstone (2002)	Speed Limit Change	US	$2.0 million	$1.54 million with a range of $1.11 - $2.42 million (1997 US$)

Table 3.5 Recent Estimates of the VLS from Meta-Analyses and Summaries

Study	Study Type	Country	VSL (2002 C$)	VSL in Original Currency
Dionne and Lanoie (2004)	Summary	Intl/Canada	$5.102 million	$5.0 million (2002 C$)
Abelson (2003)	Summary	Intl/Aus	$2.201 million	$2.5 million (AU 2002 $)
de Blaeij, Florax, Rietveld, Verhoef (2003)	Meta-analysis	Intl	$10.234 million	$7.88 million (1997 US$)
Viscusi and Aldy (2003)	Meta-analysis	Intl	Intl: $6.189 - $7.675 million US: $6.808- $9.408 million	Intl: $5/0 - $6.2 million US: $5.5 - $7.6 million (2000 US$)
Mrozek and Taylor (2002)	Meta-Analysis	Intl	$2.564 million	$2 million (1998 US$)
Devousges, Johnson, and Banzhaf (1998)	Meta-analysis	US	$5.070 million	$3.6 million (1993 US$)

Table 3.6 Values of a statistical life used by U.S. Agencies, 1985-2002

Year	Agency	Regulation	VSL (2002 C$ millions)	VSL (2000 US$ millions)
1985	Federal Aviation Administration	Protective Breathing Equipment (50 Federal Register 41452)	1.24	1
1985	Environmental Protection Agency	Regulation of Fuels and Fuel Additives; Gasoline Lead Content (50 FR 9400)	2.10	1.7
1988	Federal Aviation Administration	Improved Survival Equipment for Inadvertent Water Landings (53 FR 24890)	1.86	1.5
1988	Environmental Protection Agency	Protection of Stratospheric Ozone (53 FR 30566)	5.94	4.8
1990	Federal Aviation Administration	Proposed Establishment of the Harlingen Airport Radar Service Area, TX (55 FR 32064)	2.48	2
1994	Food and Nutrition Service (USDA)	National School Lunch Program and School Breakfast Program (59 FR 30218)	2.10; 4.33	1.7, 3.5
1994	Technical Advisory T 7570.2 (1994)	U.S. Department of Transportation Federal Highway Administration	3.586	1994 US$ 2.6
1995	Consumer Product Safety Commission	Multiple Tube Mine and Shell Fireworks Devices (60 FR 34922)	6.93	5.6
1996	Food Safety Inspection Service (USDA)	Pathogen Reduction; Hazard Analysis and Critical Control Point Systems (61 FR 38806)	2.35	1.9
1996	Food and Drug Administration	Regulations Restricting the Sale and Distribution of Cigarettes and Smokeless Tobacco to protect Children and Adolescents (61 FR 44396)	3.34	2.7
1996	Federal Aviation Administration	Aircraft Flights Simulator Use in Pilot Training, Testing, and Checking and at Training Centers (61 FR 34508)	3.71	3
1996	Environmental Protection Agency	Requirements for Lead-Based Paint Activities in Target Housing and Child-Occupied Facilities (61 FR 45778)	7.80	6.3
1996	Food and Drug Administration	Medical Devices; Current Good Manufacturing Practice Final Rule; Quality System Regulation (61 FR 52602)	6.81	5.5
1997	Environmental Protection Agency	National Ambient Air Quality Standards for Ozone (62 FR 38856)	7.80	6.3
1999	Environmental Protection Agency	Radon in Drinking Water Health Risk Reduction and Cost Analysis (63 FR 9560)[96]	7.80	6.3
1999	Environmental Protection Agency	Control of Air Pollution from New Motor Vehicles; Tier 2 Motor Vehicle Emissions Standards and Gasoline Sulfur Control Requirements (65 FR 6698)	4.83; 7.80	3.9; 6.3
2000	Consumer Product	Portable Bed Rails; Advance Notice of	6.19	5

[96] See also U.S. Environmental Protection Agency (2000).

	Safety Commission	Proposed Rulemaking (65 FR 58968)		
2002	Office of the Secretary	U.S. Department of Transportation	3.63	2002 US$ 3.0

Source: Primarily Viscusi and Aldy (2003)

Table 3.7 Values of a Statistical Life Used in Non-US Jurisdictions

Source	**Year Of Valuation**	**Country**	**Agency**	**VSL (2002 C$ millions)**	**VSL (in millions of the original currency)**
BTRE (2002)	1999 2000	Australia	Department of Transport and Regional Services (Human Capital + Willingness to Pay)	1.170 0.306 1.476	AUS $1.2 + AUS $0.327 AUS $1.527
Albelson (2003)	2000	Australia	Commonwealth Bureau of Transport Economics	1.270	AUS$1.359
NSW Roads and Traffic Authority (2002)	2002	Australia	NSW Roads and Traffic Authority (Human Capital + Willingness to Pay)	1.109	AUS $0.862 + AUS $0.397 AUS $1.26
de Borger et al. (1996)	1996	Belgium	SSTC, Services Fédéraux des Affaires Scientifiques, Techniques et Culturelles	6.426	€ 4.453
DOT (1997)	1996	Britain	Department of Transport – Aviation	1.788	UK £ 0.84758
DOT (2002)	2001	Britain	Department of Transport – Road Safety	1.49	UK £0.783
Desaigues and Rabl	1995	France	Commissariat General du Plan	1.182	FF 5.5
Transport Canada (1994)	1991	Canada	Transport Canada	1.762	C$ 1.5
HLB (2002)	1994	Canada	Various levels of government	3.586	US$ 2.6
Chestnut et al. (1999)	1996	Canada	Environment Canada – For particulate matter	5.658 4.244 4.461	C$ 5.2 (under 65) C$ 3.9 (over 65) C$4.1 (average)
	1999	Canada	Health Canada[97]	4.565	C$ 4.3
Transport Canada (2002)	2001	Canada	Transport Canada – Rail Safety Consultative Committee	1.808	C$ 1.79
European Union (2001)	2000	EU	European Union		€ 0.9-3.5; Best = € 1.4
Miller and Guria (1991)	1990	New Zealand	Land Transport Division, Ministry of Transport.	2.0	NZ$ 2.0
Trawen et al. (2002)	1999	Norway	Public Roads Administration	2.184	NOK 15.919
Trawen et al. (2002)	1999	Sweden	SIKA – Swedish National Road Administration	1.759	SEK 13

97 Krupnick et al. (2002, 180).

Table 3.8 Key Sources to Determine the Appropriate Range of the VSL for Policy Purposes in Canada

Source	Estimated VSL (2002 C$ millions)	Comments
Krupnick et al. (2002)	$1.3-$4.0	Recent Canadian CVM; figures for 1 in 10,000 and 5 in 10,000 reduced risk
Mrozek and Taylor (2002)	$2.6 ($1.6-$3.4)	Recent meta-analysis of labour market studies, imposing "good practice" specifications
Boardman et al. (2001)	$3.1-$4.8	Relatively old policy estimate based primarily on Miller (1989,1990)
Miller (2000)	$3.4 ($2.8-$4.2)	Recent meta-analysis. Best policy estimate for Canada
U.S. Dept of Transportation	$3.6	For information purposes
Chestnut et al. (1999)	$4.1	Policy suggestions for Environment Canada
Dionne and Lanoie (2004)	$5.1($3-$7)	Policy estimate, based primarily on 7 "best" studies in transport sector
Viscusi and Aldy (2003)	$3.7-$7.4	Recent comprehensive study; this range is based on Canadian labour market studies

Table 3.9 VSL for Use in Canada Based on US Estimates of the VSL (in C$) and Adjusted for Income Differences between Canada and the US

	Estimated VSL for the US (2002 $C millions)								
Income Elasticity	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
0.50	0.93	1.85	2.78	3.70	4.63	5.55	6.48	7.40	8.33
0.75	0.89	1.78	2.66	3.55	4.44	5.33	6.21	7.10	7.99
1.00	0.85	1.70	2.55	3.40	4.25	5.10	5.95	6.80	7.65

Table: 3.10 US and Canadian Occupational Fatality Rates by Industry
(US: Per 100,000 Workers; CDN: Per 100,000 Worker Years)

		US, 1992-1995		US 2002	Alberta, 1991-2000
US Industry	**Canadian Industry**	**NIOSH (NTOF)**	**BLS (CFOI)**	**BLS (CFOI)**	**WCB**
Agriculture, Forestry, & Fisheries	Agriculture & Forestry	17	23.9	22.7	26.9
Mining	Mining & Petroleum Development	24.5	26.3	23.5	17.3
Construction	Construction & Construction Trade	12.8	13.4	12.2	24.4
Manufacturing	Manufacturing & Processing	3.6	3.8	3.1	8.8
Transportation & Utilities	Transportation, Communication & Utilities	10.4	10.6	11.3	23.2
Wholesale Trade	Retail & Wholesale Trade	3.5	5.4	4.0	3.7
Retail Trade		2.8	3.6	2.1	
Finance, Insurance, & Real Estate	Business, Personal, & Professional Services	1.1	1.5	1.0	2.3
Services		1.5	1.8	1.7	
Government	Public Admin., Education, & Health Services			2.7	3.1
Construction Labourers				27.7	
Truck Drivers				25.0	
Pilots and navigators				69.8	
Average (of the first nine occupations above)		**7.5**	**8.3**	**7.4**	**11.8**
Average (for all occupations)				**4.0**	

Source: Viscusi and Aldy (2003) for US rates

Source for US 2002: US Department of Labor, Bureau of Labor Statistics, Census of Fatal Occupational Injuries, 2002

Source:Workers' Compensation Board Alberta (http://www3.gov.ab.ca/hre/whs/fatalities/f_table4.asp)

NIOSH (NTOF):National Institute of Occupational Safety and Health-National Traumatic Occupational Fatalities

BLS (CFOI): Bureau of Labour Statistics – Census of Fatal Occupational Injuries

Table 3.11 Transportation Fatality Rates in Canada, 1980-2001

	Road	Road	Air	Rail	Marine	Marine
	Fatalities per 100,000 registered vehicles	Fatalities per 100,000 population[2]	Fatal accidents per 100,000 Hours	Fatalities per million train miles	Commercial Vessels Canadian Flag[1] Fatalities per 1000 vessel movements	Commercial Vessels Foreign Flag Fatalities per 1000 vessel movements
1980	40.0					
1981	38.9					
1982	29.1					
1983	28.8					
1984	28.6		1.78	1.60		
1985	29.5		1.20	1.70		
1986	26.5		2.05	1.57		
1987	27.1		1.64	1.39	5.83	3.64
1988	25.4		1.38	1.42	5.00	3.47
1989	25.4		1.61	1.95	6.68	4.44
1990	23.3		1.38	1.51	7.38	4.01
1991	22.4		1.94	1.67	6.99	3.82
1992	21.1		1.42	1.84	5.45	3.58
1993	21.6		1.38	1.52	4.60	3.58
1994	19.2	10.9	0.87	1.36	4.66	4.33
1995	19.7		1.37	1.55	4.69	2.92
1996	17.9		1.13	1.55	5.16	2.61
1997	17.5	9.6	0.92	1.39	3.39	1.81
1998	16.3		0.78	1.34	4.16	1.96

2000	16.0	9.8				
2001	16.0					

Source: Monash University (http://www.general.monash.edu.au/muarc/fatals/fatals.htm)
Source: Transportation Safety Board of Canada, TSB Statistical Summary of Railway Occurrences 1998
Source: Transportation Safety Board of Canada, TSB Statistical Summary of Aviation Occurrences 1998
Source: Transportation Safety Board of Canada, Statistical Summary, Marine Occurrences, 1998
Source: Transport Canada, Canadian Motor Vehicle Traffic Collisions Statistics (TP 3322)

1. Notes: All commercial vessels at Canadian ports, excluding fishing vessels and pleasure craft
2. Data for 1994 and 1997 from Dionne and Lanoie (2004) p. 255.

Table 3.12 Motor Vehicle Fatality Rates in the United States, 1975-2000

Year	Total Fatalities	Fatalities per 100,000 Population	Per 100,000 Licensed Drivers	Per 100,000 Registered Motor Vehicles	Per 100m VMT
1975	44525	20.62	34.31	35.29	3.4
1976	45523	20.88	33.96	34.81	3.2
1977	47878	21.74	34.66	35.59	3.3
1978	50331	22.61	35.74	35.85	3.3
1979	51093	22.70	35.66	35.40	3.3
1980	51091	22.48	35.16	34.79	3.3
1981	49301	21.49	33.52	33.01	3.2
1982	43945	18.97	29.25	29.07	2.8
1983	42589	18.22	27.59	27.69	2.6
1984	44257	18.77	28.48	27.85	2.6
1985	43825	18.42	27.94	26.39	2.5
1986	46087	19.19	28.90	27.34	2.5
1987	46390	19.15	28.67	26.85	2.4
1988	47087	19.26	28.91	26.53	2.3
1989	45582	18.47	27.53	25.16	2.2
1990	44599	17.88	26.70	24.20	2.1
1991	41508	16.46	24.56	22.27	1.9
1992	39250	15.39	22.67	21.22	1.7
1993	40150	15.58	23.19	21.32	1.7
1994	40716	15.64	23.21	21.15	1.7
1995	41817	15.91	23.68	21.22	1.7
1996	42065	15.86	23.43	20.86	1.7
1997	42013	15.69	22.99	20.64	1.6
1998	41501	15.36	22.44	19.95	1.6

1999	41717	15.30	22.29	19.61	1.6
2000	41821	14.86	21.94	19.27	1.5

Source: NHTSA Technical Report DOT HS 809 446

Table 3.13 Road Fatality Rates in the United States

		per 100,000 registered vehicles	**per 100 million VMT**
Passenger Car Occupants	2000	16.21	1.31
	2001	17.72	1.28
Light Truck Occupants	2000	15.13	1.22
	2001	14.78	1.2
Large Truck Occupants	2000	9.4	0.37
	2001	8.96	0.34
Motorcycle Occupants	2000	66.66	27.67
	2001	64.88	33.38

Source: National Highway Traffic Safety Administration (NHTSA) Traffic Safety Facts 2001 (http://www-nrd.nhtsa.dot.gov/pdf/nrd-30/NCSA/TSFAnn/TSF2001.pdf)

Table 3.14 Mean Risk and Risk Reductions used in VSL Studies

	Study	Study Type	Country	Mean Risks	VSL (2002 C$)
1.	Viscusi and Aldy (2003)	Meta-analysis	Intl	0.0002196	Intl: $6.189 - $7.675 million US: $6.808- $9.408 million
2.	Krupnick, Alberini, Cropper, Simon, O'Brien, Goeree, Heintzelman (2002)	Contingent Valuation	Can	Risk Reduction by 5 in 10,000 and 1 in 10,000 (respectively)	$1.274-$4.034 million
3.	Jenkins, Owens, and Wiggins (2001)	Consumer Market	US	Fatality Rates for Petal Cycle US 1997 Ages 5-9: 0.00000652 10-14: 0.00001035 20-59: 0.00001189 Reduction of Risk by: Ages 5-9: 0.00000441 10-14: 0.00000615 20-59: 0.00000549	Bicycles: ages 5-9: $3.506 million, ages 10-14: $3.377 million, ages 20-59: $5.195million
4.	Mrozek and Taylor (2002)	Meta-Analysis	Intl	0.000181	$2.564 million
5.	Arabsheibani and Marin (2000)	Wage-Risk	UK	0.00005	$33.333 million
6.	Hammitt and Graham (1999)	Contingent Valuation	US	Risk Reduction from 25 to 10 and 20 to 15 per 100,000 (respectively)	Car (airbag): $1.026-2.727 million
7.	Beattie et al. (1998)	Contingent Valuation	UK	Risk Reductions from 60 to45 and 60 to 55 in 1,000,000 (respectively)	Road fatality: $8.395 - $18.872 million
8.	Devousges, Johnson, and Banzhaf (1998)	Meta-analysis	US	0.0003299 (mean of fatality rates from studies used in meta-analyses)	$5.070 million
9.	Dorman and Hagstrom (1998)	Wage-Risk	US	0.000123-0.0001639	$10.767 - $25.124 million
10.	Miller, Mulvey and Norris (1997)	Wage-Risks	Aus	0.000068	$11.841 - $20.452 million
11.	Sandy and Elliot (1996)	Wage-Risk	UK	At work risk: 0.0000446 All cause risk:0.0008339	Non-Union: at work risk $116.409, all cause risk $0.890 Union: at work risk $115.842, all cause risk $0.405
12.	Dreyfuss and Viscusi (1995)	Consumer Market	US	0.0001962	Car: $4.290 - $6.11 million
13.	Lanoie, Pedro and Latour (1995)	Contingent valuation, Wage-Risk	Can	Wage-Risk: 0.000126 CVM: average fatality rate 0.9/10,000 for Quebec workers	RP: $24.679 - $27.389 million-Job Safety CVM: $31.384 -$38.516 million -Job Safety Cars:(CVM: $2.240-$3.994 million -Car Safety)
14.	Siebert and Wei (1994)	Wage-Risk	UK	0.0000379	$22.680 million (union) $18.557 million (nonunion)

Table 3.15 Mrozek and Taylor's (2002) Estimates of the Value of Statistical Life

Risk (x 10^{-5})	VSL (2002 C$ millions)
2.5	$1.628
5.0	2.115
10.0	3.026
15.0	3.436
20.0	3.103

Source: Mrozek and Taylor (2002). Based on BLS risk data, Model (4), Table 3, p. 268.

Chapter 4: Cost of Accidents

4.1 Introduction

This chapter focuses on the costs of accidents, sometimes referred to as the costs of crashes (the terms are used interchangeably here, although the literature has moved towards using the latter term as the word "accident" implies absence of fault with is not the case in many crashes). It builds on the previous chapter which focused specifically on the valuation of loss of life. The VSL is relevant to many aspects of transportation and impacts the cost of pollution as well as the cost of accidents. This chapter combines the VSL estimate with other components to give guidance on measuring the overall costs of transportation accidents.

Conceptually, one way to compute the cost of an accident is to sum the cost of its component parts: the number of deaths x the VSL, the number of injuries x the cost of an injury, plus numerous other costs. These other costs include property damage costs, time delay costs from congestion at accident sites, environmental (product release) costs, clean-up costs, and investigation costs. Our basic approach is to estimate these individual costs and sum them.

In practice, caution is needed when adding up the component costs due to the possibility of double counting. For example, some estimates of cost of injury include property damage and time delay. In particular, willingness to pay (WTP) estimates from contingent valuation method (CVM) studies may reflect multiple dimensions or components of costs (English et al., 2000). It is also difficult to disentangle the various internal and external costs associated with different transportation modes under various insurance systems and infrastructure settings.

Section 4.2 discusses the usual methods employed to estimate the cost of accidents. Basically, the cost of an accident is the sum of various component parts. One component is the VSL which is discussed in Chapter 3. Other components are the value of a life year (VOLY) and the cost of injuries, which are discussed in Section 4.3 and Section 4.4, respectively. Both of these estimates are needed as inputs to the various subsequent sections that focus on cost of accidents for different modes. Section 4.5 discusses private versus social costs: the main issue concerns who bears the cost of injuries - the private user of transportation modes or society at large. Sections 4.6 through 4.9 provide estimates of the cost of road vehicle crashes, the cost of rail accidents, the cost of aviation accidents, and the cost of marine accidents, respectively. For each mode, we review the relevant research that has been conducted regarding accident costs for that particular mode and then discuss cost estimates used by government. We then present our "best" estimates of the cost of an accident for a particular mode, stated as a cost per unit (km, trip, or hour of flight). This information can be combined with accident rates to calculate the internal cost per accident. External costs that can be identified are discussed last. Section 4.10 offers areas for further research and Section 4.11 concludes this chapter with a summary table.

Estimating the cost of accidents is not as interesting to academics as estimating the VSL or the social cost of pollution. In practice, computing the cost of an accident is mainly a matter of adding up different cost components. It does not require developing new theory or sophisticated econometric methodology (hedonic regressions, discrete choice methods of analysis or computing dose-response functions). Not surprisingly, most academic papers on the cost of accidents stem from contracts funded by governments. The lack of independently investigated research has limited both the quantity of studies and the variation in methodologies employed. Academic research into new and novel methods for estimating the costs and economic impacts of injuries and accidents is lacking. Also, investigation into the more theoretical aspects of measuring the impacts of injury on productivity is far from sufficient. Most of the research on accidents pertains to roads. Despite exhaustive searching, we have found little research in the marine area. The main implication of this is that despite our best efforts, there is considerable uncertainty surrounding our recommendations.

The cost of accidents should include both ex ante costs (including prevention) and ex post costs (including clean-up). A major ex ante cost is slowing down to reduce the probability of an accident. Consistent with other studies, this cost is not included in our analysis of the cost of accidents. The valuation of travel time savings is the subject of chapter 2.[98] Still, it is important to remember that by excluding such costs we are in fact underestimating the total cost of an accident.

4.2 Methods for Estimating the Cost of Accidents

The usual method of computing the cost of an accident is to sum of various components. These components can be categorized into three groups: direct costs, indirect costs, and intangible costs; see Table 4.2 (Goodchild et al., 2002). Direct costs pertain to property damage and other accident costs (police and fire service), medical costs (including emergency, hospital, rehabilitation and counseling), legal costs (including criminal prosecution and insurance claim costs) and administrative costs (household help and insurance administration). Indirect costs include productivity losses, other associated work related costs, and costs imposed on family members. These include absenteeism and worker substitution costs for both the injured and their family members, productivity losses through reduced participation and ability/throughput, and tax losses. Intangible costs include loss of quality of life and pain and suffering. Total costs of accidents should be comprehensive and cover both the private costs to individuals and those costs that are accrued to society at large. To capture all of these costs in a comprehensive manner is in and of itself expensive and time consuming.

[98] That chapter does not explicitly estimate the amounts of delays associated with accidents. But the cost of congestion delays may incorporate some costs of accidents; motorists slow down in congested conditions to reduce the probability of accidents. This is a preventive consumption of time which could either be part of congestion costs or categorised as part of accident costs.

Different methods are used for estimating different components. Human capital approaches are used for productivity losses. Contingent valuation, wage risk studies, jury awards, time trade off studies and consumer market studies are used to measure the intangibles.

4.2.1 Direct Costs

Direct costs can be considered those costs related to the occurrence of an accident. This broad category includes accident costs, which pertain to property damage to vehicles and buildings. Accident costs can be substantial in the event of an accident that has environmental or long term/downstream impacts. Police costs generally fit under accident costs. Direct medical costs arise from expenditures on goods and services relating to the medical care of patients. They include payments for detection, transportation (including ambulance), treatment and rehabilitation. Capital investment in hospitals and buildings is included to represent the opportunity costs of forgone expenditure in other areas of the general economy. In practice, medical prices often do not represent the true economic value of these goods and services. Non-medical care may include such costs as informal care, household help, vocational counseling, and costs of insurance administration, and legal and court services.

Direct costs can be measured from a "top down" approach, which is easier to collect without detailed data sources, or from a "bottom up" approach, which allows comparisons at a detailed level of aggregation. The top down method is also known as the prevalence method with direct costs allocated as that proportion of the total expenditures that accrue to certain sub populations of the group of interest. Usually these prevalence measures are tallied across a consistent indicator and generate an estimate of an average as opposed to a marginal cost. An incidence approach is a bottom up approach based on the resource costs related to a well-defined population at a fine level of aggregation. Unfortunately this requires a fine level of detail in any data sources used. The incidence method is less likely to minimize distortions caused by the aggregation of data, particularly when substantial gaps may exist between marginal and average costs.

4.2.2 Indirect Costs

These costs are generally the output losses that result from an injury event, including morbidity and mortality. Morbidity losses result from changes in the productivity of workers at their jobsites and the amount of participation in the workforce that they undertake following an injury, including unwanted job changes and altered opportunities for further advancement and education. The size of these losses generally relate to the functional impairment that arises from the injury over the short, medium and long term horizon. However there is debate regarding the level of functional impairment of the individual after an injury and the impact of this on the output of firms and subsequent total economic output. Absenteeism of injured employees or family members who are providing home care is also included in indirect costs. Loss of home productivity is difficult to measure and is often excluded from studies that focus on injury costs. The ability of substitute workers to provide output at a similar level to the injured worker is also debatable.

These costs are dependent on the link between the injured person, their workforce participation and other factors. Three methods are commonly considered for valuing the indirect costs of injuries: the Human Capital Method, the Whole Economy Cost of Human Capital Method, and the Friction Cost Method.

The human capital method equates the production lost that results from an injury to a contributing member of the economy, including lost productive life years due to fatality, discounted to a present value. This method assumes that the loss of productivity reduces both current and future potential production. The Human Capital method assumes that earnings reflect productivity, and that each worker receives the value of output added by the last hired (at the margin) worker. Criticism includes the undervaluation of productivity by the unemployed, elderly and children and that earnings for some groups are not representative of the relative value of their marginal product. The human capital approach has been expanded by Landefeld and Sekin (1982) to accommodate these criticisms, by including non-labour income and a multiplication for a risk factor but these methods still are ineffective in measuring the intangible costs of injuries.

The Whole Economy Cost of Human Capital method assumes that the human capital approach is accurate, but assumes that the lost future production of the injured individual has a multiplicative effect in the wider economy, with the impact on the productivity of the whole economy being larger than the lost productivity of the individual worker. The immobility of workers and the loss of some productive members due to injury would lead to increases in wages, and is then measured in general equilibrium terms. We do not recommend use of this method.

The Friction Cost method assumes that labour is highly mobile, and that the human capital measure overestimates the indirect costs because human capital captures the potential productivity losses not the actual productivity outcomes. This method assumes that over the long term unemployed workers substitute for the injured workers, although in some cases this may take a long period in those cases of highly skilled workers. Friction training costs tend to be large, and this method does not preclude large indirect costs measures.

4.2.3 Intangible Costs

Intangible costs are the most contentious costs to estimate. Economic theory suggests that individuals are willing to pay to reduce their risk of injury. However measurement of the WTP for a wide variety of injuries in a wide variety of settings is very difficult. Disagreement exists on the validity of different methods for estimating these costs, but disregarding these costs results in misallocation of resources. Using a human capital cost method rather that a WTP method one would under-estimate total costs. Excluding “pain and suffering" can lead to decisions that suggest it is preferable to be dead over being held up in traffic.

The Hedonic Regression Method and Contingent Valuation Method (CVM) are accepted ways to capture preferences and can measure total costs or intangible costs alone. CVM methods can be used to measure the WTP for health status indices such as QALYs and Disability Adjusted Life Years (DALYs). In general, CVM methods are highly variable in their results due to the flexible nature of the instrument.[99] Other methods include the use of court awards as a proxy for preferences, assuming that they represent the collective view of the intangible costs of injuries and the use of administrative compensations which are determined by regulatory bodies.

Hybrid measures, which combine CVM methodologies with human capital approaches, are also being employed. This is the general method of Miller (1993), where he estimates WTP measures from which he subtracts the human capital component to build decomposed total cost estimates. This is the area where the issue of double counting becomes highlighted, as it is often difficult to compare across study results or to transform another author's information to a new use. There can be potentially large amounts of overlap between the WTP estimates from the CVM study and other costs.

4.3 The Value of a Life Year

A VOLY is taken to be a constant annual sum which, taken over a remaining life-span, has a discounted value equal to the estimated VSL. Put another way, researchers think about the VSL as the discounted value of the remaining life years of the average member of society. Thus, assuming the value of a life year (VOLY) is constant, it can be computed from an estimate of the VSL:

$$VOLY = \frac{VSL}{A(n,r)}$$

where A(n,r) is the annuity factor based on the expected number of remaining years of life (n) and the appropriate discount rate (r). For example, Abelson (2003) suggests the VOLY for use in public policy in Australia equals 2002 C$ 95,070 (implied by a VSL of 2002 C$ 2.201 million, 40 years of life lost and a discount rate of 3%). Abelson (2003)

[99] For more discussion on the hedonic regression method and the CVM see Chapter 2. Designed to measure preferences ex ante, the basic criticism of CVM is the lack of understanding of the actual costs or probabilities involved. Willingness to Accept measures, which look at the amount required to compensate an individual for an increased risk generally show ranges of values 3 – 5 times larger for similar levels of change in risk as compared to WTP (Leung and Guria, 2000). Again CVM is commonly employed as are compensating wage differential studies. Here as in the VSL, compensating wage differentials studies have limitations due to imperfect information as to work place risk, limitations in changing jobs, union influence and truncation bias. Consumer behaviour studies also exist which look at reduction of risk through the purchase of safety enhancing equipment, such as bicycle helmets. Time trade off studies also help to develop models that show the implied cost to individuals that is averted by the use of safety enhancing features, such as seatbelts.

argues that this estimate provides a plausible and consistent basis for valuing life-years and states of health.

Blomquist, Miller and Levy (1996) estimate the VOLY in a study on the implied VSL based on the time required to use seat belts, child restraints, and motorcycle helmets. Their findings for the implied VSL range between USD$ 1.3 million for the use of helmets and USD$ 5.1 million for child restraints. These findings reflect a valuation of the lives of children above that of the lives of parents. When conducting further examination of their findings, the authors compare the effect of remaining life years on VSL. When they control for differing life spans, the difference is reduced. By dividing the VSL for each outcome by the remaining life years (assumed as 73.8 for children and 42.6 for adults) without discounting the VOLY for adults was USD$ 52,000, which was roughly the mid point of the range of VOLY for children, which was between USD$ 39,000 and USD$ 70,000. When discounting of future life years was also introduced the VOLY difference disappears at a discount rate of 2.5%, a rate likely to be below that normally applied in valuing future life years, which can be seen in Table 4.1.

If one assumes that a VOLY is constant and then computes age-adjusted VSLs as the discounted value of future life years, then one will obtain estimates of the VSL that decline with age.[100] However, is the VSL less for an elderly person? Certainly there is some evidence in the behavior of parents when they purchase safety equipment for their children, as evidenced by Blomquist, Miller and Levy (1996). But there is also evidence of similar increased valuation for other members of an immediate family (Miller and Guria, 1991). It is difficult to justify the claim that the elderly have a lower VSL than any other age group.

This issue was examined by Krupnik et al. (2002) and Alberini et al. (2002) in two related studies that examined the impact of age on VSL in both Canada and the United States. Krupnik et al. (2002) surveyed 930 Ontarians between the ages of 40 and 75 years to determine if there was any variation in their willingness to pay to reduce mortality risk, using CVM technique, supported by audio-visual aides to increase risk comprehension and testing for misunderstanding about the probabilities tested. When excluding those persons who did not understand the probabilities correctly and risk takers, they found that the VSL for all remaining subjects was 2002 C$ 1.274 million for a 5 in 10,000 reduction in risk and 2002 C$ 3.8 million for a 1 in 10,000 risk reduction. When they examined more closely for systematic differences due to age and health status, they found that their values were relatively stable for that portion of the study cohort that was between 40 and 65 years of age, while after 70 years of age the VSL drops by roughly one third. Their study did not find a significant difference in WTP based on health status alone, but they did find that the WTP for those persons with prior cancer diagnosis were 60% higher than persons without, and that lower mental health scores correspond with lower WTP estimates.

---

[100] For example, $VSL(a) = \sum_{1}^{T-a} \frac{VOLY}{(1+r)^t}$, where a is current age, T is expected age of death and T-a is life expectancy.

Alberini et al. (2002) was a sister study to that of Krupnik et al. (2002) and presents findings for an American cohort, following the same study protocol. The major study difference was that the Krupnik study required participants to attend at a central testing location (reducing responses by the more health challenged) while the American cohort was surveyed in their homes, allowing for inclusion of individuals of more varied health levels. A second difference is that the American cohort included more visible minorities. Alberini et al. suggest that this underlies a larger baseline mortality risk in the American cohort. The Canadian cohort's underlying risk was 123 per 1,000 while the American cohort's risk was 187 per 1,000. Lastly the sample size was larger by 270 persons in the American cohort. The main findings are similar to the Canadian findings with regards to the magnitude of the WTP. Because WTP is not proportional to the size of the risk faced, the VSL found for a 1/10,000 reduction is larger than the VSL found for a larger risk reduction. They also found that health status as measured by the Short Form (SF)-36[101] did not have a significant impact on the VSL. However there are some differences found. In both, higher incomes lead to increased WTP but the effect of increased income in America is statistically significant. Conversely the American study found that the effect of ageing on the VSL was not significant. For the chronic conditions such as high blood pressure, or chronic heart and lung disease WTP is significantly larger for the American cohort, a finding not corroborated by the Canadian study. Most importantly the American study found no impact of age on the VSL, where the Canadian Study had found a statistically significant difference.

These mixed findings do not totally clarify the concern for the practice of discounting future life years, but they offer some support to the use of unadjusted statistical life values in policy by some groups such as the EPA.

In practice, Health Canada uses Quality Adjusted Life Years (QALYs) in health and safety cost benefit analyses. In perfect health the QALY is equal to one, and in death the QALY is equal to zero. QALYs help to compare the benefits to health interventions by assessing their cost based on a common unit, the life year saved. It is easy to understand that all life years are not lived with the same vigor or ability and therefore there has been extensive research conducted to develop weighting systems for various health outcomes. Utility weights differ depending upon whose preferences are measured. The preferences of the general population may differ substantially from the preferences of a particular group who share a common ailment. QALYs represent the difference in weighted health in each year of life that is above that which would have been held if no intervention had taken place. Over a life time the total number of QALY gained from an intervention is

---

[101] The SF-36 (Ware et.al., 1993) is one of several well known general health profile questionnaires and has been widely accepted to be both reliable and vilid in measuring changes in the health status of respondents. Not specifically designed as a measure of utility associated with particular health states, it is useful as supplimental information to economic analysis of health states. The scoring of this instrument, although not based on individual preferences for specific outcomes, now form the basis for the SF-6D (Brazier et. al., 1998 and 2001), a singel unit preference based index of health. The SF-6D index reconsiles the Quality Adjusted Life Year (QALY) approach and the general health profile. The primary benefit to the SF-36 health profile and it's utility index conversion, the SF-6D, is that it provides consistency in measureing between helath interventions due to the wide use of the SF-36 in clinical research.

usually calculated as the discounted sum of QALY's gained in each year of life past the time that the intervention takes place.[102]

4.4 The Cost of Injuries

Nonfatal injuries are the largest component of accident costs. Indeed, it is almost correct to say:

Cost of Accident = Cost of Injuries + Property damage

Consequently it is important that we take time to focus on the cost of injury as a stand alone topic.

Nonfatal injuries are measured in a number of different ways. Many studies simply distinguish between minor and serious injuries. The Association for the Advancement of Automotive Medicine has developed a 6-point scale, called the Abbreviated Injury Scale (AIS), which focuses on the survival threats posed by an injury. It ranks the severity of a nonfatal injury from 1, for a minor injury, to 6, for an injury that is ultimately fatal.[103] Table 4.3 shows the six levels of AIS classification with representative injury states for each level of risk for non-failure to survive.

The International Civil Aviation Organization (ICAO) uses a scale with two classifications: minor injuries (ICAO level 1) which are equivalent to AIS level 1 only and serious injuries (ICAO level 2) which are equivalent to AIS levels 2 through 6.

4.4.1 Academic Studies of the Cost of Injury

Dillingham, Miller and Levy's (1996) wage-risk study implies a WTP of between 2002 C$ 159,502 and 2002 C$ 247,856 to avoid one impaired work-year, although in Dorman and Hagstrom's (1998) and Siebert and Wei's (1994) wage-risk studies, the estimated coefficient on non-fatal risk is statistically insignificant. Dillingham et al. (1996) mention that some problems arise in trying to incorporate the multiplicity and severity of different non-fatal risks. The choice of categories of risk might be arbitrary. The likelihood or severity of one category of risk may not be representative for a person in a specific occupation or industry. The different measures of risk tend to be collinear, that is, it is difficult to untangle the true relationship between each independent variable and the dependent variable. In some studies injuries are not measured in terms that can be applied

[102] There is a possibility that to discount QALY scores is to double count, particularly if the preference weight was assessed by a time trade off technique. For a discussion of the issues related to QALYs see Chapter 6 in Drummond et al. (1997).

[103] The Abbreviated Injury Scale (AIS) is an anatomically based system that classifies individual injuries by body region on a six point scale of risk to life. The AIS does not assess the combined effects of multiple injuries. The Maximum AIS (MAIS) is the highest single AIS code for an occupant with multiple injuries. http://www.nhtsa.dot.gov/cars/rules/rulings/UpgradeTireEcon/tireupgrageVII.html

to other markets. Hence, empirical results are of limited use. However, because, in the study, expected impaired years can be applied to non-work related injuries, comparable estimates of WTP for safety can be derived for other markets. There are several limitations of this study. First, the estimation does not include an adjustment for the *ex post* compensation of injury costs through public or private transfers. Second, a work life shortened by a fatal injury was assumed to be equivalent to one shortened by a permanent and total, but non-fatal, disability. Third, the individual may self-select into an occupation and the level of risk. Fourth, the discount rate may be not appropriate. Finally, results were obtained using a unique set of injury risk data.

Lanoie, Pedro, and Latour's (1995) Canadian wage-risk study implies a value of a statistical injury of 2002 C$ 10,084. Attempting to estimate jointly the effects of non-fatal and fatal risk on workers' wages may not result in a significant effect on one of the risks since they are likely to be highly correlated and result in large standard errors. Estimating the risks independently of each other however, could result in an upwardly biased estimate (Viscusi and Aldy, 2003).

Blomquist, Miller and Levy's (1996) paper on VSL implied by time costs also includes estimates of the value of moderate to serious non-fatal injury. Their paper intends to derive values of reducing the risks of fatal and non-fatal injuries for different road users. The use data from the US Department of Transportation's Federal Highway Administration (FHWA) (1985) Nationwide Personal Transportation Study (NPTS) and the Census of Population and Housing Public Use (1980), and they use values of personal loss from the net benefit equations of Blomquist (1991). Variables included in the estimations are: family income, number of children under 16, number of licensed drivers in the household, years of schooling, motorist age, child age, miles driven in the last year, use cost, vehicle weight, vehicle age, and dummy variables for marital status, vehicle-air-bag equipped, vehicle-passive-belt equipped and vehicle-combined-belt equipped. The mean value of a non-fatal injury (from moderate to serious) implied by seat belt use is 2002 C$ 183,000, the value of reduction in non-fatal risk implied by child safety equipment is 2002 C$ 134,000, and the value of reduction in non-fatal risk implied by motorcycle helmet use is 2002 C$ 62,000.

Schwab Christie (1995) performs a CVM survey to determine the costs of road accidents in Switzerland. The goal of the study was to value explicitly the costs of road accidents in human terms and to provide separate estimates of the human costs to the victims on the one hand and to their relatives on the other. Respondents were asked how much they were willing to pay to reduce their own or a relative's risk of becoming victim of a road accident by 50%, across a range of injury severity. The severity of non-fatal injury ranged from no hospitalization, which involved some discomfort and sporadic pain for weeks, to an extended stay in the hospital where mental faculties were significantly and permanently reduced. To reduce their own risk by 50%, the respondents were willing to pay $ 431 per year for the least severe injury to $ 980 for the most severe non-fatal injury. To reduce a relative's risk by 50% the respondents were willing to pay $ 751 per year for the least severe injury to $ 1,399 for the most sever non-fatal injury. Kidholm (1995) presents results from a CVM survey of traffic safety in Denmark. Respondents were asked their WTP for risk reductions of 30% of a slight, serious and very serious injury (fractured wrist, fractured shin, and open fracture of the femoral bone respectively). The mean annual WTP for the 30% risk reductions were 2002 C$ 184 to 2002 C$ 260 for a slight injury, 2002 C$ 247 to 2002 C$ 348 for a serious injury, and 2002 C$ 328 to 2002 C$ 482 for a very serious injury.

4.4.2 Other Estimates of the Cost of Injury

Various Canadian bodies have set a value for the cost of an injury to be used in evaluating policy decisions. Lawson (1989) provides an overview of these injury valuations. Valuation of road accident costs in 1989 were 1989 C$ 3,600 for an injury of an unspecified severity (presumably an average injury), significantly smaller than the value used for a minor injury in aviation projects. Minor injuries were valued at 1989 C$ 18,000 and major injuries at 1989 C$ 47,000. The Economic Evaluation Branch used a figure closer to those for aviation at 1989 C$ 25,000 for a minor injury and 1989 C$ 66,000 for a serious injury.

Table 4.14 shows the emergency/medical costs and legal costs for injuries of different levels of severity (OST, 1993). It does not include willingness to pay estimates. WTP amounts should be added to obtain comprehensive injury cost estimates.

Table 4.4 shows the WTP costs, emergency and medical costs, legal costs and total costs of injuries incurred in the air. These figures are estimated by Hoffer et al. (1998) in a report for the Federal Aviation Administration (FAA, 1998). They represent the aggregated willingness to pay to avoid single or multiple, minor or major injuries, plus the average per injury victim emergency/medical and legal/court costs, and are based on the accepted methodology of Miller in assigning WTP for injury avoidance values as fractions of WTP to avoid a fatality. Here seriously injured persons are typically injured at AIS level 2 or higher, and minor injuries are incurred at a level of AIS 1 only. In 2002 Canadian dollars, the estimates are 2002 C$ 51,937 for a minor injury, and 2002 C$ 703,753 for a serious injury.

Miller (1993) developed a comprehensive analysis of non fatal police reported motor vehicle crashes to estimate the cost of injury from road accidents for the 5 AIS severity levels below fatal. In this analysis he gathered monetary costs from a variety of sources and added to this an estimation of quality of life lost (QOL) to create comprehensive costs. The technique employed for developing the QOL losses is based on a conversion from average health ratings by physicians to an estimation of years of functional capacity lost due to injury. This calculation involved multiplying the value of fatal risk reduction times the ratio of years of functional capacity at risk between fatal and injury level of interest. From this was subtracted the monetary component of this estimate, in order to avoid double counting. Functional capacity loss was defined as impairment along any of seven health dimensions: mobility, cognitive, self care, sensory, cosmetic, pain and ability to perform household responsibilities or wage work. Years at risk of different injuries were calculated by estimating the utility loss caused by impairment as rated by a physician, weighting the percentage contribution of each impairment to create a single value for each severity level. The years lost were computed from standard life tables as the percentage of lost time due to impairment times the expected life years remaining. Each additional injury of MAIS 2 or greater was treated as a further reduction of life years at risk after calculation of the first or most significant injury reported. MAIS 1 level injuries were only considered as a single loss of utility.

To value injuries at a particular severity, Miller (1993) used a fraction of the WTP to avoid a fatality to represent the WTP to avoid an injury of a particular severity. He discusses his method in depth. It is somewhat arbitrary, but has been widely accepted and we are not aware of a superior method.

Miller reports the monetary cost of all injuries as 2002 C$ 15,736, and the comprehensive costs as 2002 C$ 65,850. The values for the various MAIS injury levels are included in Table 4.5.

Miller suggests that a possible conversion of his findings for individual country differences can be attained by multiplying their reported values for lost wages, household production and quality of life times the ratio of the per capita income in the country of interest and the United States. This would potentially allow the development of comprehensive costs in individual countries, using their country specific values for emergency and medical costs, insurance and administration costs, and legal and court costs. All of these costs may vary significantly between countries, depending on the structure of insurance industries for both transportation and health care. Miller's method for estimating Quality of Life losses has been widely accepted, but has opponents due to its basis outside strong economic theory. There is little in theory to link functional years lost to total losses in the economy as outlined in Section 4.2 on methods of estimating costs of injuries.

Dionne et al. (1999) examined the economic impact of driving standards on costs incurred in the trucking industry. In estimating the social cost of traffic accidents he utilizes the VSL of 2002 C$ 1.74 million as presented by Lawson (1992). The authors also estimate the cost of an injury in their analysis. They chose to convert a monetary value utilized by the S.A.A.Q., Quebec's public automobile insurer for bodily injuries. The S.A.A.Q. calculates the monetary value of a fatality as 2002 C$ 442,575 and an injury as 2002 C$ 23,492. Dionne et al. use a value of 2002 C$ 92,807 for any injury regardless of severity level, calculated as the monetary cost of injury times the VSL and divided by the lost production due to fatality (20,250 x 1.5 million / 381,500)/0.862).

4.4.3 Our Estimates of the Cost of Injury for Canada

Table 4.5 lists those academic studies on the value of an injury that we feel are potentially applicable for use in the Canadian context for use in estimating the costs of accidents. It summarizes Table 4.5A and includes a weighted average ("All Level") cost of an injury. Minor injuries account for 84% of injuries and serious injuries account for

16%, based on Miller (1993). These estimates range considerably from 2002 C$ 5,848, which is based on a human capital approach, to 2002 C$ 203,679 for a wage risk approach. The median value of these estimates is 2002 C$ 60,891, which is between the estimate of Miller (1993) and the relatively high human capital / accounting valuation of the BTE (2000). The BTE study is based on a relatively unchallenged methodology and is very thorough in the cost elements included. Miller (1993) also presents a very comprehensive cost estimate of the economic resources that go into an injury, and includes some component for the intangible cost of pain and suffering.

For the purposes of this report Miller's (1993) estimates have been used as the base costs for injuries incurred in transportation accidents. These costs are not adopted without some misgivings, particularly the concern over Miller's method of allocating proportions of the VSL to the various injury categories. Secondly there is some evidence that earlier estimates of the components of Miller's comprehensive costs may be overstated, particularly the component attributed to medical care. Zaloshnja et al. (2004) have shown that medical costs may be overestimated by as much as 9%, and that they represent roughly 14% of total comprehensive costs. Other considerations are that US medical costs take up a larger component of GDP than do Canadian medical costs, roughly 14% of GDP for the US in 2000 and 10% of GDP for Canada in 2000.[104] This is also likely to be the case for US legal costs. Considering these problems with adopting Miller's (1993) estimates to Canada, there is a relatively high degree of uncertainty in the best estimate of the cost of an injury in Canada given here.

However, the cost estimates of Miller (1993) are very comprehensive in their scope and due care has been taken to potential double counting. Furthermore, we adjust these numbers reflecting the Canadian environment. Until the methodological issues surrounding Miller's method of allocating WTP to the various injury categories can be improved upon, his estimates are best suited to the task at hand.

Miller's estimates of 2002 C$ 9,200 for a minor injury and 2002 C$ 370,006 for a serious injury can be adjusted by the method proposed by Miller (1993) which uses the relative income ratio of Canada to the United States. Using a ratio of 0.85, which was derived in Chapter 2, yields estimates of the cost of injury of 2002 C$ 7,820 for a minor injury and 2002 C$ 314,505 for a serious injury. Implicitly, Miller uses an income elasticity of 1.0. Reducing Miller's estimates further by adjusting for the overestimated 14 % of medical costs by the per capita health care cost ratio of 0.56 between Canada and the US lowers these base cost estimates further. This results in a cost for a serious injury of 2002 C$ 295,131.[105]

[104] OECD reports the percent of GDP spent on health expenditures in 1998 to be 9.3 % in Canada and 12.9 % for the United States. In 2002 total expenditures on health per capita is reported by the OECD as 2002 C$ 3501 for Canada and 2002 C$ 6293 for the US a ratio of roughly 0.56 CAN/US

[105] $370,006 * .85 = $314,505 adjusts for PPP of 0.85 CAN/US
$314,505 – (314505*.14)(1-0.56) = $295,131 adjusts for the 14% of medical costs adjusted for a CAN/US health cost ratio of 0.56.

Miller's (1993) methodology employs a VSL of 1988 US$ 2.27 million (2002 C$ 3.747 million). Using the VSL for Canada proposed in Section 2 yields estimates of the cost of injury of 2002 C$ 10,133 for a minor injury and 2002 C$ 414,817 for a serious injury. Multiplying these estimates by 0.85 yields estimates of the cost of injury of 2002 C$ 8,613 for a minor injury and 2002 C$ 352,594 for a serious injury. If we used an income elasticity of 0.5, then the estimated costs would be higher: 2002 C$ 9,373 for a minor injury and 2002 C$ 383,706 for a serious injury. Once adjusted for the higher cost of US health care the lower boundary of the cost of a serious injury can be expected to be 2002 C$ 330,875. *For the purposes of this report all stated costs of accidents are calculated with the cost of a serious injury at 2002 C$ 330,875 and the cost of a fatality at 2002 C$ 4.25 million.*

4.5 Social and Private Costs

The cost of accidents incorporates several components. Some of them are private and are borne by the user of transportation and some of them are not and are borne by the rest of society. Costs not borne by the user are referred to as externalities or as uncompensated externalities.

As discussed in Chapter 1, DeSerpa is attributed with identifying an externality, a cost borne by the rest of society rather than the user, as "a relevant cost or benefit that individuals fail to consider when making rational decisions." An efficient market assumes the user of transportation bears the costs that they impose on society, including the crash cost externalities.

Delucchi (2000) presents the allocation of accident crash costs in Table 4.6, showing monetary and non-monetary costs, and private and social costs. The social costs include lost productivity, vehicle replacement and repair costs, property damage, the social value of life, pain and suffering and medical costs. However a large portion of these costs are internalized to the user through insurance premiums and are not considered externalities. By assuming that the risks associated with each possible mode of transportation are known to the users—and that the user accepts those risks when s/he begins his/her journey, whatever mode is ultimately chosen—it can be argued that productivity losses, and the pain and suffering of the users and their families are also not externalities. There is some question whether the families are any more or less informed of the risks that exist, and whether the family have any input into the choice of mode taken by the user.

Accidents and crashes are one by-product of transportation among those other considered in the larger paper to which this is but one chapter (i.e., congestion, pollution etc.). These accidents and crashes result in injuries, from minor to fatal, and property damages, from unreported to massive in the case of a high level environmental hazard due to a train derailment in an urban centre. Externalities will arise from transportation when the total of the accident costs is not covered by insurance premiums paid for a quantity of insurance coverage that is sufficient to compensate fully for the accidental outcome.

What component of uncompensated costs of accidents that remain as external costs may depend on the nature of regulation and insurance in individual jurisdictions.

Measuring externalities is not a simple task and has only begun to be evaluated in depth in the past few years. UNITE (2003) considers the external cost of accidents separately from the effect that congestion has on the rate of accidents when examining the marginal external cost of accidents. The question of external versus internal costs considers the degree to which the user of transportation considers the relevant risks to all participants in the transportation system. The congestion effect suggests that the number of accidents increases at a decreasing rate as traffic volume increases and that risk is therefore decreasing.

Finding monetary values for externalities can be difficult, particularly for those of the non-monetary type. Two basic approaches dominate, the damage cost estimate and the prevention cost estimate. Market goods are easily assessed by the damage costs estimation process, while non market goods require use of valuation techniques such as revealed preferences or implied preferences. These non market valuations increase the uncertainty in the accuracy of estimation of total social costs of transportation. The damage cost estimate is most readily applicable because externalities to transportation are those costs imposed on others by the users of the various modes of transportation. If the damage estimates are highly uncertain, the prevention method may be more practical.

The Royal Commission on National Passenger Transportation (RCNPT, 1992) uses a WTP when estimating the accident costs associated with all interurban passenger modes, and considers most of the costs to be captured by user fees (i.e., bus fees, license fees) or insurance premiums. It estimates the externalities associated with passenger vehicle travel to be about 2% of the total social costs, a negligible proportion of GDP.

Delucchi (UCD reports) (2000) estimates the proportion of costs that externalities impose by accidents to range between 0.59% and 2.10% of US GDP and the average percent of GDP consumed by externalities in a survey of 17 EU countries was found to be 2.5% (ECMT, 1998).

Preparation of credible and accurate valuations for all possible modes and circumstances is a formidable task. Political and administrative practicality needs to be considered when determining levels of resource inputs to such a task. The prevention method has been likened to a control cost, which is conjectured to be less consistently applied, possibly reflecting political and strategic influences (Bein, 1997).

Assumptions and proxy variables collected from other sources, accompanied with appropriate defense of the position taken and consideration to the possibility of double counting should provide adequate estimation of the costs of externalities to transportation use.

4.6 Estimates of the Cost of Road Vehicle Crashes

Table 4.7A shows the recent estimates of the costs of accidents found by academic researchers and government agencies including the components included in the studies. It is summarized in Table 4.7. The details of these summary estimates follow.

4.6.1 Academic Research on the Cost of Motorcycle Crashes

Lawrence, Max and Miller (2002) estimate the cost of motorcycle crashes. They reviewed 25 motorcycle safety studies that looked at the cost of injuries from motorcycle crashes in the United States. Initially locating close to 200 publications, the authors reduced the number of articles included in their survey to 25, based on criteria of direct relation of the article to motorcycle injuries, inclusion of human subjects, published in English, and originality of research. The authors note that only a couple of the surveyed articles include estimated costs of pain, suffering and quality of life lost although Miller et al. (1998b) suggest that in 1993 in the US, the total quality of life lost was 80% larger than medical and productivity costs combined.

Wang et al. (1999) report an average cost of 2002 C$ 3027 per 1000 vehicle miles traveled, and $ 268,130 per crash, where costs include medical, work loss, property damage, pain, suffering and lost quality of life. Miller et al. (1998b) report estimated motorcycle crash costs of $ 2,714 per 1000 vehicle miles traveled and $ 274,026 per crash, where crash costs include medical, work loss, property damage, emergency services, pain, suffering and lost quality of life.

4.6.2 Academic Research on the Cost of Vehicle Crashes

Besides the value of injuries implied by CVM surveys and wage-risk studies, there has also been research on the total cost of vehicle crashes. Trawen, Maraste and Persson (2002) compare the total costs of fatal traffic accidents in different countries.

Trawen et al. (2002) sent questionnaires to the 14 European nations as well as Australia, New Zealand, South Africa, and the United States about the total costs of traffic fatalities. From 1990 to 1999, the average cost per fatality increased in every country studied, and the mean increase in the total cost of a fatality was 71%. In 1999 the surveyed total costs of fatality estimates ranged from approximately $ 1.264 to $ 4.425 million. One of the reasons for the large jump in total cost of fatality was that some countries (US, Norway, and the Netherlands) added the value of a statistical life to the costs per fatality (which previously included only loss production and medical and other costs. New Zealand's increase in the total cost of a fatality was due to a methodological change; the estimate had been calculated by the human capital approach and changed to generating an estimate from WTP from CVM. Switzerland reduced the average cost per fatality by switching from WTP to court compensation payments.

Miller, Levy, Spicer, and Lestina (1998b) estimate the costs of motor vehicle crashes of different vehicle types (car, bus, and truck), using four different estimation methods. The authors note that it is difficult to determine the allocation of costs to the parties in a crash, and it may not be appropriate to assign all costs to the vehicle that caused the crash. In their methods, emphasis is placed on costs associated with injuries and fatalities rather than property damage since they make up a significant proportion of the costs. They note that harm to victims varies with vehicle weight and occupants of heavier vehicles fare better. The different cost approaches can be explained as follows:

Method 1. No assumptions are made about responsibility, severity, or injury by vehicle type; the cost of each victim is assigned to the vehicle type that s/he occupied.

Method 2. All costs are assigned to every vehicle in the crash, which involves double counting of costs; costs are later standardized to compare with other methods.

Method 3. Vehicles ranked from light to heavy, heavier vehicles are allocated excess cost of injury compared to say a crash between two same type lighter vehicles. In same vehicle type crashes, costs are assigned to their own vehicle type. In crashes of different types, the lighter vehicle is assigned the average two vehicle crash cost of that type, and the residual is applied to the heavier vehicle along with costs to the heavier vehicle.

Method 4. All costs are assigned to the heaviest vehicle. Presented for comparative purposes, the authors note that this method is widely used in tabulating crash costs and counts by vehicle types.

Annual crash costs are calculated by multiplying incidence with cost per victim by body region and Abbreviated Injury Scale (AIS) threat to survival. They include medically related costs, emergency services costs, property damage, lost productivity, and quality of life losses. The authors use crash cost estimates used in previous studies updated to reflect costs at the time of analysis. Lifetime productivity and quality of life losses are re-estimated with a 2.5% discount rate. The authors present both human capital and WTP cost estimates.

Both the WTP and human capital costs found by the four methods are shown in Tables 4.8 and 4.9. These costs of highway crashes in the US for the year 1993 are shown in 2002 Canadian dollar values, and represent cost by vehicle type per crash. The various levels of severity of injury for each crash have been incorporated in the estimates presented, although in a different fashion for each method, as described above.

Miller et al. (1998b) suggest Method 3 is the most reasonable; extra costs are allocated to the heavier vehicle but the crash is not the sole fault of the heavier vehicle. The authors also present cost per vehicle type per mile traveled, where costs are generated using the WTP estimates for Method 3. Motorcycles had the highest cost per 1000 miles traveled at 2002 C$ 2,648, followed by bus at 2002 C$ 803, then medium to heavy trucks at 2002 C$ 256, then passenger car/van at 2002 C$ 208, and finally light trucks at 2002 C$ 150.

Miller, Lestina and Spicer (1998a) provide estimates of 1993 US driver crash incidence and costs by driver age, alcohol use, victim age, and restraint use. Included in their estimates are medical, work loss, public service, employer, travel delay, property damage, monetary, and quality of life costs. Quality of life loss estimates are generated using a 2.5% discount factor and a value of life of 2002 C$ 4.054 million. Cost per highway crash victim by police reported injury severity range from 2002 C$ 22,350 for possible injury to 2002 C$ 1.816 million for a disabling injury. Miller and Blewden (2001) perform a similar exercise and look at costs of alcohol related crashes for New Zealand. They estimate crash costs per drink and cost per km by sobriety level, but also include overall crash costs in New Zealand. Estimated costs include medical costs, law enforcement costs, property damage costs, value of lost work and quality of life (from a New Zealand household survey). A 3% discount rate was used for discounting. Miller and Blewden (2001) estimate that the cost per serious injury is 2002 C$ 166,966, and the cost per minor injury is 2002 C$ 10,862.

4.6.3 Government Reports with Estimates on the Cost of Motor Vehicle Crashes

United States

The Office of the Secretary of Transportation gives a procedure for valuing injuries based on the Abbreviated Injury Scale (AIS) (OST, 1993). Table 4.3 lists a selected sample of injuries according to their AIS code. In order to establish a valuation for each AIS injury severity level, the level is related to the loss of quality and quantity of life resulting from an injury typical of that level. This loss is expressed as a percentage of the fatality. The corresponding WTP values are reported in Table 4.10.

In a 2002 National Highway Traffic Safety Administration (NHTSA) report, Blincoe, Seay, Zaloshnja, Miller, Romano, Luchter, and Spicer (2002) estimate the cost of motor vehicle crashes in the United States for the year 2000. By severity of injury, according to the maximum AIS experienced by the victim, Blincoe et al. (2002) estimate the comprehensive cost of a motor vehicle crash to range from 2002 C$ 18,585 for MAIS 1 to 2002 C$ 2.973 million for the most severe non-fatal injury MAIS 5. The total cost of a fatality is 2002 C$ 4.166 million.

The costs examined in the main part of the report are the economic costs that result from goods and services that must be purchased and productivity that is lost as a result of motor vehicle crashes. Emergency treatment, initial medical costs, rehabilitation costs, long-term care and treatment, insurance administration expenses, legal costs, and employer/workplace costs are all considered to be direct costs. Productivity costs in the workplace due to temporary and permanent disability and decreases in household productivity emanating from these disabilities are considered to be indirect costs. Any required discounting uses a 4% discount rate. The authors estimate the count of injuries by using several US data sources, the Crashworthiness Data System (CDS), the National Health Interview Survey (NHIS), and injury estimates from the Federal Highway Administration (FHWA).

The medical costs include ambulance, emergency medical, physician, hospital, rehabilitation, prescription, and related treatment costs, such as ancillary costs and the administrative costs of processing medical payments to providers. The rehabilitation cost is the cost of job or career retraining required as a result of disability caused by motor vehicle injuries. The market productivity loss is the present discounted value (at 4%) of the lost wages and benefits over the victim's remaining life span. The household productivity loss is computed as the present value of lost productive household activity, valued at the market price for hiring a person to accomplish the same tasks. Insurance administration costs are the costs associated with processing insurance claims resulting from motor vehicle crashes and defense attorney costs. The workplace costs represent the costs of workplace disruption that is due to the loss or absence of an employee. This includes the cost of retraining new employees, overtime required to accomplish work of the injured employee, and the administrative costs of processing personnel changes. The legal costs are the legal fees and court costs associated with civil litigation resulting from traffic crashes. The travel delay cost is the value of travel time delay for people who were not involved in traffic crashes, but who were delayed in the resulting traffic congestion from these crashes. The property damage cost is the value of vehicles, cargo, roadways and other items damaged in traffic crashes.

The costs described above do not represent the intangible consequences of motor vehicle crashes to individuals, such as pain and suffering and loss of life. Comprehensive costs are estimated by including all costs, including intangible costs such as pain and suffering and quality of life losses which in turn are determined using QALYs lost. QALY loss is determined by the duration and severity of the health problem. Table 4.11 presents the unit costs of the report.

In an FHWA report, Zaloshnja, Miller, and Spicer (2000) provide estimates of large truck and bus highway crash costs in the United States in the year 1999. The authors studied trucks, with and without trailers, and buses over 4,540 kg. The cost of a crash for a truck tractor with 2 or 3 trailers was highest at 1999 US$ 117,309 (2002 C$ 148,305) per crash. Average cost of trucks larger than 4,540 kg (10,000 lbs) was 2002 C$ 95,622. Medium/heavy trucks, unknown if with trailer was 2002 C$ 45,446. Buses had the lowest cost (when all configuration information was available) at 2002 C$ 68,843 per crash. The average comprehensive cost per victim injured was 2002 C$ 32,413 for possible injury to 2002 C$ 176,951 for an incapacitating injury for bus, and 2002 C$ 46,052 for possible injury to 2002 C$ 325,584 for an incapacitating injury for all large trucks. Crash costs per 1,000 truck miles were 2002 C$ 327 for single truck units, 2002 C$ 174 for single combination trucks, and 2002 C$ 169 for multiple combination trucks.

These costs are comprehensive and include medical costs, emergency costs, property damage costs, lost productivity, and costs of pain and suffering and quality of life reductions; any required discounting is at a 4% discount rate. Estimates of incidence and severity come from the NHTSA's Fatal Analysis Reporting System (FARS) and General Estimates System (GES), weighted by the Crashworthiness Data System (CDS) and NASS (National Accident Sampling System) data.

Medically related costs include hospital, rehabilitation, physician, prescription costs, and claims processing costs of medically related loss compensation through insurance and courts. Emergency services costs include fire, police, ambulance, and helicopter services. Property damage includes the cost to repair or replace vehicles, cargo, or other property from a crash and also includes damage compensation. Lost productivity includes wages, benefits, household work lost, costs of processing productivity loss compensation claims, and costs of being delayed in a crash from traffic jams and from investigation of crashes and recruiting substitute workers. Monetized QALYs includes consideration for the quality of life loss along different characteristics: cognitive, mobility, bending/grasping/lifting, sensory, cosmetic, pain, and ability to work. The QALY lost is found by averaging the fraction of perfect health lost during each year that a victim of a crash is recovering, then multiplying this average by the loss per fatality (double counting is avoided by subtracting lost productivity from estimated quality of life lost).

Australia

In Australia, the Bureau of Transport Economics (BTE) (later renamed the Bureau of Transport and Regional Economics (BTRE)) has produced two reports on transport accidents: the first on road crashes (BTE, 2000), and the second on rail accidents (BTRE,2002). It found that the average cost per road crash for all injury levels was 2002 C$ 24,265 in 1996. The cost estimates in both reports are based on the human capital approach and a 4% discount rate is used when discounting. In the report on road crashes, the BTE (2000) estimates find the cost of a fatality 2002 C$ 1.503 million, the value of a serious injury to be 2002 C$ 325,651, and a minor injury 2002 C$ 11,634.

The BTRE estimates human costs (labour losses in the workplace, households, and community), medical costs (including emergency, hospital, and rehabilitation), quality of life losses, property damage costs, travel delay costs, police and fire service costs, insurance administration costs, and legal costs (including criminal prosecution and insurance claim costs).

For the value of lost labour, the average length of stay in hospital was used as the measure of time absent from work, with an additional two days' recuperation for each day of hospitalization. The loss of a person in a road crash means that their contribution to the home and the community is foregone and therefore the cost of this loss is estimated. The labour loss (from market, household and community) from minor injuries was estimated to be relatively small and has been excluded. Workplaces of road-crash victims suffer losses as a result of crashes. Productivity declines for a time and therefore other staff work overtime or temporary staff have to be employed to fill the gap.

Loss of quality of life encompasses both the pain and suffering of the injured and their ability to return to their way of life before the injury. Economists have explored a variety of methods for valuing quality of life losses, amongst them the non-economic courts awards and the WTP. The WTP approach has a more complex relationship with quality of life loss than the court awards method. It has been proposed that the quality of life loss could be estimated by subtracting productivity loss estimates from a WTP estimate for the value of life (Miller et al. 1998b). Compensation paid to road crash victims was used as a proxy for lost quality of life. The court awards are argued to be consistent, as some Australian states require the payment to be proportional to the degree of impairment. BTRE suggests the court awards may be reasonable since the awards are ultimately determined by the state or territory parliaments (who determine the upper limits of non-economic compensation) which are representatives of their society and reflect their value of quality of life. The estimated value of lost quality of life per serious injury is 2002 C$ 34,297. Giles (2003**)** however, suggests that previous estimates of crash costs in Australia are not appropriate since they rely on the human capital approach versus the WTP approach. In the absence of WTP measures, the human capital estimates do not include factors such as age, gender, educational attainment, experience, and sector of employment, nor do they reflect a value for avoiding pain and suffering. Giles (2003) notes that there is a difference between the two estimates of crash costs. He cites recent estimates of 2002 C$ 1.503 million per fatality (BTE 2000), versus 1995 WTP estimates of 2002 C$ 1.761 million (DOT 1996) in the UK and 2002 C$ 2.873 million for Australia. Total costs of road crashes in Australia in 1996 may be more than 2002 C$ 345.51 billion if a WTP method is employed; BTE 2000 estimates the total costs of road crashes for Australia at 2002 C$ 15.01 billion using the human capital approach. This ratio of WTP/HUMAN CAPITAL estimation is 23:1, far greater than the ratio of WTP based VSL estimates to human capital based VSL estimates suggested by Viscusi (2000), where he suggests that the factor of WTP methodology over human capital is of the order of ten times.

The medical costs comprise charges arising from the use of ambulance, hospital in-patient, outpatient and casualty/emergency services, general practitioners, specialists and allied health services (e.g., radiography and physiotherapy), rehabilitation, long-term care and pharmaceutical products. The treatment a patient receives and the length of stay determine the hospital-generated costs. The approach used recognizes the base cost of a bed-day, which in Canada is between 2002 C$ 450 and 2002 C$ 700 per day, and also assumes that the period in hospital reflects the level and costs of treatment received. This approach avoids the problem where the medical costs of multiple injuries are estimated separately and then summed.

Legal costs arise from insurance claims and from crash-related criminal cases. The first source includes costs from legal assistance in either making an insurance claim or in contesting the ruling on such a claim. The second source of costs is the cost of prosecuting individuals charged with criminal offences. Table 4.12 shows the estimates for road crashes (The report on rail accidents does not provide any unit costs).

United Kingdom

In the United Kingdom, the Department for Transport's Highway Economics Notes (2002) offer estimates of the value of prevention of road accidents. The Department of Transport uses a WTP approach to value fatalities or non fatal injuries. The average value of prevention per serious injury is estimated as 2002 C$ 266,509, and per slight injury 2002 C$ 20,550. These values include lost output, medical and ambulance costs, and human costs based on WTP values (for example grief, pain, and suffering) and do not include police, insurance or property damage costs. Loss of output is calculated as the present value of the expected loss of earnings plus any non-wage payments paid by the employer. Estimates are also presented for average value of prevention per road casualty per type of road user, bus and coach occupants: 2002 C$ 40,038, goods vehicle occupants: 2002 C$ 77,818, car and taxi occupants: 2002 C$ 62,505, motorized two-wheeler riders and occupants: 2002 C$ 130,835. However, the estimates are an average of all severity types, fatal, serious and slight.

Canada

John Lawson (1989) gathered the relevant data on the cost of injuries and fatalities used by Transport Canada as well as other Canadian federal and provincial bodies. The costs per injury accident reported by Transport Canada for use in road safety and motor vehicle regulation was 2002 C$ 14,981. A damage only accident was reported to cost 2002 C$ 3,870. These are reported as minimum values and are suggested to be the "material" losses that people could expect as a result of an accident.

The Ontario Ministry of Transportation used figures of a similar magnitude for an injury accident and a damage-only accident. They are reported by Lawson as 2002 C$ 8,614 and 2002 C$ 1,960. These include direct costs plus lost earnings, with some multiplier for lost earnings to account for unvalued services.

4.6.4 Best Estimates of the Cost of Motor Vehicle Accidents

Table 4.13 shows the breakdown of the calculation for the internal, external and total cost of road transportation. The description of how these cost estimates were generated is enclosed in the following discussion.

Calculating accident costs for interurban passenger transport – Private Vehicles and Bus

Miller, Lestina and Spicer (1998a) thoroughly investigated US road crash costs, controlling for a wide variety of covariate factors including age, restraint use and the ages of both drivers and accident victims. For the estimation of the cost of road accidents in Canada, we begin with Miller et al.'s (1998b) estimates of the crash costs for both motorcycle and automotive accidents translated into costs per 1000 km traveled and then adjust them. These estimates are based on WTP models and include medical, emergency, property damage, lost productivity and quality of life costs, as discussed in the section on externalities above

Miller et al.'s estimates are 2002 C$ 1645.39 / 1000 km for motorcycle accidents and 2002 C$ 129.25 for vehicle accidents. Recognizing that there is a significant difference between the costs associated with these two modes, we have created one weighted average estimate for interurban personal transportation by assigning the respective costs a weight based on the number of licensed vehicles in Canada in 2000. These figures were collected from Transport Canada's Motor Vehicle Traffic Collision Statistics (2000). There were 14,859,000 licensed passenger vehicles and motorcycles reported; passenger vehicles represented 97.6% of vehicles driven, and motorcycles only 2.4%[106]. It should be noted that motorcycles in Canada are driven only half of the year, and it is not clear if Transport Canada figures have been adjusted for this fact. We have assumed that the 2.4% represents a yearly account of licensed motorcycles, and that any cost attributed over the full year for accidents that do not occur in the winter months, can be attributed to motorcycles accidents that occur to persons riding unlicensed motorcycles.

In order to create estimates suitable for Canadian use, we have adjusted this estimate by the relative income ratio between Canada and the United States (0.85), as was done in the chapter on the VSL. We have also adjusted for the higher cost of health care in the United States. The figure 2002 C$ 132.18 per 1,000 km is the cost of urban and interurban passenger vehicle transportation in Canada after these two adjustments.

Next, recalling that the estimates of the cost of serious injuries from Miller (1993) are based on a VSL of 2002 C$ 3.747 million, this estimate has been adjusted upwards to reflect the higher VSL proposed in Chapter 3. *The best estimate of the cost of urban and interurban passenger vehicle transport in Canada is 2002 C$ 142.76.*

No adjustment has been made for the potential differences between Canadian and US road accident risks. Basic data from the International Road Traffic and Accident Database (IRTAD) (OECD, 2004) do not demonstrate a large difference between road fatality rates in the two countries. Transport Canada's Road Safety Vision 2010 report (Update 2001) suggests that the best statistic to utilize for comparison between countries is a rate per kilometer traveled. The data from IRTAD show the road fatality rate to be 0.93 per hundred million vehicle km in Canada and 0.94 per 100 million vehicle km in the US. Further, the rate of injury accidents is stated to be larger in Canada at 0.51 per million vehicle km over 0.46 per million vehicle km in the US. Because of a lack of detail in the statistics it is not possible at this time to differentiate between the classes of vehicles and potential adjustments to be made for fatality and injury accidents by class between the two countries.

Starting with Miller et al.'s (1998b) estimate for the cost of Interurban Bus transportation converted to Canadian dollars, and adjusting for income and health cost differences, yields an estimate of 2002 C$ 446.02 per 1,000 km.

[106] This could be problematic if we believe that motorcycles generally are taken on shorter trips, and thus travel less kms than cars do, relative to the numbers of motorcycles registered.

These values seem to be good proxy measures for costing urban transportation as well, although we would suggest further considering the relative rates of accidents involving cars and buses in the urban versus interurban environments, and examining the distribution of types and severity of injuries that happen at differing speeds for these two modes in Canada.

Calculating accident costs for Freight Transport – Trucks

Here we have utilized data from Zaloshnja et al. (2000), adjusted for the relative numbers of registered trucks of different size in Canada, to create a weighted average for truck accident costs in Canada. Their data updates Miller et. al. (1998), calculating costs for freight transport accidents where the vehicles involved have gross vehicle weights that exceed 4.5 ton. Their costs are quite comprehensive in terms of scope and we are relatively confident in the application of these estimates of accident costs in Canada. [107]

The Canadian statistics that report automotive categories of "trucks" include a wide variety of vehicles.[108] Our focus is on vehicles over 4.5 tonne because it is assumed that these vehicles are used primarily for the transportation of freight, and not passengers. This is consistent with Transport Canada who states, "This is conventionally used to distinguish what might called "true" trucks - vehicles used exclusively for carrying freight - from the various forms of light truck". [109] Although lower weight vehicles may be used for transportation of freight goods, we have assumed that the majority of pickup trucks, vans, and utility vehicles involved in crashes have been categorized under passenger cars.

In 2001, the Canadian Vehicle Survey reports an estimated 329,909 "light trucks" (4.5 – 15 tonne GVW) and 253,649 "heavy trucks" (>15 tonne GVW).[110] These figures suggest that the proportion of total "true trucks" breaks down roughly to 43% heavy trucks and 57% light trucks. Using this information and the cost estimates for "light" and "heavy" trucks created by Zaloshnja et. al. (2000) we calculate the weighted average cost of accidents due to truck transport. The estimates of Zaloshnja et. al. are for vehicles with GVW larger than 4.5 tonne, however they use a slightly different categorization for there estimates of costs per vehicle kilometer. We have assumed that vehicles between 4.5 and 15 tonne represent "single unit trucks" or straight trucks with two or more axels. Their estimate for "single combination trucks" is used for trucks over 15 tonne and is assumed to represent all tractor-trailer combinations (including multiple trailers) and straight trucks with trailers. *The best estimate of the cost of freight transport is 2002 C$ 152.57.* This estimate includes more than just VSL, and represents the best pairing of the available data.

The External Costs of Vehicle Transportation

---

[107] This includes: medical, emergency services, property damages, lost productivity, and quality of life losses

[108] The authors would like to thank John Lawson for clarification on the classes of trucks.

[109] Transport Canada http://www.tc.gc.ca/pol/en/Report/anre1998/TC9815DE.HTM

[110] Transport Canada http://www.tc.gc.ca/pol/en/cvs/cvs.htm

Average external costs of passenger transportation have been measured in the European Union (INFRAS/IWW, 2000). The externalities due to passenger vehicle traffic accidents is the largest for all modes of transportation examined, creating approximately 2002 C$ 51.32 per 1000 passenger kilometers (p-km) traveled. Bus transportation is the next largest contributor of external costs due to accident creating roughly 2002 C$ 4.40 per 1000 passenger kilometers (p-km) traveled. Bus transportation is the next largest contributor of external costs due to accident creating roughly 2002 C$ 4.40 per 1000 p-km. For freight transportation every 1000 tonne-km traveled creates roughly 2002 C$ 17.60.

In order to estimate the external cost associated with all modes of travel we have compared two sources. The first is the estimated external costs from Miller et al.'s (1998a) study and the second is from Grosclaude and Soguel (1992) who examined the social and external costs in Neuchatel Switzerland in 1990. Miller et al. state externality costs per 1000 vehicle mile by type of vehicle. These values have been adjusted to 2002 Canadian Dollars per km, and further adjusted for the income ratio. When combined by the relative registered vehicles in Canada, as was done for the internal cost estimates the externality costs can be allocated to the categories of interest here, Urban and Interurban, Passenger Vehicle and Bus, and Freight Truck.

Grosclaude and Soguel (1992) use a human capital, administrative costs basis for their estimation of external costs of transportation. Based on Swiss insurance structures, they defined all compensation by the civil insurance to be internal, and only that portion of non compensated productivity as external. Subjective pain and suffering costs were considered partially internalized, with the component compensated by legal settlements being internalized (an unspecified percentage). All administrative insurance costs were considered external except for those costs associated with the civil insurance. All material costs were considered to be internal but only 10% of police and justice fees to be so.

For each vehicle type examined they estimate the external costs in Swiss cents per km. Their categorization matches very well with our classification by vehicle type and environment of use (urban versus interurban) and their estimates were directly applied to the vehicle type of interest, after adjusting for currency exchanges. Again these values were combined using the relative numbers of registered vehicles in Canada by type to create estimates for externality costs.

Miller considered costs borne by the transport user to include the costs of their vehicle occupants, including quality of life lost, human capital payments, excepting employer expenses such as training expenses, and health costs not compensated by insurance. He defines three classes of externalities, immediate external costs and ultimate external costs, which are paid for through automobile surcharges and premiums over a lifetime of driving. The third is an external cost to owners and operators of heavy trucks and other commercial vehicles, where the employer is an internal player.

As would be expected the external costs estimated by Miller are higher for all vehicle types, except for the external cost due to an urban passenger vehicle, where the cost was minimally higher for the estimate from Switzerland. For the other categories of vehicle types the estimates from Miller et al. are below 10 time those from Grosclaude and Soguel, except in the case of Urban and Interurban Bus travel where the difference is roughly 100 times larger for Miller et al.'s estimate.

Table 4.22 shows the estimated total cost of road vehicle traffic including a range of externality costs. Of particular note is that the inclusion of externality costs slightly differentiates the cost of interurban and urban passenger vehicle (i.e. car, motorcycle).

4.7 Estimates of the Costs of Rail Accidents

4.7.1 Research on the Costs of Rail Accidents

Few studies, if any, try to estimate the specific cost of an injury for rail.

As mentioned above, the Bureau of Transport Economics (BTRE) in Australia has produced two reports on transport accidents; BTE 2000 on road crashes in 1996, and BTRE 2002 on rail accidents. In these reports, a serious injury is defined as an injury resulting in hospital admission with an average length of stay of more than one day. A minor injury is defined as any lesser injury that required medical attention. Hence, injury level is determined using the average length of hospital stay. In the 2002 study on rail accidents, the average cost of a fatality is 2002 C$ 1.852 million, a serious injury 2002 C$ 26,316, and a minor injury 2002 C$ 1,949, including human costs but excluding property damage and other costs. The costs of a fatality between road and rail are slightly different depending on the mode evaluated. There is some concern that the quality of the data used to estimate the rail costs was lower than that available for estimation of road costs. However the difference between the average costs of accidents for the two modes is only 2002 C$ 0.349 million (rail > road) possibly reflecting a difference in the estimation method for rail VSL, where there was some adjustment for a WTP to avoid pain and suffering. More notably, there is a large difference in the costs of injuries between the two modes, with the costs of road injuries being roughly ten times the cost of rail injuries. The ratio of serious road costs to rail costs is 12.37:1 and the ratio of minor road to rail costs is 5.97:1. This divergence can be attributed to several differences in methodology. While the road cost estimates are comprehensive costs the rail costs reported are for human costs only, excluding property and other costs. The rail costs also are estimated for a limited set of accidents, excluding some rail related accidents, most importantly those involving motor vehicles at level crossings and attempted suicides.

Dennis (1996) estimates risk costs for hazardous materials transported by rail. Risk costs are incremental costs incurred by railroads as a result of the presence of hazardous materials. Safety measures have increased over the last decades, but at the same time the amount of hazardous materials shipped by rail increased a lot.

The intent of the author is to determine the risk costs per unit of exposure associated with railroad freight transportation of groups of hazardous materials known to have generated substantial risk costs, expressed as dollars per unit of distance. A hazardous materials incident is defined as any unintentional release of hazardous materials in railroad transportation. The study focuses on major releases. A release was considered major if it included one of the following: at least US$ 100,000 in current dollar damages, at least one death, or a release of at least of 500 gallons of hazardous materials.

A list of 669 potential major hazardous materials releases developed by the Association of American Railroads (AAR) was used as a starting point. Since the risk costs depend heavily on the circumstances of the release, seven groups were developed by the AAR. There are three safety hazard classes and three environmental hazard categories. The safety hazard classes are: poison inhalation hazard, flammable or combustible commodities, and all other commodities. The environmental hazard categories are: high, medium, and low environmental hazard. Table 4.15 shows the seven groups. Since most poisonous inhalation commodities evaporate, the environmental hazard is not an important characteristic and the poison inhalation hazards were consolidated in one group.

Total risk costs were estimated to be 1994 US$ 348 million for the major releases over the 11-year period of the study. Table 4.15 shows the average risk cost per unit of exposure for each of the seven categories.

4.7.2 Best Estimates of the Cost of Rail Accidents

Canada's definition of a "reportable railway accident" as defined by Transport Canada includes[111]:

a) A person sustaining a serious injury or is killed as a result of:
   i. Being on board or getting off the rolling stock
   ii. Coming into contact with any part of the rolling stock of its contents, or

b) The rolling stock:
   i. Is involved in a grade-crossing collision, or
   ii. Is involved in a collision or derailment and is carrying passengers, or
   iii. Is involved in a collision or derailment and is carrying dangerous goods, or is known to have last contained dangerous goods the residue of which has not been purged from the rolling stock, or
   iv. Sustains damage that affects its safe operation, or
   v. Causes or sustains a fire or explosion, or causes damage to the railway, that poses a threat to the safety of any person, property, or the environment.

In 2002, 985 rail accidents were reported in the TSB a 10% decrease over the 5 year average of 1089. Most of these, 87%, are non main track related. 47% of accidents can be characterized as minor, occurring during switching operations at speeds less than 10 mph.

[111] Transport Safety Board of Canada (Transport Canada 2002c). It applies to railway occurrences that must be reported pursuant to the *Canadian Transportation Accident Investigation and Safety Board Act*

Derailments result from less than 50% of collisions and 71% of these involve one or two cars. In 2002, there was no release of dangerous materials nor fatalities or serious injuries.

Twenty-six percent of Canadian rail accidents involved a vehicle or pedestrians at a highway rail crossing, a relatively unchanged proportion over the last 5 years. Of these crossing accidents, 25% result in serious (likely to require a hospital admission) or fatal injuries. User born costs of equipment is low, while vehicles involved are often destroyed. Typically, 13% of crossing accidents are fatal when a car is involved; this rate rises to 55% when a pedestrian is involved.

Main track derailments and collisions accounted for 13% of all accidents in 2002 and while potentially the most serious in terms of financial loss and potential risk to the public, - due to release of dangerous materials from accidents that occur in derailments at high speeds in populated areas, - half of main track derailments in 2002 involved one or two cars, while 19% involved ten cars or more (mean 18%). Twenty-six derailments involved dangerous goods (mean 25) with two resulting in release of dangerous goods. No fatalities or serious injuries resulted in 2002.

There were also 224 accidents involving rolling stock or vehicles carrying or having recently carried dangerous goods, compared to the five-year average of 241. Eighty percent of these are non main track related and four accidents involved release of dangerous goods, against a mean of seven.

There were 96 fatalities in 2002 (mean 100), 46 crossing related and 50 trespassing fatalities. Seventy-one serious injuries resulted from rail occurrences (mean 87), the decrease of which was mainly due to a decrease in employee and passenger injuries. Transport Canada (2002) note that unauthorized access to railway rights is the leading cause of death and disabling injury among railway accidents. Between 1990 and 2001 there were on average 59.1 fatalities a year associated with unauthorized access. Accounting for suicides, which are assumed to be less preventable, it is estimated that there are on average 38.4 potentially avoidable fatalities a year.

Broken down by class of train, freight trains accounted for 83% of accidents, single car 7% and passenger trains 6%.

Calculating accident costs for Passenger and Freight Transport - Rail

For passenger and freight rail transport, the calculated fatality rate is 1.26 per million track miles, and the serious injury rate is 1.09 per million main-track train-miles (mmttm). Using the VSL for rail users of 2002 C$ 4.25 million from Chapter 3, and serious injury cost of 2002 C$ 330,875 for injuries of MAIS 2 and above from section

4.4.3, the *aggregate cost is 2002 C$ 5.73 million per million main track train miles* (mmttm).[112] The details are shown in Table 4.16.

One concern it is that there is a possibility of double counting if an accident involving a vehicle at a crossing is also reported in the statistics for road accidents. We have not come across a reliable method for determining if the cost of the accident is counted twice.

A high proportion of rail fatalities are suicides. *If we do not to count those persons who intentionally end their life, then the rate of fatalities becomes 38.4/79.46 million track miles, equivalent to 2002 C$ 2.41 million per mmttm.*

As discussed above, these estimates are based on the assumption that all minor injuries have no cost. Thus, these figures are under-estimates of the true cost.

Converted to million main-track train-kilometers the costs become 2002 C$ 3.56 million, 2002 C$ 2.29 million and 2002 C$ 1.50 million per million main-track train-kilometers. We have kept the values in the imperial units for reporting purposes as these are the standard units currently collected by both transport Canada and the Transportation Safety Board.

We suggest the use of 2002 C$ 5.73 million per mmttm for passenger rail also. This is due to an absence of information distinguishing between passenger and freight rail transport. However, care should be taken to use this number only once in aggregating costs, otherwise it could be double counted: once for passengers and once for freight. A distinction might be made once we account for externalities from freight transport resulting from the transport of hazardous goods.

4.8 Estimates of the Cost of Aviation Accidents

4.8.1 Research on the Cost of Aviation Accidents

As with rail, few studies, if any, try to estimate the specific cost of an injury for air travel.

Hoffer et al. (1998) state that, most frequently, aviation injuries are reported in two categories, minor and serious, as defined by the International Civil Aviation Organization (ICAO). To calculate economic values for the ICAO serious and minor injury categories, the US Office of Aviation Policy and Plans (APO) analyzed injury data maintained by the US National Transportation Safety Board (NTSB) that contained both ICAO and AIS codes. AIS values contained in each ICAO category were summed and divided by the number of victims to determine WTP values. Table 4.4 reports estimated values.

---

[112] As noted by Transport Canada, there are potentially 38.4 potentially avoidable fatalities per year under rail transport. If it were possible to create safety improvements that could save these lives, the rate of fatalities in accidents would fall to 0.78 per mmttm, and the total cost falls to 2002 C$ 3.68 million per mmttm.

Recalling that these WTP values represent a fractional representation of an injury in comparison to a fatality, the APO recommends aggregating the WTP of each separately identified AIS level injury when a victim suffers from multiple different injuries (Hoffer & al., 1998). This accommodates the fact that, often, each person injured in an aviation accident will be associated with more than one injury, and each injury will increase the amount of pain and suffering. This requires an assumption that there is no limit to the amount of pain and suffering that can be incurred by combining injuries.

Estimates of investigation costs have be obtained from the Federal Aviation Administration (FAA, 2004). The FAA provided us with a preliminary version of an unpublished chapter on aviation accident investigation costs that will be included in an update of their document "Economic Values for Evaluation of FAA Investment and Regulatory Decisions".

American aviation investigations involve resources from the NTSB, the FAA, and the private sector. The NTSB is responsible for the investigation of all aircrafts accidents and it conducts two types of investigation, the major ones, which are directed by NTSB headquarters, and the field office ones, directed by the field offices. NTSB cost estimates were derived from budget, staff and activity data. In order to capture a wide range of accidents, the data are taken from 1991 to 2002. Once the portion of the budget devoted to aviation safety was measured, these costs were assigned to five types of investigations directed by NTSB: major air carrier, field regular, field limited, foreign major, and other foreign investigations. The costs assigned to each type was then divided by the respective number of accidents in each category to estimate a per accident investigation cost. Costs are reported in Table 4.17.

Since the FAA is a much larger organization than the NTSB, budget data are not used directly. A special study of accident investigation costs based on models developed for the report "A cost allocation study of FAA's FY 1995 costs" is used[113]. The study identifies costs attributable to investigations. Costs were then divided in each category and estimates are presented in Table 4.17.

The NTSB conducts investigations with many private parties. This results in costs arising from the private sector activities. Since no systematic measure of this cost is available, an approximation based on the NTSB's costs was made. The private sector manages the removal of aircraft wreckage[114]. Aviation insurance industry sources estimate the average cost of investigation at about 2002 C$ 164,875 (2002 US$ 138,000). Table 4.18 reports private costs.

4.8.2 Best Estimate of the Cost of Aviation Accidents

[113] Prepared by GRA Incorporated for FAA's Office of Aviation Policy and Plans (March 1997), see FAA, 2004 "Aviation Accident Investigation Costs"

[114] The clean-up cost is included in FAA's investigation costs estimates.

In 2002 a total of 323 aviation accidents were reported to the TSB, of this number, which excludes ultra lights, 274 accidents involved Canadian Registered aircraft, a decrease of 7% from 2001. Statistical analysis using linear regression indicates there has been a significant downward trend (statistically significant at probability, $p<0.001$) of reported aircraft accidents over the last 10 years. Based on a relatively unchanged estimate in flying activity, the accident rate is estimated to have fallen from 8.6 accidents per 100,000 flying hours in 2001 to 7.8 in 2002, a figure that is at its lowest in over 10 years (TSB 2002a).

There were 65 commercial airplanes (airliners, commuter aircraft, air taxi and aerial work craft) involved in accidents in 2002. Of these, four air taxis and one aerial work aircraft were involved in fatal accidents. There were no fatal accidents involving airliners or commuter aircraft in Canada during the reporting period, and although the costs associated with an airliner are significant, the probability of airliner crash is low. There were four fatalities that we were unable to attribute to any particular class of airliner, representing 9% of the total fatalities. The National Transportation Safety Board reports rates for airliners of 0.012 per 100,000 flight hours, and records 10 accidents involving fatalities in the past 5 years involving passenger airliners. US incidence for commuter aircraft and air taxi is 0.360 per 100,000 flight hours, for scheduled service and 0.64 for unscheduled service (NTSB, 2003). Our findings are similar with the rate of fatality for interurban transport being 0.15 (airliners, commercial and air taxi combined) and 0.77 for freight/work, reflecting the low risk of scheduled air service relative to unscheduled.

A total of 139 private airplanes were involved in accidents in 2002, of which 13 accidents resulted in fatalities, a decrease from the 5 year average of 17. While ultra light aircraft were involved in 28 fatal accidents, an amount also less than the 5 year average for this class of 34.

The total number of fatalities and serious injuries (47 and 42) decreased from the five-year average (71 and 50) by 33 and 15 %. Definition of a serious injury is: an injury that

- Requires hospitalization for more than 48 hours, within 7 days of the injury, or
- Results in a fracture of any bone other than small (i.e., fingers, nose), or
- Involves lacerations which cause severe hemorrhage or nerve, muscle or tendon damage, or
- Involves injury to any internal organ, or
- Involves second or third degree burns or burn affecting more than 5% of the body surface, or
- Involves verified exposure to infectious substances or injurious radiation.

Source: TSB, 2002a

To construct the fatality rates per 100,000 hours we have aggregated the classes Airlines, Commuter Aircraft and Air Taxi to Interurban and all other to Freight/work, recognizing that these divisions are somewhat open to discussion. However the division is based on the assumption that these first two carrier classes predominantly transport passengers, while the other classes are used for both lower capacities of passengers and have less flight hours annually and are subject to higher rates of accidents.

Calculating accident costs for Interurban Passenger and Freight transport – Aircraft

Table 4.19 shows the summary statistics of the calculation of aircraft costs for the two classes of air transportation of interest. Interurban travel (airlines, commuter aircraft and air taxi) includes all Canadian air travel between urban destinations both provincially and inter-provincially, accounting for roughly two thirds of all hours flown per year, and is very safe relative to Freight transportation. The fatality rate is 0.34 per 100,000 hour of flight time for Interurban relative to 2.74 per 100,000 for Freight. The unaccounted subsection of fatalities has a low rate of 0.12 per 100,000 and has not been allocated to either of the other two categories. We were also not able to classify injuries to either of the categories, and they were attributed to a class (unaccounted included) as a proportion of total injuries, based on the relative share that fatalities attributed to each class. This again reflects the relatively low risk associated with interurban air travel.

Using the VSL recommended in Chapter 2 of 2002 C$ 4.25 million, and the cost of a major injury at 2002 C$ 330,875 we used the above summary data for 2002 from the Transport Safety Board to create low estimates of accident costs for Canada. The average cost was calculated as the sum of the fatalities per 100,000 hours of flight time multiplied by the VSL and the injury rate multiplied by the cost of a serious injury. *For inter-urban air transport, the cost is at least 2002 C$1.527 million per 100,000 hours of flight.* This only includes VSL and injury costs, and excludes all other costs. *The cost of freight air transportation is much higher reflecting the increased crash incidence and is at least 2002 C$ 12.467 million per 100,000 hr of flight.*

The cost of accidents is larger if we consider property damage for accidents with no injuries or fatalities. Investigation costs were estimated using the FAA's investigation costs from Table 4.18, to arrive at a common per unit cost. These investigation costs were considered to be internalized through excise taxes paid by airports and airway users. The investigation costs amount to 2002 C$ 1.36 million for passenger flight and 2002 C$ 0.68 million for freight flight.

In total Interurban Passenger flight cost are 2002 C$ 2.89 million per 100,000 hr flown and total Freight flight cost are 2002 C$ 13.15 million per 100,000 hr flown.

Calculating the external accident cost for Interurban Passenger and Freight transport – Aircraft

Reliable estimations of externalities for aviation accidents from other papers and jurisdictions have yet to be located.

4.9 Estimates of the Cost of Marine Accidents

We were unable to locate any research studies that discussed the costs of marine accidents.

4.9.1 Best Estimate of the Costs of Marine Accidents

There has been a statistically significant reduction in shipping accidents in Canada over the past decade (significant at probability, $p<0.001$). The definition of accidents include groundings, strikings, fires and/or explosions and structural damages of various types (e.g., rudder damage), and loss of cargo among other incidents. In 2002 there were 483 marine accidents of which 93% were shipping accidents, the remainder occurring on board. The 48% of fishing vessels that reported accidents to Transportation Safety Board (TSB) represent the largest share among the different classes of vessels to report accidents. This level has consistently been near 50% on average, but the total number of vessels involved has nearly halved from 444 in 1994 to 237 in 2002. The next largest category of vessels reporting accidents are bulk carriers (12%) and tugs/barges (11%). Ferry /passenger vessels and tankers account for 10% and 2% respectively, but occurrences involving these vessels pose a greater threat to the public and environment (TSB, 2002b).

There were 27 reported fatalities in 2002 that were marine related and 73 injuries. Both of these figures are below the five-year average (1998 – 2002)[115] of 33 fatalities, and 82 injuries. All injuries reported are classified as serious, whereby a person sustains a serious injury or is killed as a result of a) being on board the ship or falling overboard from the ship, or b) coming into contact with any part of the ship or its contents.

There are roughly 49 vessels lost per year, which are reported according to their capacity, with smaller vessels being much more susceptible to sinking or being written off. Capacities for vessels are measured as Gross tons (grt – Gross registered tonnage), a measure of capacity (in cubic feet) of the spaces within the hull, and enclosed spaces above deck, save for a few exclusions not discussed here. 100 cubic feet is equal to one gross ton. The numbers of vessels lost in 2002 is estimated from bar graph and is reported in Table 4.20.

The unit of incidence chosen as reported by the TSB is "Trips" and is based on data from Transport Canada, chosen by TSB to reflect the actual level of activity. The TSB reports accident rates as the number of Canadian commercial vessels involved in shipping accidents per 1000 trips in both domestic and international trade. Commercial vessels include cargo, ferries, tankers, passenger vessels tugs and barges. This does not necessarily reflect the activity of fishing vessels, however for this analysis we have assumed that the "trip" also reflects the activity level of fishing vessels.

Calculating accident costs for marine transport – Interurban and Freight

[115] All Transportation Safety Board averages are reported for the period 1997 – 2002. The TSB maintains this five year moving average for comparison of yearly statistical reports.

Using the recommended VSL, 2002 C$ 4.25 million, and the estimated cost of a major injury at 2002 C$ 330,875 we have calculated costs for both ferry/private interurban transportation and "Work Related" marine accidents. This definition of work related accidents as defined for use here includes the TSB definition of commercial vessels and fishing vessels under one broad category.

In 2002 the accident rates per 1000 commercial trips were 0.19 for Ferry, 0.13 for Private, 0.76 for Marine and 0.73 for Fishing. As can be noted in Table 4.21 the rates of fatalities and injuries for each of these modes is highly variable, so we have created accident costs for each type and then created a weighted average cost for interurban and freight.

The cost of ferry accidents and private accidents are similar in magnitude, we would recommend using a value of at least 2002 C$ 158.67 per trip as the cost of Interurban Ferry Transportation crashes, as this figure does not represent the full cost of marine transportation. However, the losses due to fatalities and injuries are the most significant cost drivers, so this value is at least the lower boundary on the cost of Ferry accidents. We have reported private marine accident costs per trip under the urban transportation mode for the sake of completeness.

The cost of work related marine accidents and/or freight accidents has been calculated using a weighted average of the commercial and fishing accident costs found, using an allocation of 50% for each vessel type, base on the historical share of fishing accidents reported in Canada. *The recommended lower boundary for freight accidents in Canada is 2002 C$ 822.00 per trip, based on exclusion of associated and unmeasured private and social costs attributable to marine accidents.*

Calculating external accident costs for marine transport – Interurban and Freight

Reliable estimations of the average costs and the externality costs for marine accidents from other studies and jurisdictions have yet to be located

4.10 Potential Future Research Activities

Apart from the concerns of the choice of the VSL for costing accidents, referred to in section 3.11 above, there are two specific policy issues problematic in accurately assessing the true cost of accidents in Canada.

Firstly, there is the question of whether the method of Miller (1993) of apportioning a component of the VSL for fatality to injuries of various severities adequately represents the cost of reduced activity in the broad economy. As is discussed, there is little academic research outside of that contracted by government agencies into the cost of accidents due to the lack of interest in the theoretical issues that underlie this process. This has resulted in there being little development or challenge to the practices employed. Although it appears that most parties are moving away from a purely human capital approach to evaluating the economic losses, the best method for evaluating these costs has not been determined. Many researchers have adopted Miller's method, including the CTS, due to the limited time and scope inherent in the contracted research environment.

It is true that there is not adequate attention being paid to the theory underlying how to evaluate the economic costs due to injury, and funding may need to be focused towards research specifically in this area. Possibly there needs to be some linking between the way in which economic cost impacts of injury are estimated to the way that cost estimates of health treatment is conducted. Academically this is a much richer field, as health care is pressed to defend the choices of treatments available to reduce risk of illness in an economically efficient manner. There may also be some implications for evaluating the cost of injuries in one fashion and the treatment of these injuries in another, either by using a different VSL for the two categories, or for using different economic costs for similar injury states.

The second concern is the issue of externalities. Although the economic definition of an externality is relatively straightforward, the discussion of externalities can easily become clouded. Different agencies and research bodies may refer to those components of social costs that are externalities by definition, or they may refer to only that component of external social cost that remains to be internalized after appropriate pricing strategies for internalization have been implemented.

In the analysis presented here we have only been able to make crude estimates of the external costs that remain after taxes and licensing fees have been paid, and then for only a few modes. We have considered the externalities to be only those social costs that are not compensated for by insurance settlement arising from accidents. These estimates are highly uncertain, because they are adapted from other countries and therefore are affected by the regulatory environment there. Differences in public and private insurance schemes, and mandatory regulation for insurance and licensing will affect how these external costs are applicable to Canada.

In Canada, transportation is highly regulated. We can assume that the uncompensated or non-internalized social external costs of transportation accidents are low. However in order to examine the magnitude of the total social costs, either internalized/remaining external or truly external by definition would require a thought experiment and study design beyond that which could be conducted here.

Resolving the question of the impacts that larger vehicle or risky drivers place on other road users, and society in its entirety, is not simple. It can be assumed that the users of larger vehicle place external costs on smaller vehicle users, however even this is not clear-cut. There is not really a full understanding of whether all road users make their transportation choices with only the risk of their own mode in mind, or if they estimate the risk that results from use by all transport participants, thereby accounting for the risky behaviour of others in their choice of mode, or by other demand decisions.

Determining the amount of health cost that is not covered by transport regulation, licensure and insurance in Canada is complex. Each province has different insurance structures, private or public insurance schemes that may or may not be no-fault. The different provinces may also have different payment structures between the insurance programs and the publicly funded health system in Canada. These different insurance structures would also have different administrative costs and payout rates. An in-depth examination of these issues would also be of value to Transport Canada.

4.11 Conclusion

A summary of our estimates for the costs of accidents by mode, stating internalized and externalized costs where possible, is presented in Table 4.22. Again, note that the costs of time delays associated with accidents have not been included. Some such costs may be included in congestion cost estimates because part of the reason for slower operations in congestion may be transport operators taking precautions to reduce the risk of accidents. Appendix 4.1 contains sensitivity analyses with respect to the relative income in Canada to the US which varies between 0.85 and 1.0, the income elasticity of safety which varies between 0.5 and 1.0, and the VSL.

From the estimates presented in Table 4.22 one can compute the average cost per accident, if the accident rate is known. Implicitly, the cost of the average accident is computed by multiplying the average impact for each component by a cost of that component. In our opinion these costs are marginal costs – they reflect the opportunity cost of the resources. Whether this cost pertains to an individual's loss of productivity or police or hospital services, these costs are marginal costs (for the average individual or hospital). Thus, we have estimated the average marginal cost. Little is known about the shapes of the accident cost curves. However, costs are likely to vary little between one accident and another, whether it is the first or the last, at least not in a particular region. It is possible that accident costs vary from one region to another with low-accident rate regions suffering higher per accident costs due to lack of economies of scale. However, within a region, the marginal cost is unlikely to change much with changing frequency of accidents, assuming reasonably optimal provision of hospital and emergency services and assuming that accident rates do not change quickly.

Of course, if there is a major accident (a disaster), then the marginal cost of some components are likely to be higher than those we have assumed. Indeed, if circumstances were to change (i.e. risk levels increase or decrease) then the marginal cost per accident and the average cost per accident may change. In some circumstances, levels of risk could be exogenous, perhaps varying with traffic volumes such as congestion or different across modes such as would be implied by the risk of terrorist act. Under these circumstances the cost of accidents then will definitely change.

Chapter 4 References

Abelson, P. (2003): “The Value of Life and Health for Public Policy”, The Economic Record, 79 (Special Issue), pp. 2-13.

Alberini, Anna, Cropper, Maureen, Krupnick, Alan and Simon, Nathalie (2002): *Does the Value of Statistical Life Vary with Age and Health Status? Evidence from the United States and Canada*. Discussion Paper 02-19 Resources for the Future, Washington

Bein, P. (1997): *Monetization or Environmental Impacts of Road*, Ministry of Transportation and Highways, Highway Planning and Policy Branch, Victoria, B.C., Canada.

Blincoe, L., Seay, A., Zaloshnja, E., Miller, T., Romano, E., Luchter, S. and Spicer, R. (2002): “The Economic Impact of Motor Vehicle Crashes 2000”, *National Highway Traffic Safety Administration*, US Department of Transportation, DOT MS 809 446 available at http://www.nhtsa.dot.gov.

Blomquist, G.C. (1991): “Motorist Use of Safety Equipment: Expected Benefits of Risk Incompetence?” *Journal of Risk and Uncertainty*, 4:135-52.

Blomquist, G.C., Miller, T.R. and Levy, D.T. (1996): “Values of Risk Reduction Implied by Motorist Use of Protection Equipment”, *Journal of Transportation Economics and Policy*, 30(1), pp. 55-66.

Brazier, John, Tim Usherwood, Rosemary Harper and Kate Thomas (1998): “Deriving a Preference-Based Single Index from the UK SF-36 Health Survey”, *Journal of Clinical Epidemiology*, 51(11): 1115-1128.

Brazier, John, Jennifer Roberts and Mark Deverill (2002): “The Estimation of a Preference-based Measure of Health from the SF-36”, *Journal of Health Economics*, 21:271-292.

BTE (Bureau of Transport Economics), (2000): *Road Crash Costs in Australia*, Report 102, Canberra.

BTRE (Bureau of Transport and Regional Economics), (2002): *Rail Accident Costs in Australia*, Report 108, Canberra.

Cost 313 (1994): *Socioeconomic Cost of Road Accidents*. Commission of the European Communities, Brussels, Belgium.

Delucchi, M. *Social Cost of Motor Vehicles Report Series*. UCD-ITS-RR-3 (1 to 21), University of California – Davis. (There are 21 reports in this series, for a complete listing see English et al. 2000, pg. 103, below.)

Dennis, Scott M. (1996): "Estimating Risk Costs Per Unit of Exposure For Hazardous Materials Transported by Rail", *Logistics and Transportation Review*, 32(4).

DOT (Department of Transport) (1996): *Valuation of Road Accidents and Casualties* (Highway Economics Notes 1), Department of Transport (UK).

DOT (Department of Transport) (2002): *Valuation of the Benefits of Prevention of Road Accidents and Casualties* (Highway Economics Notes 1), Department of Transport, Local Government and the Regions (UK), 2002.

Dillingham, Alan and Miller, Ted (1996) "A More General and Unified Measure for Valuing Labour Market Risk," *Applied Economics,* 28:537-542.

Dionne, Georges, Claire Laberge-Nadeau, Denise Desjardins, Stephane Messier and Urs Maag (1999): "Analysis of the Economic Impact of Medical and Optometric Driving Standards on Costs Incurred by Trucking Firms and on the Social Costs of Traffic Accidents." In Dionne, G, and Laberge-Nadeau, C. (Eds.) *Automobile Insurance: Road Safety, New Drivers, Risks, Insurance Fraud and Regulation.* Boston: Kluwer Academic Publishers.

Dorman, Peter and Hagstrom, Paul (1998): "Wage Compensation for Dangerous Work Revisited," *Industrial and Labor Relations Review*, 52(1): 116-135.

Drummond, M.F., Bernie O'Brien, Greg L. Stoddart, and George W. Torrance (1997): *Methods for the Economic Evaluation of Health Care Programmes, 2nd Edition*. Oxford: Oxford University Press.

Elvik, R. (1994): "The External Costs of Traffic Injury: Definition, Estimation and Possibilities for Internalization", *Crash Analysis and Prevention*, 26(6):719-732.

English, G., Schwier, C., Lake, R., Hirshhorn, R., and Barton, R. (2000): *Internalizing the Social Cost of the Transportation Sector, Final Report*, T8080-00-1018. Prepared by the Research and Traffic Group for Transport Canada.

ECMT (European Conference of Ministers of Transport) (1998): *Efficient Transportation for Europe: Policies for Internalization of External Costs.* Paris: Organization for Economic Cooperation and Development.

European Union (2001): "Recommended Interim Values for the Value of Preventing a Fatality In DG Environment Cost Benefit Analysis," Mimeo. Available at http://europa.eu.int/comm/environment/enveco/others/recommended_interim_values.pdf

Federal Aviation Administration (2004): *Section 8: Aviation Accident Investigation Costs*, Unpublished chapter of the FAA's document "Economic Values for

Evaluation of FAA Investment and Regulatory Decisions", DOT, Washington, D.C.

Giles, Margaret (2003): "The Cost of Road Crashes: A Comparison of Methods and Recent Australian Estimates," *Journal of Transport Economics and Policy,* 37(1):95-110, 2003.

Goodchild, Mark, Kel Sanderson and Ganesh Nana (2002): *Measuring the Total Cost of Injury in New Zealand: A Review of Alternative Cost Methodologies, BERL#4172*, Prepared by Business and Economic Research Limited (BERL) for the New Zealand Department of Labour, Wellington.

Grosclaude, Pascal and Nils Soguel (1992): "Couts Externes du Traffic Routier: Evaluaton en Millieu Urban." *Swiss Journal of Economics and Statistics*. 128(3): 453-69.

Hoffer, Stefan, Berardino, Frank, Smith, Jack and Rubin, Stuart (1998): *Economic Values for Evaluation of FAA Investment and Regulatory Decisions*, Federal Aviation Administration (FAA), US DOT FAA-APO-98-8, June 1998.

INFRAS (Zurich), and IWW(Karlsruhe) (2000): *External Costs of Transport (accident, environmental and congestion costs) in Western Europe*. INFRAS Consulting Group for Policy Analysis and Implementation, IWW, University of Karlsruhe.

Johansson, Per-Olov (2002): "The Value of Statistical Life: Theoretical and Empirical Evidence", *Applied Health Economics and Health Policy*. 1(1): pp. 33-41.

Kidholm, Kristian (1995): "Assessing the Value of Traffic Safety Using the Contingent Valuation Technique: The Danish Survey," in Schwab-Christe, N.G. & Soguel, N.C. (eds.) *Contingent Valuation, Transport Safety and the Value of Life,* Boston: Kluwer, pg. 45-61.

Krupnick, Alan, Alberini, Anna, Cropper, Maureen, Simon, Nathalie, O'Brien, Bernie, Goeree, Ron and Heintzelman, Martin (2002): "Age, Health and the Willingness to Pay for Mortality Risk Reductions: A Contingent Valuation Survey of Ontario Residents." *The Journal of Risk and Uncertainty*. 24(2): 161-186.

Landefeld, J.S. and E.P. Seskin (1982): "The Economic Value of Life: Linking Theory to Practice." *American Journal of Public Health*. 72(6): 555-66.

Lanoie, Paul, Pedro, Carmen and Latour, Robert (1995): "The Value of a Statistical Life: A Comparison of Two Approaches," *Journal of Risk and Uncertainty,* 10:235-257.

Lawrence, B.A., Max, W., Miller T.R. (2002): *Cost of Injuries Resulting from Motorcycle Crashes: A Literature Review*. NHTSA, DOT HS 809 242.

Lawson, John (1992): *Cost Benefit and Cost Effectiveness of a Potential Regulation Requiring Air Bags in Passenger Cars in Canada*. Transport Canada.

Lawson, John (1989): *The Value of Transportation Safety. Final Report.* Transport Canada Report No. 10569.

Leung, J. and J. Guria (2000): *The Social Costs of Road Crashes and Injuries: June 2000 Update*. Land Transport Safety Authority of New Zealand.

Miller, Ted (1993): "Costs and Functional Consequences of US Roadway Crashes." *Accident Analysis and Prevention.* 25(5): 593-607.

Miller, Ted, Lestina, Diane and Spicer, Rebecca (1998a): "Highway Crash Costs in the United States by Driver Age, Blood Alcohol Level, Victim Age, and Restraint Use," *Accident Analysis and Prevention,* 30(2): 137-150.

Miller, Ted, Levy, David, Spicer, Rebecca and Lestina, Diane (1998b): "Allocating the Costs of Motor Vehicle Crashes Between Vehicle Types," *Transportation Research Record,* 1635: 81-87.

Miller, Ted and Blewden, Michael (2001): "Costs of Alcohol-Related crashes: New Zealand Estimates and Suggested Measures for Use Internationally," *Accident Analysis and Prevention,* 33: 783-791.

National Transportation Safety Board (2004): *Table 1 Accidents, Fatalities, and Rates, 2003 Preliminary Statistics, U.S. Aviation,* Aviation Accident Statistics. Available at http://www.ntsb.gov/aviation/Stats.htm

OECD (2001): *OECD Health at a Glance – How Canada Compares* OECD Observer. Available at http://www.oecd.org/LongAbstract/0,2546,en_2649_34489_2465549_1_1_1_1,00.html.

OECD (2002): *Total Expenditures on Health per Capita – US$ PPP*. Available at http://www.oecd.org/dataoecd/13153/31963451.xls

OECD (2004): *Selected Risk Values for the Year 2002*. International Road Traffic and Accident Database (irtad). Available at http://www.bast.de/htdocs/fachthemen/irtad//english/we2.html.

OST (Office of the Secretary of Transportation) (2002): "Revised Departmental Guidance: Treatment of Value of Life and Injuries in Preparing Economic Evaluations", *OST Memorandum*, DOT, January 29.

OST (Office of the Secretary of Transportation) (1993): "Treatment of Value of Life and Injuries in Preparing Economic Evaluations", *OST Memorandum*, DOT, January 8.

Royal Commission on National Passenger Transportation (RCNPT) (1992): *DIRECTIONS*: The Final Report of the Royal Commission on National Passenger Transportation.

Schwab-Christe, Nathalie G. (1995): "The Valuation of Human Costs by the Contingent Method: The Swiss Experience," in Schwab-Christe, N.G. and Soguel, N.C. (Eds.) *Contingent Valuation, Transport Safety and the Value of Life,* Boston: Kluwer, pg.19–43

Siebert, W.S. and Wei, X. (1994): "Compensating Wage Differentials for Workplace Accidents: Evidence for Union and Nonunion Workers in the UK," *Journal of Risk and Uncertainty,* 9: 61-76.

Transport Canada (1998): *Passenger Report*, Transport Canada Report: TP 9815. Available at http://www.tc.gc.ca/pol/en/Report/anre1998/TC9815DE.HTM

Transport Canada (2000): *Canadian Motor Vehicle Traffic Collision Statistics*, Transport Canada Report: TP 3322. Available at http://www.tc.gc.ca/roadsafety/tp/tp3322/2000/pdf/st2000e.pdf

Transport Canada (2001): *Road Safety Vision 2010-2001 Update*. Available at http://www.tc.gc.ca/roadsafety/vision/2001/world.htm.

Transport Canada (2001): *Canadian Vehicle Survey*, Transport Canada. Available at http://www.tc.gc.ca/pol/en/cvs/files/2001/Annual%_20Averages.pdf

Transportation Safety Board of Canada (2002): *TSB Statistical Summary Rail Occurrences*. Available at http://www.tsb.gc.ca/en/stats/rail/2002/StatsSummaryRail02.asp#forward

Transportation Safety Board of Canada (2002): *Aviation Occurrences in 2002.* Available at http://www.tsb.gc.ca/en/stats/air/2002/StatsSummaryAir02.asp

Transportation Safety Board of Canada (2002): *Marine occurrences in 2002*. Available at http://www.tsb.gc.ca/en/stats/marine/2002/statsummarymarine02.asp

Trawen, Anna, Maraste Pia, and Persson, Ulf (2002): "International Comparison of Costs of a Fatal Casualty of Road Accidents in 1990 and 1999," *Accident Analysis and Prevention,* 34: 323-332.

US DOT (US Department of Transportation) (2000): FAA, "Aviation Accident Investigation Costs", *APO Bulletin, APO-00-1*, August 2000.

Wang, J.S., Knipling, R.R., and Blincoe, L.J. (1999): "The Dimensions of Motor Vehicle Crash Risk," *Journal of Transportation and Statistics,* 2(1): 19-43.

Ware, J.E., K.K. Snow, M. Kolinski and B. Gandeck. (1993): *SF-36 Health Survey Manual and Interpretation Guide*. The Health Institute, New England Medical Center, Boston, MA.

Viscusi, W.K. (2000): "Misuses and Proper Uses of Hedonic Values of Life in Legal Contexts". *Journal of Forensic Economics*, 13: 111-25.

Viscusi, W Kip and Aldy, Joseph (2003): "The Value of a Statistical Life: A Critical Review of Market Estimates Throughout the World," *Journal of Risk and Uncertainty,* 27(1): 5-76.

Zaloshnja, E., Miller, T., and Spicer, R. (2000): *The Costs of Large Truck and Bus Involved Crashes*, FMCSA, Washington, D.C.

Zaloshnja, Eduard, Ted Miller, Eduardo Romano and Rebecca Spicer (2004): "Crash Costs by Body Part Injured, Fracture Involvement, and Threat to Life Severity, United States, 2000." *Accident Analysis and Prevention*. 36(3):415-427.

Table 4.1 Recent Estimates of Value of a Life Year

Study	Study Type	Application	Country	Value of Injury 2002 C$	Value of Injury in Original Currency	Components
Abelson (2003)	Meta-analysis (value from WTP)	Non specific	Intl (value for Australia)	$95,070 Value of Life Year	2002 AU$ 108,000 Value Life Year	Not mentioned
Blomquist (1996)	Contingent Valuation, Time Cost	Road	US	Child - $51,724 to 92,838 Adult –$ 6,8965	Child - 1996 US$ 39,000 to 1996 US$ 70,000 Adult - 1996 US$ 52,000	Without discounting

Table 4.2 The Ex Post Cost of Accidents

	Individual	*Family*	*Rest of Society*	*Society (Sum)*
Direct Costs				
Accident costs	✓		✓	✓
Medical costs	✓		✓	✓
Administrative costs		✓	✓	✓
Indirect Costs				
Productivity losses	✓		?	✓
Absenteeism/worker replacement			✓	✓
Family worker substitution		✓		✓
Taxation	-✓		✓	0
Intangible Costs				
Loss of life (excluding productivity)	✓	✓		✓
Loss of life expectancy	✓	✓		✓
Loss of quality of life, pain and suffering, etc.	✓	✓		✓

Table 4.3 Selected Sample of Injuries by the Abbreviated Injury Scale (AIS)

AIS Code	Injury Severity Level	Selected Injuries
1	Minor	Superficial abrasion or laceration of skin; digit sprain; first-degree burn; head trauma with headache or dizziness (no other neurological signs)
2	Moderate	Major abrasion or laceration of skin; cerebral concussion (unconscious less than 15 minutes); finger or toe crush/amputation; closed pelvic fracture with or without dislocation.
3	Serious	Major nerve laceration; multiple rib fracture (but without flail chest); abdominal organ contusion; hand, foot, or arm crush/amputation.
4	Severe	Spleen rupture; leg crush; chest-wall perforation; cerebral concussion with other neurological signs (unconscious less than 24 hours).
5	Critical	Spinal cord injury (with cord transaction); extensive second- or third-degree burns; cerebral concussion with severe neurological signs (unconscious more than 24 hours).
6	Fatal	Injuries which although not fatal within the first 30 days after an accident, ultimately result in death.

Source: Hoffer, et al. (1998)

Table 4.4 Average per Victim Injury Values for Serious and Minor Injuries – Air

ICAO Code	WTP		Emerg./Med.		Legal		Total	
	2001US$	2002C$	2001US$	2002C$	2001US$	2002C$	2001US$	2002C$
1	37 900	45 884	2 300	2 785	2 700	3 269	42 900	51 937
2	536 600	649 637	31 300	37 893	13 400	16223	580 700	703 753

Source: FAA (1998)

Table 4.5 Summary of Estimated Values of Cost of Injury, by Severity Level (2002 C$)

Source	Type Country	Injury categorization					
		AIS 1 Minor	AIS 2	AIS 3 Serious	AIS 4	AIS 5 Severe	All Levels
Miller (1993)	Estimated Comprehensive US	9,200	161,462	595,051	1,513,554	3,143,794	65,850
	Monetary						15,736
Miller (1993) as FAA (ICAO)	Estimated Comprehensive US	9,200	370,006				65,850
Dionne et al. (1999)	Estimated	92,807					92,807
Hoffer et al. (1998) FAA (ICAO)	Estimated US Air Transport	51,937	703,753				156,228
DOT (2002)	WTP UK	20,550	266,509				59,903
BTE (2000)	Human Capital Australia	11,634	325,651				61,878
Zaloshnja et al. (2000)	Human Capital US	32,413				176,951	55,539
BTRE (2002)	Human Capital Australia	1,949	26,316				5,848
Dillingham et al. (1996)	Wage Risk US	159,502 per year work-life impaired, avoided 247,856 per year work-life impaired avoided					203,679 Average
Lanoie et al. (1995)	Wage Risk Canada	10,084					10,084

Summary of Table 4.5.A

Table 4.5.A Recent Estimates of Cost of Injury

Study	Study Type	Mode	Country	Value of Injury 2002 C$	Value of Injury in Original Currency	Components Included	Components Excluded
DOT (2002)	WTP	Road	United Kingdom	Average Value of Serious Injury: $266,509 Slight Injury: $20,550 Average Value of Injury by Vehicle Type (average over fatal, serious, and slight) Bus: $40,038 Goods Vehicle: $77,818 Car and Taxi: $62,505 Motorized Two-wheeler: $130,835	Average Value of Serious Injury£140,450 Slight Injury: £10,830 Average Value of Injury by Vehicle Type (average over fatal, serious, and slight) Bus: £21,100 Goods Vehicle: £41,010 Car and Taxi: £32,940 Motorized Two-wheeler: £68,950 (2002 UK£)	• Lost output • Medical and ambulance costs • Human costs based on WTP values (for example grief, pain, and suffering)	• Police and Legal costs • Congestion • Property Damage
BTE (2000)	Accounting	Road	Australia	Value of Road Injury Serious Injury: $325,651 Minor Injury: $11,634	Value of Road Injury Serious Injury: $325,000 Minor Injury: $11,611 (1996 AU$)	• Labour losses in the workplace, households, and community • Medical costs (including emergency, hospital, and rehabilitation) • Quality of life losses • Property damage costs • Travel delay costs • Police and fire service costs • Insurance administration costs • Legal costs (including criminal prosecution and insurance claim costs).	
Zaloshnja, Miller and Spicer (2000)	Accounting	Road	US	Average Comprehensive Costs per Victim: Bus: Possible Injury $32,413 to Incapacitating Injury $176,951 Large Trucks: Possible Injury $46,052 to Incapacitating Injury $325,584	Average Comprehensive Costs per Victim: Bus: Possible Injury $25,639 to Incapacitating Injury $139,968 Large Trucks: Possible Injury $36,427 to Incapacitating Injury $257,537 (1999 US$)	• Medical costs • Emergency costs • Property damage costs • Lost productivity • Costs of pain and suffering • Quality of life reductions • Delay costs	• Police and Legal • Congestion • Insurance
Blomquist, Miller and Levy (1996)	Time Costs	Road	US	Car (seatbelt) $0.103, $0.367, $0.078 million Car (all child	Car (seatbelt) $0.07, $0.246, $0.053 million Car (all child safety equipment) $0.091 million	(Estimations of value of avoiding an injury following time costs)	• VSL • VSI • Medical • Police and Legal

				safety equipment) $0.134 million Motorcycle $0.062 Million	Motorcycle $0.042 Million (1991 US$)		• Congestion • Property Damage • Insurance
Schwab-Christe (1995)	Contingent Valuation	Road	Switzerland	WTP/Year to Reduce Own Injury Risk Least Severe: $431 Most Severe: $980 WTP/Year to Reduce Relative's Risk Least Severe: $751 Most Severe: $1,399	WTP/Year to Reduce Own Injury Risk Least Severe: 642 Sfr Most Severe: 1,458 Sfr WTP/Year to Reduce Relative's Risk Least Severe: 1117.2 Sfr Most Severe: 2080.8 Sfr (1995 Prices)	Human costs only: • Loss of life expectancy • Physical and mental suffering of victims and relatives	• Medical • Police and Legal • Congestion • Property Damage • Insurance
Kidholm (1995)	Contingent Valuation	Road	Denmark	For 30% risk reduction: Slight Injury: $184- $260 Serious Injury: $247 - $348 Very Serious Injury: $ 328 - $482	For 30% risk reduction: Slight Injury: £81.5 – £115.1 Serious Injury: £109.5 –£ 154.2 Very Serious Injury: £145.3 – £213.6 (1993 Prices)	Unmentioned	Undetermined
BTRE (2002)	Accounting	Rail	Australia	Value of Rail Injury Serious Injury: $26,316 Minor Injury: $1,949	Value of Rail Injury Serious Injury: $27,000 Minor Injury: $2,000 (1999 AU$)	• Labour losses in the workplace, households, and community • Medical costs (including emergency, hospital, and rehabilitation) • Quality of life losses • Insurance administration costs	• Property damage costs • Travel delay costs • Police and fire service costs • Legal costs (including criminal prosecution and insurance claim costs).
Dillingham, Miller and Levy (1996)	Wage-Risks	Work	US	WTP between $159,502 to $247,856 to avoid 1yr of work-life impairment	WTP between $54,700 to $85,400 to avoid 1yr of work-life impairment (1977 US$)	• Pain and suffering • Loss in lifetime earning capacity	• Medical Costs • Police and Legal • Congestion • Property Damage • Insurance
Lanoie, Pedro and Latour (1995)	Wage-Risk	Work	Can	$10,084	$8,148 (2000 US$)	Unmentioned	Undetermined

Table 4.6 Private and Social versus Monetary and Non-Monetary Costs

	Monetary	Non-monetary
Private	Repair and damage for self-cause crashes, insurance premiums for liability costs inflicted by others	Pain and suffering costs of self inflicted crashes
Social/External	Property damage costs inflicted in uninsured crashes	Pain and suffering, lost productivity inflicted on/by others and not covered by insurance payments

Source: altered from Delucchi, UCD reports

Table 4.7 Summary of the Estimates of the Cost of Accidents - Road (2002 C$)

Author	Type Country	MAIS 1 Minor	MAIS 2	MAIS 3 Serious	MAIS 4	MAIS 5 Severe
Blincoe et al. (2002)	Accounting US	18,585	195,490	388,868	905,421	2,974,005
DOT (2002)	WTP UK	31,784			319,279	
		109,602 Average cost of all accidents 33,700 Value of prevention of all accidents				
Zaloshnja et al. (2000)	Accounting US	Comprehensive Bus			165,884	
		Comprehensive Large Truck			274,343	
		Average per crash Bus			68,843	
		Average per crash Truck (>4540 kg)			95,622	
		Average per crash Truck Trailer			148,305	
Wang et al. (1999)	US	Motor cycle cost per 1000 miles		1,881		
Miller et al. (1999)	US	Motor cycle			9,172 – 24,766	
		Passenger Car/Van			146,766 – 326,881	
		Light Truck			30,020 – 70,292	
		Medium/ Heavy Truck			8,336 – 13,715	
		Bus			2,386 – 3,465	
Miller et al. (1998)	US	22,350				181,600
Miller and Blewden (2001)	New Zealand	10,862	166,966			

Table 4.7.A Recent Estimates of Cost of Accidents

Study	Study Type	Mode	Country	Cost of Accident 2002 C$	Cost of Accident in Original Currency	Components Included	Components Excluded
Blincoe, Seay, Zaloshnja, Miller, Romano, Luchter and Spicer (2002)	Accounting	Road	US	Comprehensive Crash Costs: MAIS 1 $18,585 – MAIS 5 $2,973,000	Comprehensive Crash Costs: MAIS 1 $15,017 – MAIS 5 $2,402,000 (2000 US$)	• Emergency treatment • Initial medical costs, • Rehabilitation costs • Long-term care and treatment • Insurance administration expenses • Legal costs • Employer/workplace costs • Workplace disruption • Household productivity losses • Quality of life losses	• Congestion • Property Damage
DOT (2002)	WTP	Road	United Kingdom	Average Cost of Serious Accident: $ 319,279 Slight Accident: $31,784 Average cost of all accidents: $109,602 Total Prevention of all accidents: $33,700	Average Cost of Serious Accident: £168,260 Slight Accident: £16,750 Property damage only: £1,490 Average Cost of Accidents all injury: £57,760 Total Value of Prevention of all accidents: £17,760 (2002 UK£)	• Lost output • Medical and ambulance costs • Human costs based on WTP values (for example grief, pain, and suffering)	• Police and Legal costs • Congestion • Property Damage
Zaloshnja, Miller and Spicer (2000)	Accounting	Road	US	Average Comprehensive Costs per Accident with injury: Bus$165,884 Large Trucks: $274,343 Average Comprehensive Costs per Accident with fatality: Large Trucks: $4.48 million Average Cost per crash: Bus: $68,843 Truck over 10,000 pounds: $95,622 Truck-Trailer (2 or 3 trailers): $148,305 Costs per 1000 miles: Single Truck Units: $327 Single	Average Comprehensive Costs per Accident with injury: Bus: $131,214 Large Trucks: $217,005 Average Comprehensive Costs per Accident with fatality: Large Trucks: $3.54 million Average Cost per crash: Bus: $54,455 Truck over 10,000 pounds: $75,637 Truck-Trailer (2 or 3 trailers): $117,309 Costs per 1000 miles: Single Truck Units: $259 Single Combination Trucks: $138 Multiple Combination Trucks: $134 (1999 US$)	• Medical costs • Emergency costs • Property damage costs • Lost productivity • Costs of pain and suffering • Quality of life reductions • Delay costs	• Police and Legal • Congestion • Insurance

				Combination Trucks: $174 Multiple Combination Trucks: $169			
Wang, Knipling and Blincoe (1999)		Road	US	Motorcycle Crash Costs per 1000 miles: $3,027	Motorcycle Crash Costs per 1000 miles: $2,331 (1997 US$)	• Medical • Work loss • Property damage • Pain and suffering • Lost quality of life	• Insurance • Congestion • Police and Legal
Miller, Lestina and Spicer (1998a)		Road	US	Crash Costs for: Possible Injury - Disabling Injury: $22,350 - $181,600	Crash Costs for: Possible Injury - Disabling Injury: $16,539 - $134,394 (1995 US$)	• Medical • Work loss • Public service • Employer • Travel delay • Property damage • Monetary • Quality of life costs	• Insurance? (Monetary) • Legal
Miller, Lestina and Spicer (1998b)		Road	US	Motorcycle: $9,172-$24,766 Passenger Car/Van: $146,766-$326,881 Light Truck: $30,020-$70,292 Medium/Heavy Truck: $8,336-$13,715 Bus: $2,386-$3465 Crash Costs per 1000 miles: Motorcycle: $2648 Passenger Car/Van: $208 Light Truck: $150 Medium/Heavy Truck: $256 Bus: $803	Motorcycle: $6,787 - $18,327 Passenger Car/Van: $108,607 - $241,892 Light Truck: $22,215 - $52,016 Medium/Heavy Truck: $6,169 - $10,149 Bus: $ 1,766 – $2,564 Crash Costs per 1000 miles: Motorcycle: $1,960 Passenger Car/Van: $154 Light Truck: $111 Medium Heavy Truck: $189.5 Bus: $594 (1995 US$)	• Medically related costs • Emergency services costs • Property damage • Lost Productivity • Quality of life losses	• Insurance • Congestion • Police and Legal
Miller and Blewden (2001)		Road	New Zealand	Crash Costs for: Minor Injury: $10,862 Serious Injury: $166,966	Crash Costs for: Minor Injury: $12,100 Serious Injury: $186,000 (1996 NZ$)	• Medical costs • Law enforcement • Property damage • Value of lost work • Quality of life	• Congestion
Trawen, Maraste and Persson (2002)			EU	Cost of Fatal Accident Min - $1.26 million Max - $4.43 million	Cost of Fatal Accident Min – $1.00 million Max - $3.5 million (1999 US$)	• Medical costs • Emergency services • Lost productivity • Human Costs All Costs from COST 313	• Congestion

Table 4.8 WTP Costs of Highway Crashes by Method, US, 1993 (in 2002 C$)

Vehicle Type	Method 1	Method 2	Method 3	Method 4
Motorcycle	$24,151	$19,257	$24,766	$11,915
Passenger Car/Van	322,024	350,374	326,881	295,816
Light Truck	57,616	75,030	70,292	102,378
Medium to Heavy Truck (over 4540 kg)	5,247	12,292	13,715	17,084
Bus	2,638	3,670	3,465	5,473

Table 4.9 Human Capital Costs of Highway Crashes by Method, US, 1993

Vehicle Type	Method 1	Method 2	Method 3	Method 4
Motorcycle	8,984	7,147	9,172	4,345
Passenger Car/Van	144,584	154,627	146,766	129,976
Light Truck	26,253	31,927	30,020	46,000
Medium to Heavy Truck (over 4540 kg)	7,707	7,876	8,336	9,930
Bus	2,101	2,436	2,386	3,342

Source: Miller, Levy, Spicer, and Lestina (1998)
Note: Medium to Heavy Truck estimates are averaged values for unknown medium to heavy trucks, other single trucks and combination trucks (tractor trailers, triples, and truck tractor without trailers) offered separately in the original paper.

Table 4.10 WTP Values per AIS Injury Level

AIS Code	Fraction of WTP Value of Life (%)	WTP Value (2001 US$)	WTP Value (2002 C$)
AIS 1	0.20	6 000	7 264
AIS 2	1.55	46 500	56 295
AIS 3	5.75	172 500	208 838
AIS 4	18.75	562 500	680 993
AIS 5	76.25	2 287 500	2 769 370
AIS 6	100.00	3 000 000	3 631 961

Source: OST (1993)

Table 4.11 NHTSA Unit Costs per Injury Type (2002 C$)

	PDO	MAIS 0	MAIS 1	MAIS 2	MAIS 3	MAIS 4	MAIS 5	Fatal
Medical	0	1	2,946	19,338	57,543	162,507	411,457	27,345
Emergency services	38	27	120	262	455	1,027	1,054	1,031
Market productivity	0	0	2,165	30,962	88,433	131,731	542,952	736,829
HH productivity	58	41	708	9,062	26,083	34,665	184,787	237,056

Insurance administration	144	99	917	8,551	23,382	40,019	84,402	45,941
Workplace cost	63	42	312	2,417	5,280	5,814	10,137	10,770
Legal costs	0	0	186	6,165	19,564	41,689	98,832	126,408
QALYs	0	0	5,514	112,793	158,548	474,562	1,617,371	2,956,905
Subtotal	**303**	**210**	**12,866**	**189,550**	**379,290**	**892,015**	**2,950,993**	**4,142,285**
Travel delay	994	957	962	1,047	1,163	1,236	11,322	11,322
Property damage	1,837	1,261	4,757	4,894	8,415	12,170	11,691	12,714
TOTAL	**3,134**	**2,428**	**18,585**	**195,490**	**388,868**	**905,421**	**2,974,005**	**4,166,321**

* PDO stands for Property damage only. Unit costs in this category are per damaged vehicle; otherwise unit costs are per injured (or dead) person.
Source: Blincoe et al. (2002)

Table 4.12 BTRE Unit Costs per Injury Type (2002 C$)

	Serious injury	**Minor injury**
Market	27,296	0
Household and Community	24,805	0
Labour lost	**52,100**	**0**
Lost of quality of life	**34,297**	**1,823**
Ambulance	255	138
In-patient	5,504	28
Other medical	8,263	40
Long-term care	90,657	0
Medical	**104,678**	**206**
From insurance claims	21,189	1,267
From prosecution	449	55
Legal costs	**21,638**	**1,322**
Workplace disruption	**8,318**	**539**
TOTAL	**221,031**	**3,890**

Source: BTRE (2000)

Table 4.13 Estimated Costs of Road Transportation Accidents

	Internal Cost by Source		External cost by Source				Total Cost	
	Car/bus: Miller et al. 1995 US $, Truck: Zaloshnja et al, US $, per 1000 mile	**Canadian cost per 1000 km with ppp conversion**	Miller et al. 1995 US $ per 1000 mile	Grosclaude and Soguel 2002 Swiss cent per km	**Canadian Cost per 1000 km, Miller 1998b**	**Canadian Cost per 1000 km, Grosclaude and Soguel, 1990**	**high**	**low**
Vehicle Type								
motorcycle	1960	**1471.73**	391	13.8	**152.819**	**32.9277**	**1624.54**	**1504.65**
vehicle	154	**115.64**	43	2.2	**16.8062**	**5.24934**	**132.44**	**120.88**
bus cost	594	**446.02**	514	1.3 interurban 9.5 urban	**200.893**	**3.10188**	**646.92**	**449.12**
truck - light	259	**190.92**	46	1.5	**19.22**	**3.579**	**102.57**	**86.93**
truck - heavy	138	**101.73**	173.5	1	**72.48**	**2.38607**	**214.78**	**144.68**
Registered Passenger Vehicles %								
motorcycles		0.02			0.02	0.02		
vehicles		0.98			0.98	0.98		
estimated cost of interurban vehicle		**142.76**			**19.53**	**5.80**	**162.28**	**148.56**
estimated cost of urban vehicle		**142.76**			**20.07**	**21.07**	**162.83**	**163.83**
Registered Trucks %								
light		0.57			0.57	0.57		
heavy		0.43			0.43	0.43		
estimated cost of truck		**152.57**			**42.12**	**3.07**	**194.69**	**155.64**
buses								
estimated cost of interurban bus		**446.02**			**200.893**	**0.310188**	**646.92**	**446.33**
estimated cost of urban bus		**446.02**			**200.893**	**2.26676**	**646.92**	**448.29**

Table 4.14 Per Victim Medical and Legal Costs Associated with Injuries

AIS Code	Emergency/Medical	Legal/Court	Total direct costs

	2001 US$	2002 C$	2001 US$	2002 C$	2001 US$	2002 C$
AIS 1	600	726	1 900	2 300	2 500	3 027
AIS 2	4 000	4 843	3 100	3 753	7 100	8 596
AIS 3	16 500	19 976	4 700	5 690	21 200	25 666
AIS 4	72 500	87 772	39 100	47 337	111 600	135 109
AIS 5	219 900	266 223	80 100	96 973	300 000	363 196
AIS 6	52 600	63 680	80 100	96 973	132 700	160 654

Source: OST (1993)

Table 4.45 Risk Cost per Unit of Exposure, in 2002C Cents per Loaded Car-Km (in 1994 US Cents per Loaded Car-Mile in parentheses)

Safety Hazard	**Environmental Hazard**		
	High	Medium	Low
Poison Inhalation CD (US)	1.42 (1.03)		
Flammable/Combustible	15.01 (10.88)	3.6 (2.61)	1.57 (1.33)
All Other	38.97 (28.25)	0.95 (0.69)	0.23 (0.17)

Table 4.16 Freight Transport – Internal Cost of Rail Accidents - Averages of 1998-2002

	Fatalities	Serious Injuries	
Reported			
Crossing	36.4	45.4	
Trespassing	60.2	25.2	
Other	3.8	16	
Total	100.4	86.6	
Vehicle involved	29.4	40.8	
% vehicle involved	0.30	0.47	
Million main-track train-miles (mmttm)	79.46		
	per fatality	**per serious injury**	
Cost	$4,250,000.00	$330,875.00	
	fatalities per mmttm	**serious injuries per mmttm**	**Cost per mmttm**
Rates			
Crossing	0.46	0.57	$2,136,330.56
Trespassing	0.76	0.32	$3,326,000.36
Other	0.05	0.20	$270,347.87
Total	1.26	1.09	$5,732,678.79
Vehicle involved	29.40	40.80	
% vehicle involved	0.30	0.47	
Average number of fatalities per year			
100.4361526			
Avoiding 38.4 death per year on average			

62.03615264	0.78072178	1.09	$3,678,815.21
38.4 death per year on average			
38.4	0.483262019	1.09	$2,414,611.22

*stats per million main-track train-miles
source: http://www.tsb.gc.ca/en/stats/rail/2002/statssummaryrail02.asp

Table 4.17 US Federal Accident Investigation Costs by Component (in 2002C$; 2002US$ in parentheses)

Type of investigation	NTSB	FAA				Total
		AVR	Flight inspection	Aviation Medicine	FAA Sub-total	
Major	2 308 005 (1 931 800)	812 545 (680 100)	1 195 (1 000)	717 (600)	814 456 (681 700)	3 122 461 (2 613 500)
Field office :						
Regular	45 759 (38 300)	28 793 (24 100)	1 195 (1 000)	717 (600)	30 705 (25 700)	76 464 (64 000)
Limited	358 (300)	16 487 (13 800)	0	0	16 487 (13 800)	16 846 (14 100)
Weighted Average by User Type :						
Air carrier (including taxi)	131 780 (110 300)	67 145 (56 200)	1 195 (1 000)	717 (600)	69 056 (57 800)	200 836 (168 100)
General Aviation	9 200 (7 700)	18 996 (15 900)	239 (200)	119 (100)	19 355 (16 200)	28 554 (23 900)

Table 4.18 US Federal Accident Investigation Costs (in 2002 C$; 2002 US$ in parentheses)

Type of investigation	NTSB	FAA	Total Federal	Private	TOTAL
Major	2 308 005 (1 931 800)	814 456 (681 700)	3 122 461 (2 613 500)	7 088 769 (5 933 300)	10 211 231 (8 546 800)
Field office :					
Regular	45 759 (38 300)	30 705 (25 700)	76 464 (64 000)	68 578 (57 400)	145 042 (121 400)
Limited	358 (300)	16 487 (13 800)	16 846 (14 100)	0	16 846 (14 100)
Weighted Average by User Type :					
Air carrier (including taxi)	131 780 (110 300)	69 056 (57 800)	200 836 (168 100)	335 603 (280 900)	536 440 (449 000)
General Aviation	9 200 (7 700)	19 355 (16 200)	28 554 (23 900)	13 381 (11 200)	41 935 (35 100)

Source: APO Bulletin, August 2000

Table 4.19 Internal Air Transport Costs per 100,000 flight hours, in 2002 (2002 C$)

	Cost of injury*			
Fatality	$4,250,000.00			
Serious injury	$330,875.00			
	Interurban	Freight/work	Unaccounted	total
Hours flown (100,000 hr)	20.83	13.13	33.96	33.96
Accidents	53	213		266
Accident rates per 100,000 flight hours	2.54	16.22		7.83
Fatality total	7.00	36.00	4.00	47.00
Fatality rate	0.34	2.74	0.12	1.38
Fatality (proportion of total)	0.15	0.77	0.09	1.00
Injuries	6.30	32.30	3.80	42.00
Injury rate	0.30	2.46	0.11	1.24
Cost of Accident per 100,000 flight hours	$1,527,491	$12,466,656	$536,985	$6,292,205
Costs of investigation per 100,000 flight hours	accident rate	investigation cost per accident	investigation costs	
Interurban	2.54	$536,440.00	$1,362,557.60	
Freight	16.22	$41,935.00	$680,185.70	
Total	interurban	freight		
	$2, 890049	$13,146,842		

*per 100,000 of flight time
From Transportation Safety Board Summary Air Statistics 2002
http://www.tsb.gc.ca/en/stats/air/2002/StatsSummaryAir02.asp)

Table 4.20 Number of Vessels Lost by Gross Registered Ton (grt), Canada

Vessel Capacity Category grt	**1600 +**	**150 – 1599**	**60 – 149**	**15 – 59**	**15 or less**	**Unknown tonnage**
Average Number of Vessels Lost per Year (97 – 02)	.8	3	5.7	13	18.3	7.9

Table 4.21 Total Internal Marine Accident Rates per 1000 commercial trips (in 2002 C$)

	Cost		
Injury			
Fatal	$4,250,000.00		
Serious	$330,875.00		
Category	**Rate**	**Cost per 1000 trips**	**Cost per trip**
Fatalities			
Interurban			
Ferry	0.02	$66,075.87	$66.08
Private	0.06	$264,303.48	$264.30
Work related			$726.83
Marine	0.14	$594,682.84	$594.68
Fishing	0.20	$858,986.32	$858.99
Total	0.42	$1,784,048.51	$1,784.05
Injuries			
Interurban			
Ferry	0.28	$92,595.62	$92.60
Private	0.05	$15,432.60	$15.43
Work related			$95.17
Marine	0.12	$41,153.61	$41.15
Fishing	0.45	$149,181.83	$149.18
Total	1.13	$375,526.66	$375.53
Number of trips	64,300		
	Internal cost per trip		
Urban			
Ferry	$158.67		
Private	$279.74		
Work related	$822.00		

*All stats per 1000 commercial trips, Transport Safety Board Summary Statistics for 2002, Marine

Table 4.22 Summary of Financial and Social Costs of Transportation Accidents in Canada, 2002, by Mode and Unit*

Total	Unit	Estimate range 2002 C$		Allocation	External	Internal	Internal	Costs not included
Inter urban					**General**	**WTP**	**Invest-igation**	
Private Vehicle	Per 1000 km	High 162.28	Low 148.56	**Fully?**	5.8 – 19.53	142.76		
Air	Per 100,000 hour flight time	2.89 million		**WTP , investigation**		1,527,000	1,360,000	Property damage only, cost of crash, replacement costs
Bus	Per 1000 km	High 646.92	Low 446.33	**Fully?**	0.310 - 200.89	446.02		
Rail	Per mmttm	5.732 million		**Partial**		5.732 million		property damage only, hazardous materials
Ferry	Per trip	158.67		**Partial**		158.67		property damage only, hazardous materials, replacement costs, emergency response
Urban								
Marine	Per trip	279.74				279.74		property damage only, replacement cost, emergency cost
Private Vehicle	Per 1000 km	High 163.83	Low 162.83	**Fully?**	20.07 – 21.07	142.76		
Urban Transit	Per 1000 km	High 646.92	Low 448.29	**Fully?**	2.27 - 200.90	446.02		
Freight								
Truck	Per 1000 km	High 194.69	Low 155.64	**Fully?**	3.07 - 42.12	152.57		hazardous materials
Rail	Per mmtttm	5.732 million		**Partial**		5.732 million		hazardous materials, emergency services
Marine	Per trip	822.00		**Partial**		822.00		property damage only, hazardous materials, cost of crash, emergency services
Air	Per 100,000 hour flight time	13.15 million		**Partial**		12,467,000	680,000	property damage only, cost of crash, replacement costs, emergency services

*all estimates include WTP, health and legal for costs of victims injured, by severity but do not include the cost of time delay due to accidents.

Appendix 4.1 Sensitivity Analysis Of Accident Cost Estimates With Respect To The Income Elasticity Of Safety And The Canada To Us Income Ratio

Road Accident Cost Analysis

US to CAN multiplier	0.85	0.85	0.85
Elasticity	e=0.5	e=.75	e=1
Cost			
Estimated cost of interurban vehicle	$153.21	$147.00	$140.79
Estimated cost of urban vehicle	$153.21	$147.00	$140.79
Estimated cost of truck	$98.53	$94.53	$90.54
Buses			
Estimated cost of interurban bus	$461.37	$442.67	$423.96
Estimated cost of urban bus	$461.37	$442.67	$423.96

Marine Accident Cost Analysis

US to CAN multiplier		1	0.85	0.85	0.85
Elasticity		e=1	e=0.5	e=.75	e=1
Cost					
VSL	$4,250,000	$4,250,000	$4,250,000	$4,250,000	$4,250,000
Injury	$314,505	$414,817	$383,706	$366,076	$352,594
Cost per trip					
Urban					
ferry	$154	$182	$173	$169	$165
private	$279	$284	$282	$281	$281
Work related	$817	$846	$837	$832	$828

Rail Accident Cost Analysis

US to CAN multiplier Elasticity		1 e=1	0.85 e=0.5	0.85 e=.75	0.85 e=1
Cost					
VSL	$4,250,000	$4,250,000	$4,250,000	$4,250,000	$4,250,000
Injury	$314,505	$414,817	$383,706	$366,076	$352,594
Cost per million main track miles					
Crossing	$2,126,974	$2,184,305	$2,166,525	$2,156,449	$2,148,743
Trespassing	$3,320,806	$3,352,635	$3,342,764	$3,337,170	$3,332,892
Other	$267,049	$287,259	$280,991	$277,439	$274,723
Total	**$5,714,830**	**$5,824,199**	**$5,790,280**	**$5,771,058**	**$5,756,359**
Avoiding 38.4 death per year on average	$3,660,967	$3,770,336	$3,736,417	$3,717,194	$3,770,336
38.4 death per year on average	$2,396,763	$2,506,132	$2,472,212	$2,452,990	$2,438,291

Air Accident Cost Analysis

US to CAN multiplier Elasticity		1 e=1	0.85 e=0.5	0.85 e=.75	0.85 e=1
Cost					
VSL	$4,250,000	$4,250,000	$4,250,000	$4,250,000	$4,250,000
Injury	$314,505	$414,817	$383,706	$366,076	$352,594
Cost per 100,000 hours flight					
Interurban	$1,522,580	$1,552,674	$1,543,340	$1,538,051	$1,534,007
Freight/Work	$12,426,386	$12,673,154	$12,596,620	$12,553,251	$12,520,085
Unaccounted	$535,184	$546,219	$542,797	$540,857	$539,374
Total	$6,271,906	$6,396,293	$6,357,715	$6,335,854	$6,319,136

Chapter 5: Noise Costs

5.1 Introduction

The objective of this investigation is to develop an approach to developing measures of the noise costs associated with each considered mode of transportation. Noise costs are a product of two factors: the quantity of noise and the economic valuation of the noise. Therefore, two broad research paths are to develop means of measuring noise exposure and to assess the different approaches to valuing noise.

One of the first questions asked must be, is the noise an externality to users or to those outside of the system? In some cases, congestion, for example, all users may internalize an externality in the system but not users outside of the system. In the situation of noise, users of the system internalize nothing while those outside the system internalize everything. One might argue that those who are also road users absorb road noise or that road noise is also partly internalized because others 'accept' noise on an implied contract to be able to generate noise. This type of argument could be applied to a number of externalities. In the case of noise the argument is hard to make since there is no correspondence between noise generation and noise reception at some later date, nor is there a strong general correspondence between noise generation and noise damage at some future date. Noise damage from road, rail and transit use depends on where and when the noise is generated. This is true for air, auto, rail and truck while it may be less true for public transit.[116] Therefore, the full costs of noise should be included in the calculations of full social costs because the noise externality is generated by the components of the transportation system but paid for (through a loss of consumer surplus) by agents outside the system; those beside the airport, the roadway and the rail tracks

In measuring noise generation we need to understand the linkages between economics and externalities. The underlying [economic] drivers for economic activity are principally pricing, financing, investment, regulations and policing. These lead to physical transportation activity including vehicle kilometers of travel (people and cargo), infrastructure, vehicle stock, vehicle composition, use patterns and vehicle design. Not all of these physical characteristics affect output volume and quality and hence the amount of the externality. Measuring the externality, and hence pricing it, will be contingent on given technologies. The physical outputs and features give rise to externalities, in our case measures of noise exposure. Thus the linkage is from economic conditions to physical output to externalities.

[116] I am thinking here of buses where the suppliers of transit services do not consider the external noise costs in choosing capital or operations management.

5.2 Issues in Measuring the Cost of an Externality

Revisiting the ideas explored in Chapter 1, the cost of an externality is a function of two equations. The first relates the physical production of the externality to the amount of transportation output. The second computes the economic cost per unit of externality. The amount of an externality produced by transportation is the result of the technology of the transportation, as well as the amount of defense and abatement measures undertaken. There are several issues of general concern in the physical production of externalities. They are classified as: fungibility, geography, life cycle, technology, and point of view. The more detailed exploration of this issues remains in Chapter 1.

5.3 Estimating the Cost due to Noise

5.3.1 Methods for Estimating the Amount of Noise [Exposure]

There are numerous noise metrics ranging from single event to cumulative noise measures. Gillen and Levesque (1990) provide a comprehensive survey for aviation related noise metrics. One of the difficulties they point out is the value of quiet is not independent of the metric used; a single noise event would lead to a difference in valuation than would a cumulative noise metric. There is no literature that has tried to measure these potential systematic biases.

Noise is usually defined as unwanted sound. Sound is most commonly measured by the decibel (dB), which is defined as follows (Starkie and Johnson 1975):

(1) $$\mathbf{dB = 10 \log_{10} (P^2/P_{ref})}$$

where: P = pressure in Newtons/m^2

P_{ref} = 0.00002 Newtons/ m^2, which is the quietest audible sound.

The frequency of sound is measured in cycles per second (Hertz), the range from 20 - 16,000 Hertz can be heard by the human ear. Generally, sound measures are weighted to reflect what is perceived as "loudness." The most common weight, the A scale, gives the measure dB (A), where the number of decibels is weighted by sound at various frequencies to give equivalent loudness.

When performing noise-cost studies, sound, which varies over the course of time, must be averaged to give an equivalent loudness, which is the continuous energy mean equivalent of the noise level measured over a specific period. This is further translated into an index such as the Noise Exposure Forecast (NEF), which is defined as follows for highways. Measures for air are similar though the number of events is stratified between daytime and nighttime flights and weighted accordingly.

(2) $$\mathbf{NEF = Lepn + 10 \log_{10} N - 88}$$

where: Lepn = Effective perceived noise level (loudness)
N = number of events

It is important to note that due to the logarithmic scale of noise measurement the amount of noise measured is not linearly additive with the number of vehicles. For instance, one truck may generate 80 dB (A) noise, but two trucks will only generate 83 dB (A).

5.3.2 Measuring Noise Generation

Next we need to measure the amount of noise generated by a vehicle/aircraft/unit interacting with its infrastructure and how much of this noise is received by people (noise exposure). Factors that influence this include background flow, the size of the vehicles, their speed, materials of the pavement surface, overflight paths and weather. In addition, ground cover, obstruction, barriers, the grade of the road or slope of take-off, the grade of surrounding land, and presence of buildings influence the propagation of the noise over distance. The most important factor to consider is what is ambient noise and what is the increment with the presence of a particular mode of transport.

For highways, rather than measure the noise associated with each car, the noise is generally associated with the overall flow. The basic noise level measured is L_{10}, the amount of noise exceeded 10% of the time (UK DOT 1988). The 1 hour basic noise level is given by equation (3), and the additive corrections (Cpv) for mean traffic speed and heavy vehicles is given in equation (4), and the adjustment for distance from the edge of the roadway is given in equation (5):

(3) $\mathbf{L_{10} = 42.2 + 10 \log_{10} q \text{ dB (A)}}$

(4) $\mathbf{Cpv = 33 \log_{10} (V + 40 + 500/V) + 10 \log_{10} (1 + 5p/V) - 68.8 \text{ dB(A)}}$

(5) $\mathbf{Cd = - 10 \log_{10} (d/13.5) \text{ dB(A)}}$

where: V = mean traffic speed in km/hr
p = percentage of heavy vehicles
q= hourly traffic flow
d = shortest slant distance from the effective source (meters)

Noise due to aircraft can be associated with airports and with aircraft flying overhead not in the process of takeoff or landing. Most research in this domain has dealt with noise around airports. While it is the aircraft that actually generate the noise, it is the airport, the most convenient point of complaint that is held responsible.

The annoyance caused by noise is due to a number of unique factors, including individual preferences, socio-economics, environmental conditions, local topography, specific flight paths, and number of flights. Aircraft noise production is tied to the “stage” of the aircraft, its level of technology, which is related to its age and size. The aircraft technology determines total engine thrust needed, and is thus an influence in noise production.

5.3.3 Measuring the Value of Noise [Quiet].

The damages caused by noise include the loss of sleep, lower productivity, discomfort and annoyance. These are hard to quantify, but because they are associated with a place, the amount of damage is often viewed as resulting in lower property values. This provides a basis for establishing a value for noise (quiet). A number of studies have been performed over the years to measure the decline in residential property value due to noise and its associated vibration. This has not been done for non-residential (commercial and public) buildings, however, where abatement measures are more cost-effective. Tables 5.1 and 5.2 summarize empirical findings of noise damage by roads and airports from hedonic models of housing collected by Nelson (1982a,b), Modra and Bennett (1985), and others. These studies use a noise depreciation index (NDI), the percentage reduction of house price per dB(A). The average NDI for all of the airport noise surveys since 1967 (excluding the first three) is 0.62, the same value as for highways.

5.4 Review of Noise Literature

5.4.1 Aircraft noise

Gillen and Levesque (1989) in their review of 15 HP studies on aircraft noise (and one combined HP and Delphi study) in mainly U.S. cities found NDI in the range from 0.4 to 1.1 % per dB, with a median value of 0.5-0.6 %. In a more recent review, including also recent HP studies, Bateman et al (2000) found reported NDIs (i.e. the percentage decrease in housing prices following a 1 dB increase in noise pollution) in the range from 0.29% to 2.3% for aircraft noise (see tables 5.6 and 5.7 at the end of this chapter for an overview of these studies). The variety of NDI values presented in these studies should not come as any surprise. Theoretically, we would not expect different housing markets to have the same hedonic price function and, therefore, would not expect applications of the hedonic pricing technique in different cities in different years to return identical results.

Schipper (1996) has carried out a more formal statistical test of these results using meta-analysis. He finds that the implicit price of aircraft noise pollution is influenced by a number of factors including the timing, country and specification of the original noise studies. His findings suggest that as a baseline the NDI is around 0.33% whilst for studies in the United States this rises to 0.65%.

Gillen and Levesque (1991) also examined runway expansion projects at the Pearson International Airport in Toronto, Canada. They found NDIs of 0.48 and 0.21 % for single/semi-detached houses and condominiums, respectively. Gillen and Levesque (1990) report another HP study regarding the establishment of the same airport, with estimated NDIs are 0.43 and 0.08 % for single-family homes and condominiums, respectively. They point out that these impacts should be corrected for the positive impact of accessibility (estimated as elasticity for house value with distance equal to –0.02 and –

0.04 for single family homes and condominiums, respectively) to calculate the net effect of the airport.

A HP study of rental charges for apartments in Paris (exposed to road traffic noise levels between 50 and 80 dB(A)) should also be considered. Furlan (1996) found a NDI of 0.20 – 0.33%.

Few SP studies (all contingent valuation methods - CVM) have been conducted on aircraft noise, and none present WTP in terms of annoyance levels. The first of the CVM studies seems to be Opschoor (1974), which by current standards would be considered archaic. Pommerehne (1988) conducted parallel HP and CVM studies on aircraft noise in Basel, Switzerland, and found a mean WTP per household per month of 22 and 32 SFr, respectively. Thus, for aircraft noise there is a larger difference between these two methods than observed for road traffic noise. Navrud (2000b) conducted a CVM survey of persons exposed to aircraft noise and other sources (road, train and rifle range) in the communities of Oslo and neighbouring Ullensaker (where Oslo Airport is located).Thune-Larsen (1995) performed in-person interviews of 473 respondents around the Oslo Airport Fornebu (now closed, and replaced by the Oslo Airport Gardermoen) using both CVM and conjoint analysis (CA) techniques to value aircraft noise. Scenarios with percentage reductions in noise levels were used (different percentage changes in the CA and a 50 % reduction scenario only in the CVM question). Mean WTP per household per month of 91-460 NOK and 104-353 NOK (1 NOK = 8 euro) were estimated for the CA method and CVM, respectively.

Findings in a recent article using meta-analysis (Nelson, JTEP 2004) suggested that the noise discount for housing **in the U.S.** was 0.5 to 0.6 per dB. Hence a property located in 55 dB would sell for 10-12 percent less if it were located in a 75 dB zone. However, in Canada, he found the discount seems to be higher, from 0.8 to 0.9 per cent per dB. This is a surprising result given differences in noise exposure.

5.4.2 Road traffic noise

For road traffic noise NDIs have been reported that range from 0.08% to 2.22%, see Table 5.2 below (Bateman et al, 2000). A simple mean for these studies is an NDI of around 0.55. Bateman et al (2000) conclude that an "average" value lies somewhere in the lower part of this range. Nelson (1982) reviewing 14 studies for the United States and Canada concludes that the average NDI is around 0.4% whilst more recent work by Bertrand (1997) suggests the average figure may be as high as 0.64%. Bertrand used a meta-analysis to compare 16 estimates from nine different hedonic pricing studies of noise pollution carried out in the USA, Canada, Switzerland and Finland. His results provide insights into how the hedonic price function varies from market to market. In line with expectations, the greater the average level of noise in a market and the greater the income of the market's households, then the higher the implicit price that is paid for noise pollution reductions. Nelson's (2004) recent contribution stands in contrast to Bertrand's work.

Bateman et al (2001), in their review of studies, point out that the use of a single statistic to compare studies conceals considerable heterogeneity in the exact method of their application. As an example, each of the studies deals with noise in a slightly different manner. While the majority of studies have plumped for the L_{eq} measure of noise, the method by which the noise pollution impacting on a particular house is assessed can be very different from study to study. A number of studies adopt the noise contour approach whereby data from various monitoring points are used to construct bands of similar noise pollution across the urban environment. The noise pollution experienced by any particular property will depend on the band in which it falls. Studies using this approach include Gamble et al. (1974). More advanced measures of noise pollution can be achieved by using models that take account of the exact characteristics of a particular dwelling. Data from these models are likely to be much more accurate. Studies taking this approach include Pommerehne (1988), Soguel (1991) and Vainio (1995). Bateman et al (2000) also observe that studies vary considerably in the choice and accuracy of the explanatory variables used in the regression analysis and in the choice of functional form, and this affect the level of the observed NDI.

Among studies that are not included in these reviews is the HP study in Glasgow. By using GIS they are able to increase the number of independent variables in the HP function and measure them with greater accuracy (Lake et al 1998). They construct four different models where they start with only traffic noise level and only structural variables (i.e. characteristics of the house) in Model I, and then add on neighbourhood variables, accessibility variables, and finally also variables indicating the visual (dis) amenity of the land use surrounding the property (one being views of roads and traffic flows along them) for models II, III and IV, respectively. The implicit price for noise, i.e. NDI, drops from 0.84 % in model I to 0.57, 0.42 and 0.20 in models II, III and IV, respectively. In model I the observed NDI is an indicator for multiple environmental impacts of road traffic, while the much lower NDI of the most complete specification of the HP function (model IV) is a much better representation of the specific impact of noise annoyance by road traffic. Distinguishing the separate influence of noise may be relatively difficult though it is essential to include comprehensive measures of accessibility and the visual disamenity of roads. If this is not done then it is likely that the implicit prices estimated for noise will erroneously include the impacts of these factors and will, of course, be upward biased

Bateman et al (2001) also cites the study JMP Consultants Ltd. (1996) did for the UK Department of Transport valuing the nuisance from road traffic by asking the opinion of expert property evaluators. Using a large sample they concluded that the best estimate of the NDI was 0.29% per dB increase or decrease in noise pollution. This result falls in the range of values commonly reported from hedonic studies but is somewhat lower than the average of values reported in the hedonic literature.

Pommerehne (1988), Soguel (1991,1994) and Vainio (1995) have used the contingent valuation approach to produce results that they can compare with those derived from their hedonic analyses. The Pommerehne (1988) study in Basel, Switzerland produces remarkably similar results. Estimating households' WTP to reduce noise pollution by half, the hedonic price method returns a result of 79 Swiss Fr per month compared to a value of 75 Swiss Fr per month derived from the contingent valuation survey. In a similar manner, the Soguel study in Neuchatel, Switzerland produces highly comparable results. Again valuing households' WTP to reduce noise pollution by half, the research estimates a value of 60 Swiss Fr per month from the hedonic pricing method (Soguel, 1991) and a value of between 56 and 67 Swiss Fr per month from the contingent valuation method (Soguel, 1994)

The Vainio (1995) study in Helsinki, Finland is not so favourable. Though Vainio has to make a number of assumptions to compare his two datasets, he concludes that a change in noise pollution levels from L_{eq} 65 to L_{eq} 55 would be valued at FIM 18,420 using the hedonic pricing method and at almost three times this amount (FIM 51,600) using the contingent valuation approach.

In a CVM survey of a random sample of about 1,000 households in Navrud (2001) found significantly different WTP for persons HA (highly annoyed) compared to those that were little or not annoyed. Mean WTP per household per year was 335 and 101 1996-NOK (1 NOK = 8 euro) for these two annoyance groups, respectively. Only 6 % of the households in this random sample were HA. Navrud (2000b) found a mean WTP per household per year of 1.520 – 2.200 NOK (equivalent to 165-275 euro) for the elimination of the noise annoyance from road traffic in Oslo. Assuming that this is equivalent to a reduction in experienced noise level by 8 dB (A), it implies an economic value of 21-34 euro per dB per exposed household per year. All households interviewed were exposed to noise levels of 65 dB and above. No significant difference in WTP was found for the four different annoyance levels in which respondents classified themselves, nor between WTP and the noise levels respondents were exposed to.

In a CVM survey of 331 households living along highways in the Rhône-Alpes Region in France Lambert et al (2001) found significantly different WTP for a public program that would eliminate noise annoyance at home for respondents that classified themselves in five different annoyance levels. While the overall mean WTP per household per year was 73 euros, the corresponding values for the annoyance levels "not at all", "slightly", "moderately", "very" and "extremely" were 47, 61,78, 101 and 130 euros, respectively.

The Thune-Larsen (1995) study also used CVM to value road traffic noise in the same area and for the same respondents. Mean WTP per household per month for a 50 % reduction in noise level was valued at 78 NOK (about 10 euro) per household per month (which was lower than the corresponding value for the same percentage reduction in aircraft noise from the CVM study).

Table 5.1: Hedonic pricing studies of loss in property value from *Road Traffic* noise (% depreciation in house prices per 1 dB(A) increase in noise level)

Source Study	Study Year	Study Area	Noise Measure	NSDI

Allen, 1980†	1977-79	North Virginia, Va., USA	L_{10}	0.15
	1977-79	Tidewater, Va., USA	L_{10}	0.14
Anderson and Wise, 1977†	1969-71	Towson, Md., USA.	NPL	0.43
	1969-71	North Springfield, Va., USA	NPL	0.14
Bailey, 1977†	1968-76	North Springfield, Va., USA	Log of Distance	0.3
Gamble et al., 1974†	1969-71	Bogotoa, N.J., USA	NPL	2.22
	1969-71	Rosendale, Md., USA	NPL	0.24
	1969-71	North Springfield, Va., USA	NPL	0.21
	1969-71	All three areas	NPL	0.26
Grue et al.,1997		Oslo, Norway – *Obos*	L_{eq}	0.24
		Oslo, Norway – *Flats*	L_{eq}	0.21
		Oslo, Norway – *Houses*	L_{eq}	0.54
Hidano et al., 1992*		Tokyo, Japan	L_{eq}	0.7
Hall et al., 1978†	1975-77	Toronto, Canada	L_{eq}	1.05
Hall et al., 1982		Toronto, Canada – *Arterial*	L_{eq}	0.42
		Toronto, Canada – *Expressway*	L_{eq}	0.52
Hammar, 1974		Stockholm, Sweden	L_{eq}	0.8 –1.7
Iten and Maggi, 1990		Zurich, Switzerland	-	0.9
Langley, 1976†	1962-72	North Springfield, Va., USA	NPL	0.22
Nelson, 1978†	1970	Washington, D.C., USA	L_{dn}	0.87
Palmquist, 1980, 1981†	1962-76	Kingsgate, WA., USA	L_{10}	0.48
	1958-76	North King County, WA, USA	L_{10}	0.3
	1950-78	Spokane, WA, USA	L_{10}	0.08
Pommerherne, 1988	1986	Basel, Switzerland	L_{eq}	1.26
Renew, 1996a		Brisbane, Australia	L_{eq}	1.0
Soguel, 1991	1990	Neuchatel, Switzerland	L_{eq}	0.91
Vainio, 1995		Helsinki, Finland	L_{eq}	0.36
Vaughan & Huckins, 1975†	1971-72	Chicago, USA	L_{eq}	0.65

Wibe (1997) performed a CVM study of 4000 randomly selected people in Sweden, asking for their WTP in terms of increased rental charges for their dwelling to eliminate noise from all sources. A response rate of 58 % in this postal survey gave 2322 useable observations. 50 % stated zero WTP, while the remaining 50 % were willing to pay 400 SEK per month per household. Thus, the overall WTP for the sample was estimated at about 200 SEK per month per household, or about 6.5 % of the mean monthly rental charge. Questions about level of annoyance from different noise sources (including noise from neighbours) were also asked.

Arsenio et al (2000) and Sælensminde and Hammer (19949 / Sælendminde 2000 both apply choice experiments (CE) to road traffic noise in Lisbon, Portugal and Oslo/Akershus in Norway, respectively. Arsenia et al interviewed 412 persons, and found a WTP of about 7900 escudos per month to avoid doubling of noise. They found virtually no relationship between the absolute rankings and physical noise measures. Sælendminde (2000) reports WTP per annoyed person per year of 3,550-7,100 NOK for road traffic noise.[117] Garrod et al (2001) also use CE to estimate WTP of a sample of local residents in three English towns for traffic calming measures. Scarpa et al (2001a)) reports the results from a DC-CV study on the benefits of speed reductions on rural trunk roads in the UK. Scarpa et al (2001b) compares the results from the two SP techniques.

5.4.3 Rail noise

Only two original valuation studies on rail noise have been identified, both of them HP studies. However, the CVM scenario, annoyance level questions and noise exposure data of Navrud (2000b) also include railway noise.

Strand and Vågnes (1996) used both HP and Delphi studies of real estate brokers in one part of Oslo (Gamlebyen near the Main Railway station, using a Multi Criteria Analysis technique): Using distance to the rails as an proxy of noise, that semi-detached and single family houses would be exposed to, this HP study finds that a doubling of the distance to the tracks would mean a 10 % increase in property prices. In the Delphi study a mean WTP of 2,000 1996 NOK per meter increased distance to the track was found. All results are for apartments. For single family and detached houses the impact is 20-27 % higher than for apartments.

A HP study on railway noise n Sydney, Australia (Holsman and Paparoulas 1982) found that the occurrence of railway noise in areas with no benefits from increased accessibility reduce property prices by 10 %.

5.4.4 Industrial noise and other types of noise

No valuation studies specifically on industrial noise have been identified. However, the HP study of Oosterhuis & Van der Pligts (1985) looked at both road traffic noise and industrial noise. They found a NDI of 0.4 % for the combined impact of the two noise sources. The CVM scenario, annoyance level questions and noise exposure data of Navrud (2000b) also included rifle range noise and industrial noise (but no noise exposure data for the latter).

[117] NOK is Norwegian Kroner. At current exchange rates, $1 CAN=5.50 NOK

5.4.5 Summary

The noise valuation literature is dominated by HP studies (most of them old) on road traffic and aircraft noise of varying quality. However, NDI estimates from HP studies seem to be problematic to transfer, both theoretically and in practice (Day 2001).

There is an increasing number of SP studies on road traffic noise, but only a few present WTP in terms of "euro per annoyed person per year" for different annoyance levels, which correspond to endpoints of exposure response functions (ERFs). Due to the low number of studies that can be used for this approach, a "second-best" alternative is to evaluate all these SP studies with regards to quality (e.g. avoid using studies with scenarios based on changes in exposure rather than annoyance and health impacts), choose the best ones, and calculate a value in terms of "euro per dB per person per year". The number of high quality European studies on road traffic noise might be sufficient to establish a EU value based on this approach. For noise from air, rail and industry there seem to be too few SP studies to evaluate whether the same values as for road traffic noise can be used. Due to the different characteristics of these four types of noise, one would expect that these exposure-based values would differ between different noise sources (while the preferred annoyance based unit value would probably not be so sensitive to the source of noise). Another uncertainty the per dB approach faces is the conversion of WTP values for relatively large discrete changes in noise valued in SP studies to marginal values assuming linearity. Benefit function transfer might be used to reduce this uncertainty.

In addition to benefit transfer in space, one might also have to transfer values in time. This is usually one using the consumer price index (CPI) as a proxy. However, it is still an open question whether the CPI of the study country or the policy country that should be used. Also, one should consider whether the CPI is representative of the change in value over time for noise annoyance.

5.4.6 Integration

In order to translate noise production rates into economic damage costs we must estimate total residential property damage costs per linear kilometer of a roadway or around airports. A model was developed and run through a number of scenarios to develop simplified average (and marginal) cost functions by applying the equations in the earlier subsections. Application of the noise model under certain assumptions, gives us an average cost curve for the noise damage associated with each passenger kilometer traveled depending on the number of vehicles per hour (Qh).

The model is solved by dividing the area on each side of the roadway into 10-meter strips (s) parallel to the road. Each 10-meter by one kilometer strip has a number of housing units (Hs) depending on the density. The total damage for each strip is computed based on multiplying the homes by the value (HV) of each home by the noise depreciation index (NDI) by the net increase in the NEF (after (NEFa) - before (NEFb)). The total damage as a present cost (P) is summed over all the ten-meter strips for a one-kilometer stretch.

$$P = \sum_{s} (H_s)(HV)(NDI)(NEF_a - NEF_b)$$

Because of the logarithmic shape of the noise curves, the higher the level of background noise, the smaller the percentage increase in noise production, but individual sensitivity to noise rises non-linearly with increases in noise. The costs are linear with respect to density, home value, noise depreciation index, and the number of passengers (as determined by capacity and load factor). It is non-linear with respect to speed and number of vehicles per hour. For automobile travel the integrated highway noise model gives a range of between \$0.0001/vkt and \$0.0060/vkt average cost, depending on flow, when we assume a speed of 100 km/hr and 10% heavy vehicles, a discount rate of 7.5%, a noise depreciation index of 0.62, an average home value of \$250,000 and a typical suburban density of 360 houses per square kilometre. At an auto occupancy of 1.5 and flow of 6,000 vehicles per hour, this converts to <u>\$0.0045/pkt</u>.

AChn = [- 0.018 + 0.0028 ln (Qh)] fD * fH * fC
where: fD = Density/360 (default = 1)
fH = House Value/\$250,000 (default = 1)
fC = Cost per dB(A)/0.0062 (default = 1)

To compare, INFRAS/IWW (1995) gives noise estimates from Europe of \$0.0058/pkt for automobiles, about the same for buses (\$0.0054/pkt) and \$0.0163/tkt (tonne km traveled) by truck. This study calculated an estimated noise cost per exposed person, mostly derived from willingness to pay studies, and the estimated number of exposed persons at various levels of exposure. Based on macroscopic mode shares, and adjusting for the noisiness of modes, the total costs were allocated. It is notable that the results are on the same order of magnitude as our own with such widely diverging methodologies. For cars, Miller and Moffet (1993) report a range from \$0.0008/pkt to \$0.0013/pkt, in 1990 U.S. dollars. For buses, they take \$0.0003/pkt as an acceptable value.

Table 5.3 shows the estimated noise costs per passenger kilometer traveled generated by air travel in eight countries. The average value for these results is <u>\$0.0048/pkt (\$C 2002)</u>, which is used here. For two reasons those numbers should be expected to be higher in Europe than in the United States. First noise standards are not as strict on aircraft engines, and second population densities (and thus impacted populations) are higher.

An alternative approach would require conducting economic engineering studies around specific airports. In principle the methodology would be similar to that used for highways. However specific details about the noise generation of aircraft using each airport, flight paths, airline schedules, land uses, and topography would be required. This would provide the effective perceived noise level and noise exposure forecast for specific geographical zones. For each zone, a hedonic model could be applied to estimate the reduction in property value due to air traffic noise. This capitalized value would need to be allocated to specific aircraft, and then to passengers and passenger kilometers based on flight lengths.

A third approach would use the implied value of noise damage resulting from damages awarded by courts settling lawsuits. A given award would be taken to be damages, which again would need to be allocated to aircraft, passengers, and passenger kilometres.

Table 5.2 Noise Depreciation Near Airports

Researcher	Study Area	Range of noise level	Range of NDI	Best NDI (NEF)	Year	Average House Value
			(%)	(%)		
Paik	New York	20-40	1.9-2.0	1.9	1960	$16,656
Paik	Los Angeles	20-40	1.8-2.0	1.8	1960	$19,772
Paik	Dallas	20-40	2.3-2.6	2.3	1960	$18,011
Emerson	Minneapolis	20-50	0.4	0.58	1967	$19,683
Dygert	San Francisco	25-45	0.5-2.0	0.50	1970	$27,600
Dygert	San Jose	25-45	0.1-1.5	0.70	1970	$21,000
Price	Boston	25-45	0.6	0.83	1970	$13,000
Mieszkowski	Toronto/ Etobicoke	20-35	0.3-1.3	0.50	1969-73	
De Vany	Dallas	20-55	0.2-0.8	0.58		
Nelson	Washington, DC	20-35	1.0-1.1	1.10	1970	$32,724
	Rochester		0.55	0.55	1980	
	Sydney/ Marrickville		0.50	0.50	1980	
	Edmonton		0.50	0.50	1980	
	London		0.68	0.68	1980	
O'Byrne	Atlanta					
Pennington	Manchester	27-40		0.47	1990	£30,886
Gillen, Levesque	Toronto	0-40		0.18	1990	C195,809
	AVERAGE			**0.62**		

Table 5.3 Noise Costs Generated by Air Travel

Country	**Average Cost/pkt**
Canada	0.0043
Germany	0.0054
Italy	0.0087
Holland	0.0110
Sweden	0.0015
Switzerland	0.0019
France	0.0033
United Kingdom	0.0020
Average	0.0048

source: Quinet 1990, IBI 1995
note: all values converted to $C 2002

5.5 Practical Applications of Noise Charges

Europe is the only jurisdiction where some airports levy noise charges in an attempt to encourage the use of quieter aircraft or quieter flying. The US does not have a formal noise charge policy but some airports have put in place penalties if an aircraft when taking off or landing exceeds a specified noise level. Similar types of penalties have been put in place in Australia but only in limited circumstances. Canada has no noise charges.

ICAO (*ICAO Manual of Airport and Air Navigation Facility Tariffs* (Doc 7100)) has developed a set of criteria on which to base noise related charges. However, the primary focus on reducing noise is through technology (quieter aircraft and engines). Aircraft manufacturers, Boeing for example, are developing procedures to reduce noise mostly on takeoff.

5.5.1 European Noise Charging/Mitigation Systems

Some examples of European noise charging systems are outlined below. These charges are not driven by the need to recoup costs, and in some cases the revenues are used off-site to fund mitigation measures (e.g. soundproofing neighbouring properties).

Schiphol Noise Charging Scheme (CAA Netherlands 2002)

Section 1
"The charge applicable according to the amount of noise generated, is related to the extent to which individual aircraft engage available capacity within Schiphol's noise contours. The basis is the noise production in EPNdB values per aircraft, according to the certification as acknowledged and accepted by ICAO. Within the Chapter 3 certified aircraft the DEPNdB has to be determined. The DEPNdB is calculated by subtracting the sum of the three Chapter 3 limit values (in accordance with ICAO document ANNEX 16, Volume 1) by the sum of the three EPNdB noise certification values. The following noise categories have been defined:

- noise category A: 0 ³ DEPNdB > -9 (noisiest aircraft);
- noise category B: -9 ³ DEPNdB > -18 (average-noise-producing aircraft);
- noise category C: DEPNdB **L** -18 (relative-low noise aircraft).

Amsterdam Airport Schiphol establishes the noise categories, in accordance with Section 4 of this article.

Section 2
For aircraft, which are not Chapter 3 certified, the following is applicable:

- noise category B: Chapter 2 aircraft;
- noise category B: all helicopters;
- noise category C: all aircraft < 6 tonnes MTOW and all (turbo)prop aircraft **L** 9 tonnes MTOW.

Section 3
If the noise certification values of an aircraft are not available for Amsterdam Airport Schiphol the charges according to noise will be based on the most unfavourable configuration of that aircraft type .

Section 4
A change in the noise category can be established at any time, given that such a change can only be executed after proper consultation of the airlines at the airport and/or their representative bodies (SAOC/BARIN). Any of the airlines at the airport and/or their representative bodies (SAOC/BARIN) can request the airport for a change in noise categories. The airport will then start the consultation process with the airlines and/or their representative bodies (SAOC/BARIN) and will provide a well-founded decision as to whether it will honour the request or not within four weeks.

The effect of changes cannot take place sooner than one month after Amsterdam Airport Schiphol has given notice of its intention to the airlines at the airport and/or their representative bodies (SAOC/BARIN). A change cannot be enforced retroactively.

Section 5
The applicable noise categories will be made public to all airlines at the airport and their representative bodies (SAOC, BARIN and IATA). The airport will do this by sending them the Airport Charges Regulation.**"**

Frankfurt Airport[FRA] Noise Charging Scheme
A new schedule of noise charges became effective at FRA from January 2001. The new system ties charges to actual measured noise emissions with higher charges for night-time flights. Unlike in the past when charges were based primarily on aircraft weight, the new charges are primarily based on actually measured aircraft noise levels. Particularly high charges apply for loud aircraft during night-time hours.

Aeroports de Paris
The airports charge aircraft for noise generation in the same way as Frankfurt, complying with ICAO methods and standards. In both cases the noise charge is added into the landing fee and is based on weight and engineering noise characteristics, not actual noise generated. It is also not clear how 'noise damage' is established in setting the level of the charge.

BAA (Heathrow, Gatwick, Stansted)
BAA does not have a noise charge in place at any of the airports but does have a system of fines if a given flight path is not followed. The use of quieter aircraft is a result of negotiated agreements with the carriers.

EU Directive on Environmental Noise
On 21st May, 2002, the Council of Ministers formally approved the EU Environmental Noise Directive. Directive 2002/49/EC of the European Parliament and of the Council of 25th June 2002 relating to the assessment and management of environmental noise is now being implemented in the EU Member States.

The Environmental Noise Directive is a direct result of the European Union's Noise Policy Green Paper from 1996. It covers transportation and industrial noise in the environment. The directive requires that noise maps and action plans (noise policy) be made for:

- Settlements with populations greater than 100 000
- Major roads with more than 3 000 000 vehicles a year (approximately 8 000 a day)
- Major railways with more than 30 000 trains a year
- Major civil airports with more than 50 000 operations year (approximately 135/ day)

Noise maps show the L_{DEN} (the L_{Aeq} where evening and night time levels are given a penalty of 5 and 10 dB, respectively) and L_{night} (the night time L_{Aeq}) of each type of source (road, rail, industry, etc.) at a height of 4m over the ground. Aggregation of levels from different sources can be performed with a stated method. The European Union required maps made of transportation and industrial noise to use current models that comply with certain demands. The following methods were recommended:

Industrial sites: ISO 9613
Roads: NMPB-96 (the French method)
Railways: RLM2 (the Dutch method)
Airports: ECAC 29

The first maps for major areas are required by mid 2007, and action plans required one year later. These activities are repeated at five yearly intervals and all defined areas are incorporated in the following round of deadlines starting in 2012. The above are minimum requirements and some countries are expected to go further.

EU countries have moved forward on developing noise strategies for road and rail in a number of cases but there is a less comprehensive policy and set of strategies for air. These strategies appear to be much more focused on limiting noise to some set standard, where the standard is established on a mix of health and economic data. The initial work is establishing a base line with noise mapping and establishing the amount of noise that people are exposed to from different sources. The underlying economic cost measures are seemingly based on a review of the numerous studies that have been carried out in Europe and elsewhere. Noise depreciation indices are used to provide a basis of willingness to pay to reduce noise.

Aviation and Full Social Costing

There are no examples of full social cost prices being introduced at airports or for any other mode of transportation. A study carried out in 1986 for Toronto International airport calculated a set of socially optimal prices taking account of infrastructure and operating costs for the airport but also congestion and noise costs.[118] Examining Table

[118] See D. Gillen. M. Tretheway and T. Oum, *A Study of Peak Period Pricing with an Application to Toronto International Airport* (report to Airport Authority Group, Transport Canada May 1988)

5.4 it is evident that noise costs constitute almost half of total social prices for peak pricing and the majority of the price for off-peak prices.

Table 5.4 Social Marginal Cost Pricing per Operation

Social Marginal Cost Pricing per Operation by Time of day and Aircraft Type

				External Congestion Costs**			
				Peak Season		Off-Peak Season	
Aircraft Type	Noise Cost	SRMC (to airport)	Off-Peak SRMC*	High Peak	Low Peak	High Peak	Low Peak
B747-200	$ 200	$ 6	$ 206	$ 220	$ 40	$ 65	$ 20
L1011	$ 132	$ 6	$ 138	$ 220	$ 40	$ 65	$ 20
DC10-30	$ 150	$ 6	$ 156	$ 220	$ 40	$ 65	$ 20
DC10-10	$ 125	$ 6	$ 131	$ 220	$ 40	$ 65	$ 20
B737-200	$ 123	$ 6	$ 129	$ 140	$ 25	$ 41	$ 13
B727-200	$ 132	$ 6	$ 138	$ 140	$ 25	$ 41	$ 13
B767-200	$ 89	$ 6	$ 95	$ 220	$ 40	$ 65	$ 20
DC9-30	$ 138	$ 6	$ 144	$ 140	$ 25	$ 41	$ 13
A310-300	$ 102	$ 6	$ 108	$ 220	$ 40	$ 65	$ 20
DNC-7	$ 67	$ 6	$ 73	$ 140	$ 25	$ 41	$ 13
DHC-8	$ 67	$ 6	$ 73	$ 140	$ 25	$ 41	$ 13
J31	$ 46	$ 6	$ 52	$ 130	$ 24	$ 39	$ 12
Business Jet	$ 75	$ 6	$ 81	$ 130	$ 24	$ 39	$ 12
GA	$ 25	$ 6	$ 31	$ 130	$ 24	$ 39	$ 12
DC-8-63	$ 164	$ 6	$ 170	$ 220	$ 40	$ 65	$ 20
B737-300	$ 105	$ 6	$ 111	$ 140	$ 25	$ 41	$ 13
MD-80	$ 96	$ 6	$ 102	$ 140	$ 25	$ 41	$ 13
B757	NA	$ 6	NA	$ 140	$ 25	$ 41	$ 13

Notes:
* Sum of noise and SRMC
** Added to off-peak SMC to obtain total peak SMC
Study: D Gillen, M Tretheway and T Oum, *Social Margianl Cost Pricing for PIA* (TC 1986)

The ability to levy noise charges requires that the noise cost be expressed in terms of the unit of output for the mode of transportation. In the case of air it would be per flight or per passenger; most likely per flight since noise and aircraft size to vary. For road, rail and truck modes it would be per vehicle km of travel. While absolute noise levels will depend not only on the vehicle type but on operating conditions and total volume of transportation and other noise generating activity, this level of complexity is difficult to produce in results. This is the reason Gillen and Levinson (1996) use pkt (per kilometer of travel) in their development of noise costs since these must be aggregated with other costs, infrastructure, operations and other externalities, to establish the full social cost.

Land use and Airports

In the EU directive on noise policy, one of the costs identified was the reduction in productivity (or utility) of or from land in areas of high noise. The lowering of utility would be captured by the noise depreciation index from hedonic price studies. The reduced productivity may not be captured since land use planning has been in place for a number of years. However, the primary motivation for restricting land use near airports and along approach and departure paths was initially due to safety not noise concerns.[119] Subsequently noise became a bigger issue.

The issue of land use and alternative uses is more of a general equilibrium problem since the thought experiment would not be what would land use be if there was less or no noise associated with the airport. Rather it would be what would land use be in the absence of having an airport? One could also make the argument that the amount of land around an airport represents a small proportion of total land in an urban and near urban area. Thus even admitting some limitations on land use, there will be a very small impact on overall supply of land for particular uses.

Recent ICAO Discussions

Aircraft noise characteristics are included under Annex 16 in the ICAO standards and under Stage 3 in the FAA standards. The two sets of standards are quite similar and for the most part FAA designations are used in common practice. An aircraft is technically measured based on take-off and landing weight, engine type and type of aircraft body and wing to have certain thrust, sideline, takeoff and landing features. In each case a particular aircraft with a specific type of engine (make and size) will have a given noise footprint (for landing and one for takeoff) which describes the amount of noise, measured in dB (A) received for a standard takeoff and landing sequence. The noise is produced not as measured noise but as the [theoretical] amount of noise that would be produced according to a set of technical specifications.

While ICAO members in different regions of the world, may hold differing views when it comes to noise regulation, the ICAO does provide statements regarding noise mitigation and management to guide countries, in their words, to a balanced, consistent and efficient approach to noise problems. In the past and this seems to be the current thinking, noise solutions are technical not market based. The emphasis is therefore on reducing engine noise at source including quieter engines, fuselage design and operational procedures not on providing incentives to produce the optimal amount of noise through either technical features or flying methods. In addition land use planning to reduce the numbers of people exposed to noise is a 'recommended' option. In all, the ICAO approach is supply side oriented in that the emphasis is on the continued provision of air service and the protection of suppliers. To quote:

> *"8.8.1 The existing ICAO guidance identifies the principle that noise related charges should be non discriminatory between users and not be established at such levels as to be prohibitively high for the operation of certain aircraft. However, a noise-related economic instrument, depending on application, could have an unexpected and unintended effect on the operators or a specific*

[119] This comment would apply to restrictions on building heights as well.

operator at an airport by limiting access to that airport. Whether or not an economic instrument may impose a restriction on an operation at an airport, its impact would be determined by an assessment of the situation at the airport and in consultation, consistent with the balanced approach, between the Authority and the stakeholders."

Section 8.8.1 is effectively minimizing the role and adoption of pricing and any other economic instrument as a means of moving in the direction of an economically efficient level of noise at a given location.

5.6 Numbers for Applying Noise Charges in Social Marginal Cost Pricing

Integration of the costs of noise externalities into socially efficient pricing of transportation services requires a means of modelling a 'representative' consumer in a representative environment. This means that introducing a price for using 'quiet' must be implementable in a relatively easy fashion, otherwise the costs of implementation may override the gains in economic efficiency.

In the case of aircraft noise the value of quiet has been relatively well established. Nelson (2003) for example, provides fairly strong evidence that the 'representative' noise depreciation index would be approximately 0.5 to 0.6 per dB change from the current value of noise exposure. We noted earlier that his finding for Canada was a depreciation of 0.8 to 0.9. This would mean a home in an area with a status quo ambient sound of 55 dB would fall in value by 17 % in Canada (and 12% elsewhere) if noise increased to 75 dB.

However, examining the change in noise level does not necessarily provide the correct basis for levying noise charges. It would be in the case of a benefit-cost assessment of a change in noise generating activity resulting from an investment in capacity or a change in management strategy, for example. The question to ask for integrating noise costs into pricing might be, 'what would the level of noise be if there were an optimal level of activity'? As the benchmark for measuring the noise costs, it would be for an airport, the optimal amount of traffic for which social marginal costs equal social marginal benefits; where the sum of social costs and avoidance costs are minimized. This level of traffic, in the case of airports, would yield a level of noise measured by NEF or some other conventional cumulative noise metric.[120]

The value of quiet could be established using the following social experiment. Reduce noise exposure around a 'representative' airport to a level coincident with the socially optimal amount of traffic.[121] Next for a 'representative' homeowner, start taking money

[120] The noise level would take a range depending on the type of aircraft used and the timing of the flights. Timing would affect the day-night noise weighting.

[121] The reasoning appears circular here since having a socially efficient level of traffic implies one already has an efficient price for noise. But this is not necessarily the case since the optimal traffic level is where the sum of social cost and abatement cost are minimized. A noise price is not required to establish this level of traffic.

for the noise reduction and continue taking money until the homeowner states any further payment would not be worth the noise reduction. This is a measure of willingness to pay. The use of property value models to establish noise valuation accomplishes, in effect, the same thing as this choice experiment, similarly for valuing quiet from road noise. [122]

Therefore a total noise cost for a facility (road, rail or airport) could be measured as the value lost from housing for both value in exchange (lost property value) and value in use (utility from use). The first is represented as asset depreciation costs:

$$\sum_{i=1}^{l}\sum_{j=1}^{q}\sum_{t=1}^{r}\left[\left(V_{ijt}\right)\bullet\left(P_{ij}\right)\bullet\left(d_t\right)\left(\Delta N_{ijt}\right)\bullet\left(M_{ijt}\right)\right]\bullet\left(\frac{1}{1+i}\right)^t$$

and the second by noise nuisance costs (measuring the lost usage value for those who do not move):

$$\sum_{i=1}^{l}\sum_{j=1}^{q}\sum_{t=1}^{r}\left[\left(V_{ijt}\right)\bullet\left(P_{ij}\right)\bullet\left(\Delta N_{ijt}\right)\bullet\left(NM_{ijt}\right)\right]\bullet\left(\frac{1}{1+i}\right)^t$$

where:

V_{ijt} is the weighted average market value of house type i in noise exposure contour j at time t.

P_{ij} is the property depreciation or price of noise.

ΔN_{ijt} is the change in the number of houses of each type in a noise exposure contour as a result of a shift in noise contours.

M_{ijt} is a measure of the 'movers'; those who leave (enter) the area for reasons other than noise as well as because of increase (decrease) in noise exposure.

NM_{ijt} is the number of people who remain in the neighbourhood with the change in airport operations

V^*_{ijt} is the valuation of the average house by the homeowner reflecting the utility, consumption and investment value of the house.

d_t is the duration cost to the homeowner and is a measure of the discounted present value of foregone income as a result of houses in noisy neighbourhoods being on the market for a longer period of time.

In principle the noise cost will be contingent on the impact on the different types of housing (in most cases detached, attached and rental are used), the division between those who move out of the environment and those who choose not to do so, the impact of noise as measured by the noise depreciation index and the discounting of all measured costs over a time horizon.

As an example, we use information from a study of Noise Costs at Pearson International Airport by Gillen and Levesque (1991) in which the change in costs is measured for a change in noise exposure. With a 16% change in the average level of noise exposure,

[122] Keep in mind the assumptions underlying these models of full information and full mobility.

using the two formula**e** illustrated above, total noise costs over 5 years (discounted at 4%) were C$366,198,102. The number of operations over this 5-year period was estimated to be 1,828,390. **Thus, the noise cost per operation would be approximately $200. The average aircraft size using Pearson International Airport was 120 seats, and the noise charge per seat would be $1.67. With inflation this figure in 2002 $ would be approximately $1.96/passenger.** This figure is not significantly different from that developed by Gillen, Oum and Tretheway (1986) in a study discussed earlier.

The calculation for airports is on a per operation basis since the noise externality is localized. For roadways the measure would be better based on a per km use of facilities. There have been a number of studies that have calculated values per passenger kilometre of travel (pkt). Gillen and Levinson (1995) calculate a range of **$** .0001 to .0060 per pkt (the range in 2002 $C is 0.0007 – 0.007), INFRAS calculates a value of.0058 pkt (US$s) and Miller & Moffett find arrange of **$** .0008 to .0013 (US$s) **In the table below the average for the three studies is calculated as well as the value of the cost per year for an average driving distance of 12,000km. The cost per year would, on average be approximately $45.67/year ($C 2002) or .0038 cents per km.** However, it seems more reasonable to affix the price on a per km basis, or some combination of fixed and variable fee, in order that cost is directly tied to use.

There are not sufficient numbers of studies for rail or other modes to provide reasonable estimates of noise charges. A number of studies for truck noise charges have been made. Such charges would depend to a large extent on how jurisdictions routed t**r**ucks through urban and near-urban areas.

Table 5.5 Range of Measures of Unit Noise Cost for Roadway Noise ($C 2002)

Study	Low	Mean	High
Gillen & Levinson	0.0006	0.0038	0.0070
INFRAS		0.0064	
Miller & Moffett	0.0009	0.0012	0.0015
Average	0.0008	0.0038	0.0042
Cost per year ($C 2002)	$ 9.09	$ 45.67	$ 50.92

Summary

Implementation requires a significant investment in information. The Europeans who are currently working at moving to socially efficient pricing for all modes of transportation have recognized this fact. As we have pointed out above their first task in developing noise strategies is to first develop noise maps for areas meeting specific criterion. In the case of noise, the noise damage is contingent on a number of factors including population density, ambient sound levels, noise exposure, discount rates and broad macroeconomic conditions in the housing market. With road noise, for example, a 600 km trip from Toronto to Montreal would be mostly (80%) through low or zero density housing and therefore no noise exposure would be experienced. The numbers calculated from the table above assume all 12,000 km of travel are in urban or near urban areas. Efficient pricing is directed to having an economically efficient level of traffic and overpricing in rural areas will simply lead to an inefficient level of use of infrastructure.

Populating the Table (Noise Externalities)

The economically efficient regulatory solution to the noise externality is to set a [Pigouvian] tax that removes the difference between the marginal social and marginal private cost of modal activity i. Activity would be flights for airplane noise, km for auto, truck, bus, transit and rail. The tax would be the marginal cost incurred by homeowners of an additional flight or an additional km. Note that figures quoted are in 1995 US$s, conversion to $C will be at current exchange rates.

Aggregate Aircraft Noise Costs and Noise Tax

Following Morrison, Winston and Watson (1999)[123] it is reasonable to assume each flight adds about 0.02 dBA to the <u>daily</u> day-night noise level and about 0.000055 dBA to the <u>annual</u> day-night noise level.[124] Each flight has an arrival and departure, despite difference in the noise levels of each respective event (takeoffs generate more noise than landings), we assume an average and therefore <u>each flight</u> adds 0.00011 dB to the <u>annual</u>

[123] See *Journal of Law and Economics*, Vol. Vill, No. 2 (October) 723-745

[124] Based on FAA information for measuring noise characteristics of aircraft and classifying Stage 3 and 3+ aircraft.

noise levels at the houses surrounding airports. The consensus from the literature is a measured willingness to pay 0.5 to 0.7 % per each decibel reduction. Morrison and Winston (1999) argue, I believe correctly, that willingness to pay measures derived from hedonic studies do not account for noise impacts on recreational properties, institutions and businesses. Therefore they suggest increasing the noise depreciation to *1 % per decibel*; this means a 1 dB reduction in noise increases the present value of affected homes by 1 %.

To construct a noise tax for each of the 26 NAS airports in Canada, assume each added flight, in perpetuity, depreciates the value of affected homes surrounding these airports by 0.00011 % for a flight. If we assume a discount rate of 5 %, this yields an annualized depreciation of 0.0000055 %.

Information requirements for each airport include: the number of homes exposed to 65 dBA (inside the 35 NEF noise contour), median values for these homes, the number of annual operations at each airport and the marginal private cost of a flight. The marginal private cost is calculated as the weighted average CASM [cost per available seat mile] for an average of Air Canada (a representative full service airline) and Westjet (a representative low cost carrier), multiplied by the average stage length flown by each carrier.

Aggregate Road/Rail Noise Costs and Noise Tax

The basis of the calculation for aggregate noise costs, and the subsequent tax, follows the procedures developed by Gillen et al. (1996).[125] The cost per unit of output is calculated separately for highway (car), truck and rail. The noise depreciation is set at 0.62 % for each unit increase in dB. Unlike air, the value was not adjusted for depreciation of business and institutions since a number of studies have found conflicting evidence as to what the net affect of noise exposure is on property values since noise exposure is tied to access; locations with better access generally have more noise. When studies included access and noise exposure in regressions, the depreciation index averaged 0.6 % per dB.

In order to translate noise production rates into economic damage costs the following model is developed. This model estimates total residential property damage costs per linear kilometer of a roadway or railway. The model was run through a number of scenarios to develop simplified average and marginal cost functions (see Gillen et al. 1996, Chapter 3). Costs are calculated per vehicle kilometer of travel.

Rail: the average social costs [ASC] per tonne kilometer is given by:

$ASC= [0.0050 - 0.0015\ ln\ Q_t]/12$ where Q_t is the number of trains per hour..

The underlying assumptions include the value of homes, density of homes along the track, noise depreciation index, change in amount of noise and speeds. For rail the speed

[125] See D. Gillen, D. Levinson, A. Kanafani and Jean-Michael Mathieu, *The Full Costs of Intercity Transportation: A Comparison of High Speed Rail, Air and Highway Transportation in California*, (Institute for Transportation Studies, University of California, UCB-ITS-RR-96-3

is assumed to be 200 kilometers per hour. To translate the cost per passenger kilometer, to tonne kilometers divide the calculated cost by 12.[126]

To calculate the total noise costs for Canada we need the number of trains per hour in a given jurisdiction. As with airports selecting the top metropolitan areas that account for 90 % of the Canadian population would provide a reasonable estimate of rail noise costs.

Highway-car: as with rail the noise costs depend on the assumptions regarding house values, density of population, noise depreciation, measuring willingness-to-pay, and speed and flow of vehicles. For automobile travel a range of between \$0.0007/vkt and \$0.0070/vkt average cost, depending on flow, given the assumptions of Interest Rate = 7%, Years = 30, Home Value = \$250,000 Density = 360HH/sqkm, Cost/dB(A) = 0.0068 (\$C 2002), a speed of 100 km/hr, and a maximum range of 500 m on each side of the highway. This converts to \$0.0045/pkt, however this value is extremely sensitive to assumptions. [127]

Calculations for specific jurisdictions can be made using the model developed by Gillen et al. (1996) in which the average cost (AC_{HA}) for automobiles per vehicle km of travel (vkt) is:

$$AC_{HA} = f(D)* f(H) * f(C) (- 0.018 + 0.0028 \ln (Q_h))$$

where Q_h is the traffic flow in vehicles per hour, and f(D) is housing density, f(H) is value of home and f(C) is the noise discount rate.[128] The total costs of noise for automobile for a given jurisdiction can be calculated with information on the total vehicle-km of travel in a year.

Highway- truck and Bus: There are a limited number of studies that have separately estimated noise costs for bus and truck. INFRAS/IWW (1995) provides noise estimates from Europe of \$0.0054/pkt for buses and \$0.0163/tkt (tonne km traveled) by truck. This study calculated an estimated noise cost per exposed person, mostly derived from willingness to pay studies, and the estimated number of exposed persons at various levels of exposure. Based on macroscopic mode shares, and adjusting for the noisiness of modes, the total costs were allocated. It is notable that the results are on the same order of magnitude as in Gillen et al. (1996) with such widely diverging methodologies.

For cars, NRDC (Miller and Moffet 1993) reports a range from \$0.0008/pkt to \$0.0013/pkt urban based on studies by Keeler (1975) and Hokanson (1981), in 1990 U.S. \$s. For buses, they take \$0.0003/pkt as an acceptable value.

---

[126] Generally a passenger is assumed to be 200 pounds. Thus 10 passengers would be 1 tonne. This calculation is based on air travel. For rail, expectations are people would travel lighter thus 12 persons is used instead of 10.
[127] This value is established assuming an auto occupancy of 1.5 and flow of 6,000 vehicles per hour.
[128] The values used in the modelling were assumed to be f(D) = Density/360 (default = 1), f(H) = House Value/\$250,000 (default = 1) and, f(C) = Cost per dB(A)/0.0062 (default = 1). Thus to use different values they would be expressed in terms of the values originally used. For example, if housing density is assumed to be 400, it would be expressed as f(D)=(400/360)=1.11 or a 11% higher density.

Therefore total noise cost calculation for truck would be based on a value of $.018/tkt ($C 2002) times the total tonne–km for a given jurisdiction. It would seem reasonable that the jurisdictions used in measuring auto noise costs would be used for truck noise as well. For bus the total noise costs would be calculated as $0.0044 per passenger km ($C 2002), again using the same jurisdictions as for auto and truck.

Appendix A

Relationship between NEF and LdN

The relationship between the components of the NEF measure and between NEF and Ldn (used predominantly in the U.S.) are presented below. Sel and Epnl are similar measures of the single event noise level and are measured in decibels. The N_d, N_e and N_n are the number of day (0700-1900), evening (1900-2200) and night (2200-0700) flights respectively. The formulas for NEF and Ldn place different weights on each type of flight. Night flights are weighted at 16 times day flights, for example. The formulas for the two measures are:

$$NEF = Epnl + 10 \log (n_d + n_d + 16.67\ n_n) - 88$$
$$Ldn = Sel + 10 \log (n_d + n_d + 10\ n_n) - 49.4$$

The first thing one notes upon examining the table is the close correspondence between the two measures, however, it is also evident that the variance in the two measures differs according to the source. In the first six rows, the number of flights is held constant, as are the proportions between day, night and evening flights. Only the level of sound is allowed to vary. An increase in the sound level from 80 to 108 decibels (a 35% increase) results in a more than doubling of the NEF measure (a 132% increase) and a 47.42% increase in the Ldn measure. The remaining three parts of the table illustrate changes in Ldn and NEF with changes in the frequency of flights.

Sel	**Epnl**	**Nd**	**Ne**	**Nn**	**Ldn**	**NEF**	**Ldn-NEF**
108	108	360	140	20	87.05	49.21	37.84
105	105	360	140	20	84.05	46.21	37.84
102	102	360	140	20	81.05	43.21	37.84
101	101	360	140	20	80.05	42.21	37.84
98	98	360	140	20	77.05	39.21	37.84
80	80	360	140	20	59.05	21.21	37.84
90	90	500	140	20	69.84	31.88	37.96
90	90	450	140	20	69.58	31.65	37.92
90	90	400	140	20	69.29	31.41	37.88
90	90	350	140	20	68.99	31.16	37.83
90	90	300	140	20	68.66	30.88	37.78
90	90	250	140	20	68.31	30.59	37.71
90	90	360	300	20	69.94	31.97	37.97
90	90	360	250	20	69.68	31.75	37.94
90	90	360	200	20	69.41	31.51	37.90
90	90	360	150	20	69.11	31.26	37.85
90	90	360	100	20	68.80	30.99	37.80
90	90	360	50	20	68.45	30.71	37.74
90	90	360	140	100	72.36	35.36	37.00

90	90	360	140	90	72.06	35.01	37.05
90	90	360	140	80	71.74	34.63	37.11
90	90	360	140	70	71.39	34.22	37.17
90	90	360	140	60	71.01	33.76	37.25
90	90	360	140	50	70.60	33.25	37.35

It is evident that increasing (doubling) the number of day or evening flights has little impact on the value of Ldn or NEF. There is some marginal increase in the value of the two measures when the frequency of night flights is doubled which is a consequence of the weighting scheme.

Chapter 5 References

Abelson, P. W., (1979) "Property prices and the value of amenities", *Journal of Environmental Economics and Management*, 6, 11-28

Adamowicz, W. L., P. C. Boxall, J. J. Louviere, J. Swait, and M. Williams, (1999) "Stated preference methods for valuing environmental amenities", in I. J. Bateman and K. G. Willis (eds.), *Contingent Valuation of Environmental Preferences: Theory and Practice in the US, Europe and Developing Countries*, Oxford University Press, Oxford, 460-480,

Adamowicz, W. L., Louviere, J. and Williams, M., (1994) "Combining stated and revealed preference methods for valuing environmental amenities", *Journal of Environmental Economics and Management*, 26: 271-292

Allen, G. R., (1980) *Relationship between highway noise, noise mitigation and resident property values*, FHWA/VA-81/1. Charlottesville, Va.: Virginia Highways and Transportation Research Council.

Appel, D., (1980) *Estimating the benefits of air quality improvement: An hedonic price index approach applied to the New York Metropolitan Area*, PhD dissertation, Rutgers University, UMI Order No. 8022540

Anselin, L., (1993) "Discrete space autoregressive models" in M. F. Goodchild, B. O. Parks and L. T. Steyaert (eds), *Environmental Modelling with GIS*, Oxford University Press, Oxford, 454-68

Anderson, L. M. and H. K. Cordell, (1988) "Influence of trees on residential property values in Athens, Georgia (U.S.A.): A survey based on actual sales prices." *Landscape and Urban Planning*, 15(1-2), 153-164

Anderson, R. J. and D. E. Wise, (1977) *The effects of highway noise and accessibility on residential property values*, DOT-FH-11-8841. Springfield, Va.: National Technical Information Service.

Arsenio, E., A.L. Bristow and M. Wardman (2001): An innovative stated preference computer survey model for valuing noise impacts from road traffic. Institute for Transport Studies, University of Leeds, United Kingdom

Atkinson, R. J., Jr., and T. D. Crocker, (1971) "Air pollution and residential property value", *Urban Studies*, 8, 171-80.

Bailey, M. J. (1977), *Report on pilot study: Highway noise and property values*, unpublished paper, University of Maryland.

Ball, M. J. and R. M. Kirwan, (1977) "Accessibility and supply constraints in the urban housing market", *Urban Studies*, 14, 11-32.

Barde, J-P. and Pearce, D.W. (eds.) (1991), *Valuing the Environment*, Earthscan, London.

Bateman, I. J., (1992) "The economic evaluation of environmental goods and services", *Integrated Environmental Management*, 14, 11-14.

Bateman, I. J., (1995) "Environmental and economic appraisal", in T. O'Riordan (ed), *Environmental Science for Environmental Management*, Longmans, 45-65.

Bateman, I.J., Environmental impact assessment, cost-benefit analysis and the valuation of environmental impacts, in Petts, J. (ed.) *Handbook of Environmental Impact Assessment, Volume 1 - Environmental Impact Assessment: Process, Methods and Potential*, Blackwell Science, Oxford, 93-120, 1999.

Bateman, I. J. and F. Bryan, "Recent advances in the monetary evaluation of environmental preferences", in proceedings of the conference, *Environmental Economics, Sustainable Management and the Countryside*, Countryside Recreation Network, Cardiff, 1994.

Bateman, I.J., Garrod, G.D., Brainard, J.S. and Lovett, A.A., "Measurement, valuation and estimation issues in the travel cost method: A geographical information systems approach", *Journal of Agricultural Economics*, 47(2): 191-205, 1996.

Bein, P., T. Litman and C. Johnson, "*Unit costs of environmental impacts"*, draft report for the Ministry of Transportation and Highways, British Columbia, 1994.

Bell, K. and N. E. Bockstael, N.E., *Applying the generalised method of moments approach to spatial problems involving micro-level data*, Working Paper 97-03, Department of Agricultural and Resource Economics, University of Maryland, College Park, 1997.

Bender, B. T., J. Gronberg and H.-S. Hwang, "Choice of functional form and the demand for air quality", *Review of Economics and Statistics*, 62, 638-43, 1980.

Berry, B. J. L., "Ghetto expansion and single-family housing prices: Chicago, 1968-1972", *Journal of Urban Economics*, 3, 397-423, 1976.

Bertrand, N. F., *Meta-analysis of studies of willingness to pay to reduce traffic noise*, unpublished MSc dissertation, University College London, 1997.

Blamire, P.A., & Barnsley, M.J., Inferring urban land use from an analysis of the spatial and morphological characteristics of discrete scene objects. *In Proceedings of the 22nd Annual conference and exhibition of the Remote Sensing Society,* 1996.

Bown, W., “Dying from too much dust”, *New Scientist*, 12 March, 12-13, 1994.

Box, G. E. P. and Cox, D. R., “An analysis of transformation”, *Journal of the Royal Statistical Society*, 26, 211-243, 1964.

Brookshire, D. S., R. C. d’Arge, W. D. Schulze and M. A. Thayer, *Experiments in valuing non-market goods: A case study of alternative benefit measures of air pollution control in the south coast sir basin of Southern California*, vol. 2 of *Methods of Development for Assessing Air Pollution Costs and Benefits*, Washington: Environmental Protection Agency, 1979.

Brookshire, D. S., M. A. Thayer, W. D. Schulze and R. C. d’Arge, “Valuing public goods: A comparison of survey and hedonic approaches”, *A.E.R.*, 72, 165-77, 1982.

Brucato, P. F., Jr., J. C. Murdoch and M. A. Thayer, “Urban air quality improvements: A comparison of aggregate health and welfare benefits to hedonic price differential”, *J. Environmental Management*, 30, 265-79, 1990.

Buckley, G. P. (ed.), *Biological habitat reconstruction*, Belhaven Press, London, 1989.

Butler, R. V. “Cross-sectional variation in the hedonic relationship for urban housing markets”, *Journal of Regional Science*, 20, 439-453, 1980.

CAA Netherlands **“**Governmental Noise Charges on Dutch Airports , Transport and Water Management” Civil Aviation Authority, Netherlands, Division Aircraft , Technical and Airworthiness Standards Department , January, 2002

Calthrop, E. J., *The external costs of road transport fuel: Should the fiscal stance towards diesel be altered?*, unpublished MSc dissertation, University College London, 1995.

Cicchetti, C. J. and Freeman, A. M., “Optimal demand and consumer's surplus: further comment”, *Quarterly Journal of Economics*, 85:528-539, 1971.

Collins, A. and A. Evans, “Aircraft noise and residential property values: An artificial neural network approach”, *Journal of Transport Economics and Policy*, May, 175-97, 1994.

Countryside Commission, *A Countryside for the 21st Century*, Countryside Commission, Cheltenham, 1990.

Crawley, R. W., “A case study of the effects of an airport on land values”, *Journal of Transport Economics and Policy*, May, 144-52, 1973.

Cropper, M. L., L. B. Deck and K. E. McConnell, "On the choice of functional form for hedonic price functions", *Review of Economics and Statistics*, 70, 668-75, 1988.

De Vany, A. S., "An economic model of airport noise pollution in an urban environment", in *Theory and Measurement of Economic Externalities*, S. A. Y. Lin (ed.), 205-214, Academic Press, New York, 1976.

Department of the Environment, *Urban Motorways*, The Urban Motorways Project Team, HMSO, London, 1972.

Department of the Environment, *Handling Geographic Information*, Report of the Committee of Enquiry chaired by Lord Chorley, HMSO, London, 1987.

Department of Transport (Welsh Office), *Calculation of Road Traffic Noise*. London: HMSO, 1988.

Department of Transport, *Transport statistics Great Britain 1991*. London: HMSO, 1991.

Department of Transport, *Vehicle speeds in Great Britain 1992*. London: Transport Statistics Report, Department of Transport, 1993.

Dunteman, G.H., "Principal components analysis", pp.157-245 in M.S. Lewis-Beck (ed.) *Factor Analysis & Related Techniques*, International Handbooks of Quantitative Applications in the Social Sciences, **5**, Sage Publications, London, 1994.

Dygert P. K., *Estimation of the cost aircraft noise to residential activities*, unpublished PhD dissertation, University of Michigan, 1973.

Edmonds, R. G., Jr., "Some evidence on the inter-temporal stability of hedonic price functions", *Land Economics*, 61, 445-51, 1985.

Egan, F. J., *Air pollution and property values in the Hartford Metropolitan Region*, PhD dissertation, Fordham University, UMI Order No. 74-2777, 1973.

Emerson F. C., "Valuation of residential amenities: An econometric approach", *Appraisal Journal*, 40, 268-278, 1972.

Foster, V. and S. Mourato, "Behavioral consistency, statistical specification and validity in the contingent ranking method: Evidence from a survey of the impacts of pesticide use in the UK", *CSERGE Global Environmental Change Working Paper GEC 97-09*, Centre for Social and Economic Research on the Global Environment, University College London and University of East Anglia, 1997a.

Foster, V. and S. Mourato, "Are consumers rational? Evidence from a contingent ranking experiment", paper presented at the *Eighth Annual Conference of the European*

Association of Environmental and Resource Economists (EAERE), Center for Economic Research, Tilburg University, the Netherlands, 26-28 June, 1997b.

Freeman A. M., *The measurement of environmental and resource values: Theory and methods*, Resources for the Future, Washington, D.C., 1993.

Furlan, S. 1996: *Evaluation du coût externe du bruit généré par le traffic automobile pour la ville de Paris* (External cost of road traffic noise in Paris). In French. University of Bourgogne - Institut Francais du Pétrole. PhD: thesis

Gautrin, J.-F., "An evaluation of the impact of aircraft noise on property values with a simple model of urban land rent", *Land Economics*, 51, 80-86, 1975.

Gamble, H. B., O. H. Sauerlender and C. J. Langley, "Adverse and beneficial effects of highways on property values", *Transport Research Record*, 508, 37-48, 1974.

Garrod, G., & Willis, K.G., "Valuing goods' characteristics: an application of the hedonic price method to environmental attributes," *Journal of Environmental management*, 34(1), 59-76, 1992a.

Garrod, G. D., Scarpa, R., and K. G. Willis (1998). Estimating The Benefits of Traffic Calming on Through Routes: A Choice Experiment Approach, Transportation research. Part D, Transport and Environment. Vol. 3D, no. 3 (May 1998)

Gent, van H. A. and P. Rietveld, "Road transport and the environment in Europe", *The Science of the Total Environment*, 129, 205-18, 1993.

Gillen and Levesque (1989), *The Economics and Management of Noise* (Research report Volume 1, Transport Development agency, Montreal)

Gillen and Levesque (1990), *Measuring the Costs and benefits of Noise Management Strategies* (report to Transport Canada, Economic Policy Branch, June 1990)

Gillen and Levesque (1991), *Measuring the Social Costs of Runway Expansion Options at Pearson International Airport* (Research Report to Environmental Review Panel, Transport Canada)

Gillen and Levinson (1996), "The Social Costs of Intercity Transportation: A review and Comparison of Air and Highway" *Transport Reviews*, Vol. 18, No. 3 pp.215-240 (1996)

Gillen, Oum and Tretheway (1986), Social Marginal Cost Pricing for Pearson International Airport (Research report to Economic Policy Group, Transport Canada)

Gillen and Levinson (1995), The Full Cost of Transportation: An Intermodal Comparison in California", (ITS-RR-95-3, Institute of Transportation Studies, University of California, Berkeley

Grue, B., J. L. Langeland and O. I. Larsen, *Housing Prices – impacts of exposure to road traffic and location*, TØI report 351/1997, Oslo, 1997.

Harrison D. and D. L. Rubinfeld, "Hedonic housing prices and the demand for clean air", *Journal of Environmental Economics and Management*, 5, 81-102, 1978.

Hidano, N., Y. Hayashiyama and M. Inoue, "Measuring the external effects of noise and vibration of urban transportation by the hedonic approach", *Environmental Science*, 9(3), pp 401-409, Tokyo, 1992.

Hall, F. L., B. E. Breston and S. M. Taylor, "Effects of highway noise on residential property values", *Transportation Research Record*, 686, 38-43, 1978.

Hall, F. L., B. E. Breston and S. M. Taylor, "The effect of road traffic noise on house prices", *Journal of Sound and Vibration*, 80(4), 523-541, 1982.

Hanemann, W. M., "Willingness to pay and willingness to accept: How much can they differ?" *American Economic Review,* 81(3), 635-47, 1991.

Holland, M. R. and N. Eyre, "Evaluation of the external costs of a UK coal fired power station on agricultural crops", *Proceedings of the 2nd International Conference on the External Costs of Electrical Power*, September 1992, Racine, Wisconsin, 1992.

Holsman, A. J. & Paparoulas, A. (1982). `Impact of the Eastern Suburbs Railway on Property Prices in Edgecliff, NSW'. THE VALUER, 255-260

Howes, D., & Gatrell, A., Visibility analysis in GIS: Issues in the environmental impact assessment of wind farm developments. *Proceeding of the Fourth European Conference and Exhibition on Geographical Information Systems*. Genoa, Italy, 1993.

INFRAS, IWW. 1995. External Effects of Transport. International Union of Railways, IWW - Karlsruhe University, INFRAS Consultants.

Institution of Highways and Transportation with the Department of Transport, *Roads and Traffic in Urban Areas*. London: H.M.S.O., 1987.

Irwin, E. G. and N. E. Bockstael, "Interacting agents, spatial externalities and the endogenous evolution of land use pattern", *Working Paper 98-24*, Department of Agricultural and Resource Economics, University of Maryland, College Park, 1998.

Jackson, J. R., “Intraurban variation in the price of housing”, *J. Urban Econ.*, 6, 464-79, 1979.

JMP Consultants, *Monetary valuation of road traffic nuisance*, report to the Department of Transport, Job No. 8329, 1996.

Kaiser, H.F., “The application of electronic computers to factor analysis”*, Educational and Psychological Measurement*, 20, 141-151, 1960.

Krumm, R. J., Neighbourhood amenities: An economic analysis, *J. Urban Econ.*, 7, 208-24, 1980.

Krutilla, J. V. and Fisher, A. C., *The Economics of Natural Environments: Studies in the Valuation of Commodity and Amenity Resources*, Johns Hopkins University Press (for Resources for the Future), Baltimore, MD, 1975.

Lake, I., A. A. Lovett, I. J. Bateman and I. H. Langford, “Modelling environmental influences on property prices in an urban environment”, *Computers, Environment and Urban Systems*, 22, 121-136, 1998.

Lambert, J, F. Poisson and P. Champlovier 2001: Valuing benefits of a road traffic noise abatement programme: a contingent valuation study. INRETS-LTE, Bron, France

Langley, C. J., “Adverse impacts of the Washington beltway on residential property values”, *Land Economics*, 52, 54-65, 1976.

Levesque, T. J., “Modelling the effects of airport noise on residential housing markets: A case study of Winnipeg International Airport”, *Journal of Transport Economics and Policy*, 199-210, 1994.

Li, M. M. and H. J. Brown, “Micro-neighbourhood externalities and hedonic housing prices”, *Land Economics*, 56, 125-41, 1980.

Litman, T., *Transportation cost analysis, estimates and implications*, Victoria Transport Policy, B.C., 1995.

London Research Centre, *London energy study; Energy use and the environment*, London Research Centre, London, 1993.

Maddison, D., D. Pearce, O. Johansson, E. Calthrop, T. Litman and E. Verhoef, *Blueprint 5. The True Cost of Road Transport*, Earthscan, London, 1996.

Maguire, D.J., Goodchild, M.F., & Rhind, D.W. (Eds.), *Geographical information systems; vol.1: principles*. Harlow: Longman Scientific & Technical, 1991.

Martin, D., Longley, P., & Higgs, D., "The use of GIS in the analysis of diverse urban datasets." *Computers, Environment and Urban Systems*, 18(1), 55-56, 1994.

Maser, S. M., W. H. Riker and R. N. Rosett, "The effects of zoning and externalities on the price of land: An empirical analysis of Monroe County, New York", *Journal of Law and Economics*, 20, 111-132, 1977.

McLeod, P.B., "The demand for local amenity: An hedonic price analysis", *Environment and Planning A*, 16(3), 389-400, 1984.

McDonald, R. and D. Harrison, "Willingness to pay in Boston and Los Angeles for a reduction in automobile-related improvements, air quality and automobile emission control: A report by the coordinating committee on air quality studies", in *Report of the National Academy of Science*, vol. 4, Washington: National Academy of Science, 1974.

McMillan, M. L., B. G. Reid and D. W. Gillen, *An approach towards improved estimates of willingness to pay for public goods from hedonic price functions: A case study of aircraft noise*, unpublished paper, University of Alberta, 1978.

Medley, G., "Nature, the environment and the future", paper presented at *The University of the Third Age, 1992 International Symposium: The Challenges of the Future*, 13th-18th September 1992, Kings College, Cambridge, 1992.

Mieskowski, P. and A. M. Saper, "An estimate of the effects of airport noise on property values" *J. Urban Econ.*, 5, 425-440, 1978.

Miller, Peter and John Moffet. 1993. The Price of Mobility: Uncovering the Hidden Costs of Transportation (Oct. 93). National Resources Defense Council : San Francisco

Modra, J. D. and Bennett, D.W. 1985. *Cost-Benefit Analysis of the Application of Traffic Noise Insulation Measures to Existing Houses*. Forum Papers of 10th Australian Research Forum, Melbourne 13-15 May 1985, Vol. 1, p. 63-86.

National Roads Directorate, *The Effect of Road Traffic on Residential Property Values*, Annex I of Project Brief, The Scottish Office Development Department, Edinburgh, 1998.

Navrud, S. The State of the Art on the Economic Valuation of Noise (Department of Economics and Social Sciences Agricultural University of Norway Discussion paper, 2001)

Navrud, S. 2000b: Economic benefits of a program to reduce transportation and community noise – A contingent valuation survey. In *Proceedings of Internoise 2000*, Nice, France

Nelson, J. P., *Economic analysis of transportation noise abatement*, Ballinger, Cambridge, Mass, 1978a.

Nelson, J. P., “Residential choice, hedonic prices and the demand for urban air quality”, *J. Urban Econ*, 5, 357-69, 1978b.

Nelson, J. P., “Airport Noise, location rent and the market for residential amenities”, *Journal of Environmental Economics and Management*, 6, 320-331, 1979.

Nelson, J. P., “Airports and property values: A survey of recent evidence”, *Journal of Transport Economics and Policy*, 14(1), 37-52, 1980.

Nelson, J. P., “Highway noise and property values: A survey of recent evidence”, *Journal of Transport Economics and Policy*, 16(2), 117-38, 1982.

Nelson, J.P, Meta-Analysis of Airport Noise and Hedonic Property Values: Problems and Prospects, Journal of Transport Economics and Policy, January 2004, 1-29

Norusis, M.J., *SPSS-X Advanced Statistics Guide*, McGraw-Hill, New York, 1985.

O’Byrne, P. H., J. P. Nelson and J. J. Seneca, “Housing values, census estimates, disequilibrium and the environmental costs of airport noise: A case study of Atlanta”, *Journal of Environmental Economics and Management*, 12, 169-178, 1985.

Oosterhuis F. & Van der Pligt 1985: Kosten der Baten van de Wet Geluidshiner. (In Dutch). Commissie Evaluatie Wet Geluidshiner. CW-AS-06

Openshaw, S. (Ed.), *Census users’ handbook*. Cambridge: Pearson Professional Limited, 1995.

Opschoor, J.B. (1986). “A review of monetary estimates of benefits of environmental improvements in the Netherlands.” Report prepared for OECD-CEE workshop on benefits of environmental policy and decision-making, Avignon, in Pearce, D.W. & Markandya, A. (1989). “Environmental policy benefits: monetary valuation.” OECD, Paris

Ordnance Survey, Digital Map Data and Customised Services. *Catalogue* produced by the Ordnance Survey. Southampton, 1996.

Ostro B., *Estimating health effects of air pollution: A methodology with an application to Jakarta*, World Bank, Washington, D.C., 1994.

Paik, I. K., *Measurement of environmental externality in particular reference to noise*, unpublished PhD dissertation, Georgetown University, 1972.

Palmquist, R. B., *Impact of highway improvements on property values in Washington*, WA-RD-37.1. Springfield, Va.: National Technical Information Service, 1980.

Palmquist, R. B., “Measuring environmental effects on property prices values with hedonic regressions”, *Journal of Urban Economics*, 11, 333-47, 1982a.

Palmquist, R. B., “Estimating the demand for air quality from property value studies”, manuscript, Raleigh: North Carolina State University, 1982b.

Palmquist, R. B., *Estimating the demand for air quality from property value studies: Further results*, unpublished manuscript, Raleigh: North Carolina State University, 1983.

Palmquist, R. B., “Estimating the demand for the characteristics of housing”, *Review of Economics and Statistics*, 66, 394-404, 1984.

Palmquist, R. B., “Hedonic methods” in *Measuring the Demand for Environmental Quality*, J. B. Braden and C. D. Kolstad (eds.), Amsterdam: North Holland, 1991.

Pearce, D. W. and Markandya, A., *The Benefits of Environmental Policy*, Organisation of Economic Cooperation and Development, Paris, 1989.

Pearce, D.W. and Turner, R.K., *The Economics of Natural Resources and the Environment*, Harvester Wheatsheaf, Hemel Hempstead, 1990.

Pennington, G., N. Topham and R. Ward, “Aircraft noise and residential property values adjacent to Manchester International Airport”, *Journal of Transport Economics and Policy*, 24(1), 49-59, 1990.

Polinsky A. M. and D. L. Rubinfeld, Property values and the benefits of environmental improvements: Theory and measurement”, in *Public Economics and the Quality of Life*, L. Wingo and A. Evans (eds.), Baltimore, John Hopkins University Press (for Resources for the Future), 1977.

Pommerehne, W. W., Measuring environmental benefits: Comparison of a hedonic technique and CVM”, in *Welfare and Efficiency in Public Economics*, D. Bos, M. Rose and C. Seidl (ed.), Berlin, 1988.

Price, I., *he social cost of airport noise as measured by rental changes: The case of Logan Airport*, unpublished PhD dissertation, Boston University, 1974.

Randall, A. and J. R. Stoll, Consumer's surplus in commodity space”, *American Economic Review*, 70(3), 49-55, 1980.

Renew, W. D., T*he relationship between traffic noise and house price*, Conference of the Australian Acoustical Society, Brisbane, 13-15th November, 1996a.

Renew, W. D., *The relationship between traffic house prices and traffic noise in Brisbane*, Draft report, Department of the Environment, Australia, 1996b.

Ridker, R. A. and J. A. Henning, "The determinants of residential property values with special reference to air pollution", *Rev. Econ. St.*, 49, 246-57, 1967.

Rosen, S., "Hedonic prices and implicit markets: Product differentiation in pure competition", *Journal of Political Economy*, (82), 34-55, 1974.

Scarpa, R. Willis, K. G. and G. D. Garrod 2001a. Estimating WTP for Effective Enforcement of Speed Reduction from Dichotomous-Choice CV: The Case of Rural Trunk Roads. Forthcoming in *Environmental and Resource Economics*

Scarpa, G.D. Garrod and K. G. Willis 2001b: Valuing local public goods with advanced stated preference models: traffic calming schemes in Northern England

Schipper, Y. J. J., *On the valuation of aircraft noise: A meta-analysis*, unpublished paper, Titenberg Institute, Free University of Amsterdam, 1996.

Schultz, W., "A survey on the status of research concerning the evaluation of benefits of environmental policy in the Federal Republic of Germany", paper presented to the *OECD Workshop on the Benefits of Environmental Policy and Decision Making*, Avignon, 1986.

Smith, B. A., "Measuring the value of urban amenities", *J. Urban Econ.*, 5, 370-87, 1978.

Smith, V. K. and T. A. Deyak, "Measuring the impact of air pollution on property values", *Journal of Regional Science*, 15(3), 277-88, 1975.

Smith V.K. and J.-C. Huang, "Can markets value air quality? A meta-analysis of hedonic property values", *J. Pol. Econ.*, 103, 209-27, 1995.

Soguel, N., *Evaluation de cout social du bruit genere par le trafic routier en Ville de Neuchatel*, IRER, WP N^{o}. 9105, Universite de Neuchatel, 1991.

Soguel, N., *Evaluation monetaire des atteinties a l'environment: Une etude hedoniste et contingente sur l'impact des transports*, Imprimerie de L'evolve SA Neuchatel, 1994.

Soskin, M. D., *Detection and treatment of multicollinearity with application to problems of estimating pollution costs from housing market models*, PhD dissertation, Pennsylvania State University, UMI Order No, 8006059, 1979.

Starkie, D.N.M. and D.M. Johnson The Economic Value of Peace and Quiet Saxon House/ Lexington Books, 1975

Straszheim, M. R., "Hedonic estimation of housing market prices: A further comment", *Review of Economics and Statistics*, 56, 404-06, 1974.

Sælensminde, K. & F. Hammer 1994: *Verdsetting av miljøgoder ved bruk av samvalgsanalyse. Hovedundersøkelse*. TØI report 251/1994. Institute for Transport Economics (TØI), Oslo. 59 pp

Sælensminde, K. 2000: Valuation of nonmarket goods for use in cost-benefit analyses. Methodological issues. PhD: dissertation 1999, Department of Economics and Social Sciences, Agricultural University of Norway. TØI report 491/2000. Institute for Transport Economics (TØI); Oslo

Thune-Larsen, H. 1995: Flystøyavgifter basert på betalingsvillighet. (In Norwegian) TØI-report 289/1995. Institute for Transport Economics (TØI), Oslo. 86 pp

Tinch, R., *Valuation of environmental externalities*, report to the Department of Transport, London, 1995.

Turner, R.K. and I. J. Bateman, *A Critical Review of Monetary Assessment Methods and Techniques*, Report to the Transport and Road Research Laboratory, Environmental Appraisal Group, University of East Anglia, 1990.

Turner, R. K., Bateman, I. J. and Brooke, J. S., "Valuing the benefits of coastal defence: a case study of the Aldeburgh sea defence scheme", in A. Coker and C. Richards (eds.), *Valuing the Environment: Economic Approaches to Environmental Evaluation*, Belhaven Press, London, 77-100, 1992.

Turner, R. K., D. W. Pearce, and I. J. Bateman, *Environmental Economics: An Elementary Introduction*, Harvester Wheatsheaf, Hemel Hempstead and the Johns Hopkins University Press, Baltimore, 1994.

United Kingdom Department of Transport Calculation of Road Traffic Noise, Department of Transport, Welsh Office, HMSO, 1988.

Uyeno, D., S. W. Hamilton and A. Biggs, "Density of residential land use and the impact of airport noise", *Journal of Transport and Economics and Policy*, 27(1), 3-18, 1993.

Vainio, M., *Traffic noise and air pollution: Valuation of Externalities with the hedonic price and contingent valuation methods*, PhD Thesis, School of Economics and Business Administration, Helsinki, 1995.

Vaughan, R. J. and L. Huckins, *The economics of expressway noise and pollution abatement*, P-5475, Santa Monica, CA: Ballinger, 1975.

Walters, A. A., *Noise and prices*, Oxford University Press, London, 1975.

Webster, R. and Oliver, M.A., *Statistical Methods in Soil and Land Resource Survey*, Oxford University Press, Oxford, 1990.

Weisbrod, B. A., "Collective - consumption services of individual consumption goods", *Quarterly Journal of Economics*, 78:471-477, 1964.

Wibe, S. 1997: Efterfrågan på tyst boende (The demand for quiet dwellings) (In Swedish) Report to Byggforskningsrådet, Stockholm, Sweden. Report (Anslagsrapport) no. A4:1997

Wieand, K. F., "Air pollution and property values: A study of the St. Louis area", *Journal of Regional Science*, 13, 91-95, 1973.

Willig, R. D., "Consumers surplus: a rigorous cookbook", *Technical Report No. 98*, Institute for Mathematical Studies in the Social Sciences, Stanford University, 1973.

Willig, R. D., "Consumer's surplus without apology", *American Economic Review*, 66(4), pp 587-97, 1976.

Yamaguchi, Y., *Estimating the cost of aircraft noise around airports in London*, unpublished MSc dissertation, University College London, 1996.

Young, M. D., *Sustainable Investment and Resource Use*, UNESCO/Parthenon, Carnforth, 1992.

Table 5. 6 US Studies

Study	Location	Type of noise	Means of valuation	Results
Emerson (1969, 1972)	Minneapolis	Aircraft noise	Hedonic house pricing	0.58 NDI
Paik (1972)	New York Los Angeles Dallas	Aircraft noise	Hedonic house pricing	1.9 NDI 1.8 NDI 2.3 NDI
Gamble *et al* (1974)	Bogotoa Rosendale North Springfield All three areas	Traffic noise	Hedonic house pricing	2.22 NDI 0.24 NDI 0.21 NDI 0.26 NDI
Price (1974)	Boston	Aircraft noise	Hedonic house pricing	0.83 NDI
Vaughan & Huckins (1975)	Chicago	Traffic noise	Hedonic house pricing	0.65 NDI
De Vany (1976)	Dallas	Aircraft noise	Hedonic house pricing	0.8 NDI
Dygert (1976)	San Francisco San Jose	Aircraft noise	Hedonic house pricing	0.5 NDI 0.7 NDI
Langley (1976)	North Springfield	Traffic noise	Hedonic house pricing	0.22 NDI
Anderson & Wise (1977)	Towson North Springfield	Traffic noise	Hedonic house pricing	0.43 NDI 0.14 NDI
Bailey (1977)	North Springfield	Traffic noise	Hedonic house pricing	0.30 NDI
Maser *et al* (1977)	Rochester, N.Y. – city – suburban	Aircraft noise	Hedonic house pricing	 0.88 NDI 0.61 NDI
Nelson (1978)	Washington	Traffic noise	Hedonic house pricing	0.87 NDI
Nelson (1978)	Washington	Aircraft noise	Hedonic house pricing	1.06 NDI
Nelson (1979)	San Francisco St. Louis Cleveland New Orleans San Diego Buffalo	Aircraft noise	Hedonic house pricing	0.58 NDI 0.51 NDI 0.29 NDI 0.4 NDI 0.75 NDI 0.52 NDI
Allen (1980)	North Virginia Tidewater	Traffic noise	Hedonic house pricing	0.15 NDI 0.14 NDI
Nelson (1980)	Review of existing studies	Aircraft noise	Hedonic house pricing	0.62 NDI
Palmquist (1980, 1981)	Kingsgate North King County Spokane	Traffic noise	Hedonic house pricing	0.48 NDI 0.30 NDI 0.08 NDI
Nelson (1982)	Review of existing studies	Traffic noise	Hedonic house pricing	0.40 NDI
Kanafani (1983)	Review of existing studies	Traffic noise	Review of existing studies	0.06-0.12 % of GDP
O'Byrne *et al* (1985)	Atlanta (1980) Atlanta (1970)	Aircraft noise	Hedonic house pricing	0.69 NDI 0.64 NDI

Table 5.7 European and Canadian Studies of Noise Valuation

Study	Location	Type of noise	Means of valuation	Results
Hall *et al* (1978)	Toronto, Canada	Traffic noise	Hedonic house pricing	1.05 NDI
Mieskowski & Saper (1978)	Toronto, Canada	Aircraft noise	Hedonic house pricing	0.52 NDI
Abelson (1979)	Marrickville, Australia Rockdale, Australia	Aircraft noise	Hedonic house pricing	0.40 NDI 0.50 NDI
McMillan *et al* (1980)	Edmonton, Canada	Aircraft noise	Hedonic house pricing	0.51 NDI
Hall *et al* (1982)	Toronto, Canada *– Arterial* *– Expressway*	Traffic noise	Hedonic house pricing	 0.42 NDI 0.52 NDI
Quinet (1989)	Review of existing studies	Traffic noise	Productivity loss and annoyance	0.1% of GDP
Hidano *et al* (1992)	Tokyo, Japan	Traffic noise	Hedonic house pricing	0.70 NDI
Quinet (1993)	Review of existing studies	Noise pollution	Review of existing studies	0.20-2.00 % of GDP

Uyeno *et al* (1993)	Vancouver, Canada - detached houses - condominiums - vacant land	Aircraft noise	Hedonic house pricing	 0.65 NDI 0.90 NDI 1.66 NDI
INRETS (1994)	Variety of countries	Noise exposure 1970s1980s	Hedonic house pricing	 0.3-0.8 NDI 1.00 NDI

Chapter 6: Air Pollution Costs

6.1 Introduction

Transportation produces air pollutants directly from vehicle operations and related infrastructure during construction, and indirectly from vehicle manufacturing, fuel extraction and processing, and manufacturing of construction materials and machinery. This chapter focuses primarily on direct emissions. In addition, impacts of air pollutants can be either local or global. This chapter will focus on local air pollution whose impacts take place in the area where the emission occurs. Emissions such as greenhouse gases can cause global impacts, and will be dealt with in the following chapter (Chapter 7).

More specifically, our main objective in this chapter is to provide an estimation towards the full costs of transportation by focusing on emissions of air pollutants. The following transport modes are considered:

- Interurban passenger transport: i) Private vehicle; ii) Aircraft; iii) Bus; iv) Train; v) Ferry
- Urban passenger transport: i) Private vehicle; ii) Urban transit
- Freight transport: i) Truck; ii) Rail; iii) Marine; iv) Aircraft

In the literature, there are two main approaches to the estimation of air pollution costs of transportation. First, the hedonic-pricing method has been used in some studies. The second approach is referred to as the "dose response," or "damage function," approach. Compared with the hedonic-pricing method, the damage-function method appears to be a more accepted, and certainly more widely used, approach to the estimation of air pollution costs of transportation. In this chapter we shall use the damage-function approach. We shall divide it into six specific tasks:

1. Identify important air pollutants that will result in damages to the environment;
2. Establish the relationship between the emissions of air pollutants identified and damage effects on such targets as human being and materials. In particular, dose-response functions link air pollutants with mortality and morbidity, based on epidemiology studies;
3. An air dispersion model is used to estimate the atmospheric concentration a specific pollutant;
4. Estimate the emission rates of air pollutants for each transport mode;
5. The monetary value of the damage incurred is estimated drawing from economic studies, which place values on mortality and morbidity (e.g., short-term illness, chronic morbidity, productivity loss, and cancer);
6. The results from the epidemiological and engineering literature are merged with the results from the economic literature to arrive at marginal social costs of air pollution for each transportation mode.

Whenever possible, attempts are made to use Canadian studies and employ Canadian figures.

The chapter is organized as follows. Section 6.2 provides a theoretical introduction and Section 6.3 reviews existing studies and research methods. Section 6.4 will discuss in detail the first three steps of the damage-function approach. Section 6.5 discusses emission factors, whereas Section 6.6 is devoted to the issue of monetary valuations. Finally, Section 6.7 derives our estimates of marginal social costs by combining the results from the earlier five steps. A number of sensitivity checks will be undertaken, and the important issues of marginal vs. average costs, and internal vs. external costs will be discussed.

6.2 Conceptual Issues and Development

Air pollution is a good example of a negative externality (for more discussion on "externalities" see Chapter 1). Although research on the external cost of pollution has made significant progress only during the past two decades, the literature on the subject can be dated back to Pigou's discussion in 1915 (see, e.g., Pigou 1938). In particular, Pigou proposed that to achieve the social efficient equilibrium, governments need to impose a tax on polluters. The required tax, referred to as Pigouvian tax, is equal to the value of the marginal external cost at the optimal output. Later, Knight (1924) argued, that the problem is not so much an instance of the divergence between social costs and private costs but rather an instance of the wasteful exploitation of a scarce natural resource. If the externality is placed under private ownership, a price will be imputed to it, which is equal to the full earnings of the owner. In a competitive situation this price will be its true scarcity value. Another important conceptual contribution originates from Coase (1960). The Coase theorem states that when property rights are clear and enforceable, when all economic agents have full information, and when transaction costs are low, there is no need for government intervention to correct externalities, because the economic agents can bargain among themselves to achieve a Pareto optimal allocation of resources. Further, the ability of economic agents to achieve the Pareto optimal allocation does not depend on which economic agent is given the property rights. In the case of pollution, either the property right of "clean" environment is assigned to the polluter or the victim, and through bargaining, the social optimum can be achieved. Furthermore, Turvey (1963) argued that if the parties involved are able and willing to negotiate to their mutual advantage, government intervention is unnecessary to ensure social optimum. Also, he stated that the imposition of a tax upon the party imposing externality can be a very complicated matter, so that the *a priori* prescription of such a tax is unwise.

In practice, the transaction cost of such bargaining in the pollution case is usually substantial because there are many victims who are usually dispersed. Another problem lies in the nature of environmental quality. Environmental quality may be considered as a public good, which exhibits consumption indivisibilities and is fully accessible to all.[129]

[129] Consumption is said to be indivisible when one person's consumption of a good does not diminish the amount available for others.

As a result, the property right is hard to define. Under such circumstances, government intervention may be necessary.

Although pollution is regarded as a public "bad," it does not necessarily imply that society should have a zero amount of pollution. Pollution, or waste, unused resources, is a consequence of production; as such, in some environmental economics modeling, it is considered as one of the inputs to the production function. On the other hand, the external cost of pollution and its abatement cost should also be taken into account in the production function. To achieve the social optimum, an "optimal" pollution level should be maintained. Existing government regulations and economic instruments with respect to transportation include taxes on gasoline, vehicle registration fees, tolls, marketable pollution permits, and environmental standards. Of these regulatory methods, taxes and standards are commonly used, with standards referring to, among others, the establishment of particular levels of environmental concentration for pollutants, and controls of emission level or equipment performance. Many economists appear to favour a Pigouvian tax system because it makes use of market mechanisms by charging a price for hitherto un-priced but valuable services provided by the natural environment. Baumol and Oates (1971) suggested that the tax solution system will tend to be a lower cost method than standard-setting system in implementation.[130] The costs of administration will be different to the full costs of implementation.

To find the optimal Pigouvian tax, a damage function needs to be identified. The damage function indicates how pollution damage varies with the level of pollution emitted and what the monetary value of that damage is. Thus, putting a money value on damage done to the environment is part of the procedure. Here, an important concept in environment economics is "total economic value," which consists of three elements: user value, option value and pure existence value. The user-value category includes: direct "nonrivalrous" goods that are consumed on-site, such as hiking and bird watching that do not interfere with other users or uses; indirect nonrivalrous consumption which takes place off-site, such as deriving value from watching wildlife films; and "rivalrous" goods, such as consuming trees for wood products or other uses. The option value is related to the passive use of a good. It has been pointed out, for example, that estimates of the benefits of preserving a national park based solely on the benefits accruing to actual visitors do not capture its value to those who anticipate visiting it sometime in the future but actually never do. These non-visitors would be willing to pay something to preserve the option of visiting. This amount is an "option value," a separate benefit category in valuing assets, such as natural resources, that offer opportunities for future consumption. Finally, pure existence value arises because people believe the good (e.g., "environmental quality") has intrinsic value apart from its use. This may arise from a notion such as altruism where some people are willing to pay to preserve a wilderness area, for instance, because they get pleasure from knowing that others use it.

In general, the costs of local air pollution include human mortality and morbidity, reduced visibility, corrosion of materials (buildings, rubber products, etc.), reduced

[130] It is noted that an important assumption in the context of imposing Pigouvian tax is perfect competition. If this assumption is relaxed, the "optimal" tax may not achieve the social optimum.

agricultural production and damages to ecological systems. Before examining these costs, it is useful to revisit the two broad approaches to the valuation of (non-market) public goods such as environmental quality. The "revealed preference" (RP) method infers consumers' valuations from their actual choices in markets affected by them. Hedonic pricing (HP) methods, for example, assume that an individual buys goods for their various attributes. Thus, for example, a house has attributes such as floor area, the number of bathrooms, the view it provides, access to schools, hospitals, entertainment, and jobs, quietness and air quality. By estimating the demand for houses with different sets of attributes, we can estimate how much people value noise and air quality. One can thus estimate "pseudo-demand curves" for non-market goods such as noise and air quality. Another RP model is the "travel costs method," which has been mostly used to value recreational sites. Its basic idea is as follows: If the "market" for visits to a site is geographically extensive, then visitors from different origins bear different travel costs depending on their proximity to the site. The resulting differences in total costs, which include the cost of traveling to the site, entry fees, and on-site expenditures, and the differences in the rates of visits that they induce, provide a basis for estimating a demand curve for the site.

The second major approach in valuation is the "stated preference" (SP) approach. The contingent valuation method (CVM) works by directly soliciting from a sample of consumers their willingness to pay or (WTP) or willingness to accept (WTA) a change in the level of environmental service flows, in a carefully structured hypothetical market (Davis 1963).[131] CVM is one of the most commonly used methods in the estimation of an economic value for environmental goods, with hundreds of studies having been completed in the U.S. and Western Europe (Mitchell and Carson 1989, Bishop and Romano 1998). Its approach in general takes the following steps: First, a sample of respondents from the population is identified. Second, respondents are asked questions about their valuations of an environmental good under consideration. Third, their responses provide information that enables analysts to estimate the respondents' WTP for the good. Fourth, the WTP amounts for the sample are extrapolated to the entire population. If, for instance, the respondents comprise a random sample of the population such that each member of the population had an equal chance of being in the sample, then the average WTP for the sample would simply be multiplied by the size of the population to arrive at the aggregate WTP (see, e.g., Boardman et al. 2001).

Of the two approaches, McCubbin and Delucchi (2003) suggested that the advantage of RP is that it is based on actual behaviour, while the advantage of SP is that it specifies precisely and explicitly what is to be valued.

---

[131] An individual's preference for "clean" environment will show up in the form of a "willingness to pay" (WTP) for it. Alternatively, the value may come from asking how much people are willing to accept (WTA) in the way of compensation to the pollution. For further discussion see Chapter 1.

6.3 Review of Existing Studies and Research Methods

6.3.1 Transportation Literature

In the academic literature, emissions from different modes of transportation are measured (e.g., Small and Kazimi 1995, Mayeres et al. 1996). An "air dispersion" model is used to calibrate how the emissions change their atmospheric concentration, and usually the cost per travel distance by modes, or the cost per air pollutants emission, are reported. More specifically, Small and Kazimi (1995) estimated the pollution cost of driving a motor vehicle one mile. Their baseline estimate is about 4 cents per vehicle-mile for a typical automobile and 72 cents per vehicle-mile for a heavy-duty diesel truck driven in Los Angeles. (All the figures reported in this sub-section 6.3.1 are in 2002 $C.) These costs were predicted to fall to 2 cents and 53 cents as the vehicle technology improves.

Mayeres et al. (1996) computed the marginal external costs for cars, buses, trams, metro and trucks. To estimate the air pollution cost, they followed Small and Kazimi (1995) in using a direct damage estimation approach. The methodology is described and applied to the urban area of Brussels for the year 2005. Marginal costs of air pollution range from 3.7 cents to 69.3 cents per vehicle-km in peak hours, and from 2.7 cents to 55.1 cents in off-peak hours, if the existing transport policy does not change in 2005. Marginal social costs of Belgian emissions of PM_{10}, NO_x, VOCs and SO_2 are, respectively, $133,130, $22,084, $4,721 and $152,366 per ton.[132]

Danielis et al. (1998) provided an estimate of air pollution costs in Italy. They first estimated the number of people who would die if exposed to a given annual PM concentration level. Then the total number of deaths is multiplied by the VSL to obtain the overall monetary cost. Next, using the CORINAIR (COoRdination of Information on AIR) emission estimates, the calculated costs of PM_{10} emissions are ranged from $0.59 to $2.31 per vehicle-km, depending on the size of the city and the vehicle type. Finally, McCubbin and Delucchi (1999) estimated the health costs of motor-vehicle-related air pollution for both U.S. urban areas and for Los Angeles metropolitan area. The paper reviewed the epidemiological literature and considered CO, NO_2, ozone, PM and toxic pollutants. The cost per vehicle-km of motor vehicle travel ranges from $0.74 to $1.25.

6.3.2 Applied Research Conducted/Commissioned by Governments

US DOT (2000) estimated air pollution costs attributable to highway use by motor vehicles to reflect the research by the U.S. EPA on social costs associated with air pollution. The addendum to the 1997 HCAS presented estimates of air pollution-related costs of highway use and summarized how these costs are related to other costs analyzed in the 1997 Federal HCAS. The addendum estimated the average air pollution costs attributable to highway per vehicle-km between $0.02 and $0.08 (in 2002 $C).

[132] Short tons are used here.

Some studies provide benefits of reducing air pollution. These benefits might be regarded as air pollution costs if, say, the regulation were not implemented. However, these studies do not provide additional estimates of unit/marginal costs. For example, US EPA (1999) estimated the impact of the Clean Air Act Amendments (CAAA) of 1990 by analyzing the difference in the expected incidence of adverse health effects between the pre- and post-CAAA regulatory scenarios. Three steps were followed: i) estimate the changes in air quality for the pre- and post-CAAA scenarios in 2000 and 2010; ii) estimate the number of people exposed to air pollution at a given location; and iii) examine concentration-response functions. The study suggested that the monetary benefits of the CAAA would be US$68 billion and US$110 billion in 2000 and 2010, respectively. Best et al. (2003) conducted a cost-benefit analysis on a new regulation on particulate matter missions from stationary compression ignition internal combustion engines in the State of Wisconsin. Their analysis has found that such a regulation has the potential to produce over US$92 million in net social benefits for Wisconsin, roughly US$23 thousand in benefits per engine regulated. The major health benefits come from reducing diesel emissions. Moreover, the use of ultra low sulphur fuel causes sulphur dioxide emissions to fall.

ExternE (1996), funded by the European Commission (EC), developed and applied a methodology for quantifying energy-related environmental externalities of transportation, based on a bottom-up approach. The bottom-up approach is based on a detailed model of emissions and impacts. The methodology is applied to a series of case studies in Germany, the United Kingdom, the Netherlands, France, Greece and Italy. The marginal damage costs of air pollution for diesel passenger cars range from $0.10 to $0.78 per vehicle-km (in 2002 $C). The counterparts for "three-way-catalyst" passenger cars range from $0.00 to $0.03 per vehicle-km.

BeTa Version E1.02a was created for EC DG Environment to estimate the marginal external costs of air pollution in Europe in the late 1990s. The estimates that have been adopted for this study are calculated using the ExternE methodology. This follows the "impact pathway approach" tracing emissions through dispersion and environmental chemistry, to exposure of sensitive receptors, to impacts and finally to economic valuation using the WTP approach. The study reported that the marginal costs of emission of SO_2, NO_x, $PM_{2.5}$ and VOCs are, respectively, $7,545, $6,094, $20,314 and $3,047 per tonne (in 2002 $C).[133]

Another project commissioned by EC is UNITE (UNIfication of accounts and marginal costs for Transport Efficiency) (Nash 2003). The UNITE project was designed to meet the research needs of decision makers involved in the development of pricing and taxation policies for all significant passenger and freight modes in Europe. The bottom-up impact pathway approach was also employed in the project to calculate environmental

[133] It is noted that the values are quite different from the results of Mayeres et al. (1996), especially for SO_2 (note that $PM_{2.5}$ is considered in BeTA whilst PM_{10} is considered in Mayeres et al.) This can be partly explained by the fact that they used quite different valuations of mortality and morbidity.

costs due to all modes of transport. It estimated that total air-pollution cost due to transportation in Europe in 1998 was $66.57 billion (in 2002 $C).

It is important to point out that UNITE derives its values from ExternE, which in turn uses U.S. EPA values. As a result, UNITE, ExternE and U.S. EPA all have similar cost estimates.

Finally, the Ministry of Transport, New Zealand, commissioned a report (Fisher et al. 2002) to assess the health effects due to air pollution emissions from vehicles on the population of New Zealand. The background issues of the health effects of vehicle emissions were discussed, highlighting the priority focus on particulates. Secondly, an assessment was made of the overseas research results and their applicability to the New Zealand case. Using all relevant and available particulate monitoring data from New Zealand, exposure information was derived for all people living in cities and towns with population over 5,000. The study reported that long-term mortality estimates for adults (> 30 years old) due to traffic air pollution range from 241 to 566 cases with 399 as the best estimates. However, the report did not assess the value of this damage.

6.3.3 Methods

To reiterate from section 6.1, in the literature, there are two main approaches to the estimation of air pollution costs of transportation. First, the hedonic-pricing method has been used in some studies. Giannias (1989) applied a simultaneous equations estimation technique to estimate a hedonic equilibrium model, and the estimation results were then used to compute consumer benefit from air quality improvements in terms of the rental prices. Smith and Huang (1995) estimated the marginal WTP for reducing particulate matter from a hedonic property values model. Their mean estimate is $231 (in 2002 $C) per house per microgram per cubic meter. However, the variance of the estimates is large which partially reflects the fact that they are for different cities, are estimated with different data, pertain to different time periods, and are based on different models and estimation techniques. Moreover, Smith and Huang suggested that although the hedonic estimates partially reflect perceived health effects from pollution, they are probably more strongly influenced by “aesthetics, materials and soiling effects.”

The second approach is referred to as the “dose response,” or “damage function,” approach. Compared with the hedonic-pricing method, the damage-function method appears to be a more accepted, and certainly more widely used, approach to the estimation of air pollution costs of transportation. This can also be seen from the above survey of major existing studies, most of which have used the damage-function approach.

6.4 First Three Steps in the Damage-Function Approach

The six steps of the damage function approach are given in section 6.1.

6.4.1 Identifying Important Air Pollutants

As indicated above, the first step of the damage-function approach is to identify important air pollutants that cause damages to society. In general, air pollutants emitted from the transportation sector include particulate matter, volatile organic compounds (VOCs), carbon monoxide, carbon dioxide, sulphur oxides and nitrogen oxides. A major impact of carbon dioxide is the so-called "greenhouse effect," which will be dealt with in Chapter 7. As the damage caused by VOCs and nitrogen oxides is mainly evident through their role in the formation of ozone, we will consider the effects of ozone instead.

Particulate Matter

Particulate matter (PM), which is a heterogeneous mix of solid or liquid compounds, is regarded by some as the most damaging air pollutant to human health (McCubbin and Delucchi 1999). Studies have shown that the concentration of PM in the local atmosphere is positively correlated to mortality. For example, Pope et al. (1992) linked daily mortality with ambient particulate concentration using time-series analysis, whereas Schwartz and Dockery (1992a, 1992b) found a statistically significant relationship between mortality and PM in Philadelphia and Steubenville, Ohio. Further, the inhalation of particulate matter can cause respiratory problems. Several studies (e.g., Chapman et al. 1985, Dockery et al. 1989) have found a positive correlation between particulates and respiratory illness, such as chronic coughs, chronic phlegm, wheezing, chest illness, and bronchitis.

In addition to human health, particulate matter may cause material damage. PM emissions gradually settle on exposed surfaces and cause soiling. Studies (Cummings et al. 1981, Manuel et al. 1982, Watson and Jaksch, 1982) provide estimates of economic effects to households from PM soiling. For example, Manuel et al. (1982) find that PM is statistically significantly related to household expenditures in laundry, cleaning, and utilities.

In the literature PM is classified according to its size. The three most widely used are Total Suspended Particulate (TSP), $PM_{2.5}$ and PM_{10}. TSP includes air-borne particles (aerosols) of various dimensions (from hundreds of microns up to tens of microns) and weight; $PM_{2.5}$ and PM_{10} include all particles with an aerodynamic diameter less than 2.5 and 10 micrometers, respectively. McCubbin and Delucchi (1999) considered that particulates larger than 10 microns are generally not harmful to human health. Hence, this study will not use TSP as a measure of particulate matter. As particles with diameters between 2.5 and 10 micrometers do have significant impacts on human health, PM_{10} will be used instead of $PM_{2.5}$, noting again that the latter includes only particles with diameter less than 2.5 micrometers, whilst the former includes all the particles with diameter less than 10 micrometers.

Ozone

Ozone is not emitted by vehicles directly but is formed through chemical reaction among nitrous oxides (NO_x), VOCs and some other compounds in the atmosphere.[134] Unlike PM, studies have reached somewhat different conclusions about the linkage between ozone and mortality. On one hand, some studies (e.g., Kinney and Ozkaynak 1991, Moolgavkar et al. 1995) found that the linkage is statistically significant. On the other hand, after controlling for particulate matters, Kinney et al. (1995) found the relationship is no longer significant. Following McCubbin and Delucchi (1999), we shall consider the concentration of ozone will have an impact on mortality.

There is, however, strong evidence that ozone is linked to several adverse morbidity effects. McCubbin and Delucchi (1999) cited epidemiological studies that the health effects include eye irritation, asthma attacks, and other acute lower and upper respiratory symptoms. In particular, Holguin et al. (1985) and Stock et al. (1988) found a positive correlation between asthma symptoms and ozone concentrations.

Carcinogenic Toxics

Although other toxic air pollutants are also emitted from vehicles, only carcinogenic air toxins will be considered due to limited available data. The link between carcinogenic air toxins and the increase in cancer cases is mainly through inhalation with subsequent absorption into the body through the lungs. Following the Air Quality Valuation Model (AQVM) used by Environment Canada, formaldehyde, benzene, acetaldehyde, 1,3-butadiene will be included later in our calculation.

Carbon Monoxide

Carbon monoxide (CO) binds with haemoglobin in the blood to form carboxyhaemoglobin, and reduces the oxygen carrying capacity of the blood and limits the release of oxygen from circulating haemoglobin (McCubbin and Delucchi 1999). Studies by, e.g., Schwartz (1997) and Morris et al. (1995) have shown that the concentration of CO is linked to cardiovascular problems. Moreover, Schwartz and Morris (1995) and Burnett et al. (1996) studied cardiac hospital admissions to provide quantitative evidence of a relationship between day-to-day fluctuations in ambient outdoor CO concentrations and cardiac hospital admissions for the elderly.

Sulphur Dioxide

In their estimation of the health costs of motor-vehicle related air pollution, McCubbin and Delucchi (1999) did not include sulphur dioxide (SO_2), because they did not find

[134] McCubbin and Delucchi (1999) used a nonlinear function to model the ozone formation (Ozone = $(VOCs)^{0.55}(NOx)^{0.45}$.

enough evidence that the air pollutant has an effect independent of other pollutants. Hence, we will not include SO_2 when estimating mortality and morbidity. The damage due to SO_2 comes mainly from materials soiling. SO_2 atmospheric emissions form sulphuric acid – acid rain. In particular, Baedecker et al. (1990) cited a number of studies that suggest SO_2 exposure is correlated with the corrosion of exposed metal surfaces, specifically galvanized steel.

6.4.2 Estimating Damage by the Dose-response Function

Given a change in the atmospheric concentration of a given pollutant, we need to estimate a dose-response relationship. Here, engineering and epidemiological studies are relied upon. Taking the mortality due to PM_{10} as an example, the method of calculating the deaths per year is the following (Schwartz et al. 1996):

*Increase in No. of Deaths annually = [(total population) * (change in concentration) * 4.4E-06]*

We shall report the low, best, and high estimates in such dose-response relationships, with the low (high) estimate being the smallest (largest) concentration response parameter found among the studies. To arrive at the best estimates, weights are assigned to the dose-response functions found in different studies using the following criteria, which were suggested by US EPA (1994). First, peer reviewed research is preferred to research that has not undergone the peer review process. Second, among studies that consider chronic exposure, prospective cohort studies are preferred over cross-sectional studies. The former are studies that follow individuals forward in time for a specified period, periodically evaluating each individual's exposure and health status. Hence, prospective cohort studies can have better control over individual specific factors, such as smoking behavior. Third, studies examining a relatively longer period of time and a relatively large sample are preferred. Short-term exposure studies attempt to relate short-term (often day-to-day) changes in pollutant concentrations and changes in daily mortality rates/morbidity rates up to several days after a period of elevated pollution concentration. Long-term exposure studies examine the potential relationship in a longer term (e.g., over a year). Long-term studies are preferred, because short-term studies focus only on the acute effects associated with daily weak exposures and are therefore unable to evaluate the degree to which observed excess mortality is premature. Finally, a potential double counting problem needs to be taken into account. Several endpoints reported in the health effects literature overlap with each other. While the benefits analysis estimates the benefits associated with individual endpoints, it takes care in deciding which endpoints to include in an estimate of total benefits, in order to avoid double-counting of benefits from overlapping endpoints.

In this chapter, the dose-response functions are based on Air Quality Valuation Model (AQVM) 3.0 documentation, which generally fulfills the above criteria and has been adjusted for Canada. AQVM 3.0 has baseline air quality for the selected air pollutants based on Environment Canada's National Air Pollution Survey data for the years 1991 through 1993. It also includes baseline pollution levels for select pollutants at the census metropolitan area (CMA) level. Baseline population data for AQVM 3.0 at both the Census Division (CD) and CMA levels come from the 1996 national Canadian census.[135] The results are summarized in Tables 6.1-6.5.

Table 6.1. Dose-response Function of PM_{10}

Health Impacts	Study	Concentration Response Parameters (Risk factors given 1μg/m³ change)		
		Low estimate	Best estimate	High estimate
Mortality	Schwartz et al. (1996), Pope et al. (1995)	4.4E-6	12.1E-6	28.2E-6
Chronic bronchitis[136]	Abbey et al. (1993)	3E-5	6.1E-5	9.3E-5
Respiratory hospital admission	Burnett et al. (1995), Pope (1991)	2.34E-06	2.85E-06	1.19E-05
Cardiac hospital admission	Burnett et al. (1995)	1.8E-06	2.4E-06	3.0E-06
Net emergency room visit	Stieb et al. (1995)	1.1E-05	1.3E-05	5.2E-05
Asthma symptom day	Whittemore and Korn (1980), Ostro et al. (1991)	5.91E-02	6.28E-02	6.64E-1
Restricted activity day	Ostro (1987), Ostro and Rothschild (1989)	2.9E-02	5.8E-02	9.1E-02
Net days with acute respiratory symptoms	Krupnick et al. (1990)	5.9E-02	1.3E-01	1.9E-01
Children with acute bronchitis (B)	Dockery et al. (1996)	5.7E-04	1.4E-03	2.3E-03

Source: AQVM 3.0.

[135] The dose-response function is adjusted for Canada in different aspects. For example, changes in daily premature mortality in Canada per μg/m³ change in 24-hour PM_{10} are calculated based on the average annual Canadian non-accidental mortality rate of 6,700 per 1,000,000 people and the low, central, and high percentage changes in PM_{10}-related premature mortality selected above. Moreover, it takes the lower pollutant concentration in Canada into account. On the other hand, the resulting ASD (asthma symptom day) concentration-response parameters are applied to the diagnosed asthmatic population (estimated to be 6.0% of the Canadian population, Statistics Canada, 1994).

[136] Age 25 years or over.

Table 6.2. Dose-response Function of Ozone

Health Impacts	Study	Concentration Response Parameters (Risk factors given 1ppb/m^3 change)		
		Low estimate	Best estimate	High estimate
Mortality	Schwartz et al. (1996)	0.0E+00	1.6E-06	2.7E-06
Respiratory hospital admission	Burnett et al. (1997)	2.2E-06	4.0E-06	5.8E-06
Net emergency room visit	Stieb et al. (1995)	9.5E-06	1.7E-05	2.5E-05
Asthma symptom day	Whittemore and Korn (1980), Stock et al. (1988)	5.91E-2	6.28E-02	6.66E-02
Minor restricted activity day	Ostro and Rothschild (1989)	7.2E-03	1.7E-02	2.7E-02
Net days with acute respiratory symptoms	Krupnick et al. (1990)	1.9E-02	3.3E-02	4.7E-02

Source: AQVM 3.0.

Table 6.3. Dose-response Function of Air Toxics

Toxic	Study	Type of Cancer	Inhalation Unit Risk Estimate (Risk factors given 1μg/m^3 change)
Acetaldehyde	US EPA (1994)	Nasal	2.20E-06
1,3 Butadiene	US EPA (1994)	Incidence in multiple sites	2.80E-04
Formaldehyde	US EPA (1994)	Nasal	1.30E-05

Source: AQVM 3.0.

Table 6.4. Dose-response Function of Air Toxics for Elderly Population (65 or over)

Health Impacts	Study	Concentration Response Parameters (Risk factors given change in annual average of daily high-hour CO in ppm)		
		Min	Mean	Max
Cardiac hospital admission	Schwartz and Morris (1995)	0	2.76E-04	6.74E-04

Source: AQVM 3.0.

Table 6.5. Dose-response Function for Ozone and Crop Yield Loss

	Study	Concentration Response Parameters (% reduction in yield for 1ppb increase in ozone)		
Crop	Heagle et al. (1988)	Min	Mean	Max
Corn		0.0	0.15	0.2
Soybean		0.1	0.3	0.45
Wheat		0.2	0.3	0.6
Hay (alfalfa)		0.2	0.3	0.6
Hay (other hay)		0.3	0.6	1.2
Tobacco		0.2	0.4	0.8

Source: AQVM 3.0.

Particulate matter and long-term mortality

Both cross-sectional and time-series methodologies have been used in investigating the relationship between PM and mortality. The cross-sectional studies in the literature include Lipfert (1994), Ozkaynak and Thurston (1987), and Evans et al. (1984). As suggested in US EPA (1994), time-series studies are preferred to their cross-sectional counterparts, since most cross-sectional studies have not controlled for the differences between target cities/metropolitan areas, such as demographic factors. As a result, they may yield biased estimates owing to omitted variables. Hence, only time-series studies will be examined here.

Three recent studies have examined the relationship between mortality and long-term exposure to PM: Dockery el al. (1993), Pope et al. (1995), and Schwartz et al. (1996).[137] In these studies the mortality data were for identified individuals, so the analysis was able to provide controls for mortality risks associated with differences in body mass, occupational exposure, smoking (past and resent), alcohol use, age and gender. Dockery et al. (1993) conducted a prospective cohort study and analyzed data from 8,111 adults from six cities in the eastern U.S. over a 14-year period, whereas Pope et al. (1995) linked ambient air pollution data from 151 U.S. metropolitan areas in 1980 with individual risk factors on 552,138 adults who resided in these areas when enrolled in a prospective study in 1982. The latter study developed risk ratios from Cox proportional hazard models in which the median fine particulate concentration for a metropolitan area over the period from 1979 to 1983 was entered as an independent variable, along with socioeconomic variables accounting for, among other factors, a subject's education, smoking status, and alcohol consumption. In addition, meteorological controls were included to account for relatively hot or cold conditions. Finally, Schwartz et al. (1996)

[137] In addition, Abbey et al. (1991) reported the relationship between long-term ambient concentrations of TSP and mortality in a cohort of 6,000 Seventh-day Adventist nonsmokers who were residents of California.

contained a time-series analysis of the pooled results across six North American cities.

The central dose-response function for mortality risks in UNITE (2001a) is based on Pope et al. (1995). There, a relation between pollutant concentration and changes in age-specific mortality risks was established, and the lost life years and premature deaths were estimated accordingly. US EPA (1999) also preferred using Pope et al. (1995) as the basis for developing the primary PM/mortality estimates because, according to US EPA (1999), Pope et al. studied the largest cohort, had the broadest geographic scope, and effectively controlled for potentially significant sources of interference. Although US EPA (1999) used the Pope et al. exclusively in its estimation, it also pointed out that Dockery et al. (1993) used a slightly broader study population (adults aged 25 and older) and a follow-up period nearly twice as long as that of Pope et al.

Ozone and mortality

Recent epidemiological studies provided evidence examining the relationship between fluctuations in ambient ozone levels and observed daily mortality. As mentioned earlier, some studies found that, after taking PM into account, the relationship between ozone and mortality was weakened or even vanished. To avoid this problem, the selected studies should be taken from a model that controls for the influence of particulates.

This chapter will follow the estimation in AQVM 3.0,[138] which selected eight studies which fulfilled the criteria discussed above. In the analysis, results from the daily time-series studies were combined in a random effects model to estimate a central weighted average concentration-response parameter. The concentration-response parameters from the studies were combined using weights developed on the basis of the inverse of the variance associated with a study's parameter estimate. The random effects pooling method builds on the results of the fixed effects model, so whether the results are consistent with fixed effects model assumptions is tested statistically before the random effects model is applied.

6.4.3 Estimating the Concentration Change

The next step is to estimate how the emission of air pollutants affects their atmospheric concentration. This estimation requires an air dispersion model. We now review air dispersion models used in different countries.

United States and Canada

The air dispersion models used by US EPA include:[139]

- U.S. EPAISC (Industrial Source Complex Model) is a steady-state Gaussian model, which can be used to assess pollutant concentrations from a wide variety

[138] Chapter 4, AQVM 3.0 Documentation.
[139] U.S. Environmental Protection Agency website, http://www.epa.gov/ttn/atw/wks/fs_dispmodel.pdf

of sources associated with an industrial complex to a distance of 50 kilometers. Now with its third generation (ISCST3), in addition to air concentrations, it can estimate deposition rates and is appropriate for simple and complex terrain.

- ASPEN (Assessment System for Population Exposure Nationwide) is a Gaussian model used to estimate toxic air pollutant concentrations over a large-scale domain such as the entire continental U.S.

- AERMOD is a steady-state plume-based model designed to estimate near-field impacts from a variety of industrial source types. This model takes into account the effect of planetary boundary layer turbulence on air dispersion. It is being considered as a replacement to the ISCST3 model.

- REMSAD (Regulatory Modeling System for Aerosols and Deposition) is a three-dimensional grid-based model designed to simulate long-term (for example, annual) concentrations and deposition fluxes of atmospheric pollutants over a large geographic domain (for example, Southeast U.S.). Currently REMSAD can address toxic pollutants such as mercury, cadmium, chlorinated dibenzodioxins, polycyclic organic matter, and atrazine. Other air toxic pollutants may be added in the future.

- CALPUFF is a multi-layer, multi-species non-steady-state puff dispersion model that simulates the effects of time- and space-varying meteorological conditions on pollution transport, transformation and removal. CALPUFF can be applied on scales of tens to hundreds of kilometers. It includes algorithms for sub-grid scale effects (such as terrain impingement), as well as longer range effects (such as pollutant removal due to wet scavenging and dry deposition, chemical transformation, and visibility effects of PM concentrations).

Some of the above air dispersion models are used in different provinces in Canada. For example, in Alberta, AERMOD and CALPUFF are the air dispersion models recommended by the Provincial Government.[140] Moreover, CALPUFF model has been used on several occasions in B.C. (Hrebenyk 2003).

On the other hand, a project to evaluate the Atmospheric Environment Service (AES) Lagrangian model and Eulerian (Acidic Deposition Oxidant Model, or ADOM) model was conducted in Ontario with cooperation from the AES Air Quality and Inter Environmental Research Branch, Modelling and Integration Division (ARQI) and the Ministry of Environment and Energy. The models were evaluated for the Panel of Energy and Research and Development (PERD) episode of June 8-18, 1983. Measured data for sulphate, sulphur dioxide and ozone for a number of Canadian stations in Ontario, Quebec and some Maritime provinces were collected.[141]

---

[140] http://www3.gov.ab.ca/env/air/airqual/recmods.html.
[141] http://www.on.ec.gc.ca.

Europe

Several models are used within the series of ExternE Projects on “External Costs of Energy” funded by the European Commission. Concentrations for the short range or local scale are calculated by ROADPOL (Vossiniotis, et al. 1996), a software tool provided by the National Technical University of Athens for the ExternE Transport Project. The software employed a steady state Gaussian dispersion algorithm for predicting local-scale transport patterns and the resulting atmospheric concentrations of pollutants emitted from a line source. Long-range or regional-scale transport of airborne pollutants is modeled by EcoSense (Krewitt, 1997). EcoSense allows a user to change emissions from a selected sector (e.g., road transport) within a specific administrative unit, creates a new European-wide emission scenario for air quality modeling, and compares environmental impacts and resulting damage costs between different emission scenarios. The model calculates ground-level concentrations by using a Windrose Trajectory Model (WTM) (Trukenmüller et al. 1995), which is an adaptation of the Harwell dispersion model developed by Derwent and colleagues at AEA Technology, Harwell Laboratory in the UK. Concentrations are estimated for primary pollutants (e.g., PM_{10}, CO, SO_2) and secondary pollutants (nitrate and sulphate aerosols), which form in the air via chemical transformations of NO_x and SO_2.

Applying the methodology developed by ExternE, BeTa Version E1.02a estimated the marginal cost of air pollutants in Europe. It estimated the relationship between air pollutants emitted and the changes in their atmospheric concentration. The results are summarized in Tables 6.6-6.7. The study distinguished the emissions in urban and rural areas only for effects of SO_2 and particulates. As NO_x and VOCs emissions need to be transported some distance before chemical processes in the atmosphere are able to generate significant levels of the secondary pollutants associated with them, there is no specific urban quantification necessary (at least as a first approximation), and the figures derived for rural areas may be used.

Table 6.6. Rural Exposure Indices (Unit: person·ug (10^{-6} gm) per cubic meter per tonne)

	SO_2-SO_2	SO_2-SO_4	NO_x-NO_3	NO_x-ozone	PM_{10}[1]	VOC-ozone
Austria	371	98	258		310	180
Belgium	405	107	179		509	385
Denmark	171	45	125		123	935
EU-15average	266	70	157	106[2]	312	278
Finland	50	13	33	83	33	64
France	380	101	283	90	345	254
Germany	316	84	154		376	364
Greece	211	56	186	146	179	120
Ireland	133	35	106		94	171
Italy	260	69	268		263	359
Netherlands	360	95	151		414	313
Portugal	154	41	116	129	134	189
Spain	191	51	153	84	181	114
Sweden	88	23	67	106	40	89
UK	232	61	97		222	241

Source: BeTa.
Notes: 1. Assume that the change in concentration of PM_{10} is proportional to the change in $PM_{2.5}$.
2. Average value of the available figures from five countries.

Table 6.7. Urban Exposure Indices (Unit: person·ug (10^{-6} gm) per cubic meter per tonne)

Population	SO_2-SO_2	PM_{10}[1]
100,000	762	745
200,000	1524	1490
500,000	3810	3725
1,000,000	5715	5587
Many millions	11430	11174

Source: BeTa.
Notes: 1. Assume that the change in concentration of PM_{10} is proportional to the change in $PM_{2.5}$.

Link et al. (2001) also used the EcoSense model to estimate air pollution cost in Germany. In the study, an emission inventory was created for each mode or vehicle category (e.g., road passenger transport, motorcycles, heavy goods vehicles). Within the project, two air quality models were used from the three available within the EcoSense system. First, the WTM was used to estimate the concentration and deposition of acid species on a regional scale. Second, the Source-Receptor Ozone Model (SROM), based on the European Monitoring and Evaluation Programme (EMEP) country-to-grid matrices (Simpson et al. 1997), was used to estimate ozone concentrations on a European scale.

Asia

Peng (2002) used emission inventory data to assess the air quality and health effects in a Chinese city, Shijiazhuang. The air dispersion model used in this study was the urban branching atmospheric trajectory (UrBAT) model (Calori and Carmichael, 1999). UrBAT is a modified version of the atmospheric transport and deposition (ATMOS) model (Heffter 1983, Arndt et al. 1998), a software package developed as part of the regional air pollution information system for Asia (RAINS-Asia) to trace the causes and consequences of air pollution across 23 countries and 94 sub-regions in Asia (IIASA 2001, Shah et al. 2000).

Given the information available and the dose-response approach we have adopted, we will apply Tables 6.6-6.7 in our calculation of social costs of emissions (see Section 6.7).

6.5 Emission of Different Pollutants

The fourth step in the damage-function approach is to estimate, for each transport mode, the emission levels of major pollutants, namely, PM_{10}, VOCs, NO_x, CO and SO_2. US EPA has developed several Air Quality Emission Factor Models for the transportation sector,[142] which include:

- MOBILE Model links to information on the MOBILE vehicle emission factor model, which is a software tool for predicting gram per mile emissions of hydrocarbons, carbon monoxide, oxides of nitrogen, carbon dioxide, particulate matter, and toxics from cars, trucks, and motorcycles under various conditions.

- NONROAD Model links to information on the NONROAD emission inventory model, which is a software tool for predicting emissions of hydrocarbons, carbon monoxide, oxides of nitrogen, particulate matter, and sulfur dioxides from small and large non-road vehicles, equipment, and engines.

- MOVES, or Motor Vehicle Emission Simulator, is an effort to develop a new set of modeling tools for the estimation of emissions produced by on-road and non-road mobile sources. Also known as the "New Generation Model," MOVES will encompass all pollutants (including hydrocarbons, carbon monoxide, oxides of

[142] U.S. Environmental Protection Agency (U.S. EPA) website, http://www.epa.gov/otaq/models.htm.

nitrogen, particulate matter, air toxics, and greenhouse gases) and all mobile sources at different levels of resolution.

- Fuels Model links to information on US EPA's heavy-duty diesel fuel analysis program, which seeks to quantify the air pollution emission effects of diesel fuel parameters on various non-road and highway heavy-duty diesel engines. It also links to the Complex Model and the Simple Model used for the Reformulated Gasoline Program.

Note that emissions can vary substantially with technology mix and operating conditions. Moreover, environmental conditions have a direct effect on emissions levels. For example, it is recognized that NO_x emissions tend to increase at higher ambient temperatures or lower humidity levels. Similarly, higher altitudes (low barometric pressures) can also cause higher smoke and PM emissions with some reduction in NO_x. Dodge et al. (2003) found evidence that regional ambient variations can significantly impact emission levels, thus various correction factors have to be developed in order to standardize these emissions.

6.5.1 Passenger Transport

Table 6.13 below will provide emission factors of air pollutants for each transport mode. Note that emission factors (per vehicle-km, passenger-km, or tonne-km) can differ substantially across countries/regions, arising from differences in technology and in operating conditions. Canada may, for instance, have superior road vehicle emission control technology and fuels, owing to the more stringent and earlier regulation, but inferior urban transit and intercity rail as compared to Western Europe. Thus, whenever possible, we prefer using figures from Canadian studies to using results from other countries. For passenger transport, Table 6.13 lists three sources, Transport Canada, Mayeres et al. (1996) and KPMG (1992). Mayeres et al. estimated the emission factors for Brussels, whereas KPMG estimated emission rates for various modes under average and peak urban conditions in the Vancouver, B.C. region. We make use of figures from Transport Canada for inter-urban passenger bus, train and ferry, while using KPMG figures for the rest of other road transportation modes. Where possible, we modify urban-based figures to reflect intercity operating characteristics. Our recommended estimates of emission factors are used later in Section 6.7 as inputs to calculate our recommended estimates of social costs of emissions.[143]

Furthermore, since some emission factors in the literature are reported in terms of vehicle-km, vehicle occupancy rates are needed in the computation of the emission factors for passenger transport.[144] Again, different countries may have different

[143] It is noted that KPMG (1992) figures might not be consistent with the federal estimates. Further, the KPMG figures might not be up-to-date, while the emission rates are sensitive to technology and regulation changes. On the other hand, we were unable to obtain authoritative Canadian estimates. We would recommend that our estimates be revised once such emission factors are available.

[144] The passenger-km figure is obtained by dividing the vehicle-km figures by the occupancy rate.

occupancy rates. Within a country, different modes may have different rates; for example, the number of passengers per private vehicle for urban transport is likely different from that for intercity transport. In Table 6.13 we use the following average occupancy rates for Canada: 2.15 passengers per interurban private vehicle, 1.4 passengers per urban private vehicle, 31 passengers per interurban bus and 17 passengers per urban transit bus. These figures were used by Transport Canada to create Table 2.6 of the Transportation Table's Options Paper (1999), - but not published in that report -- obtained now from Transport Canada.

6.5.2 Freight Transport

Table 6.13 also requires the emission rate information for freight transportation. We now turn our attention to this issue for four transportation modes: truck, air, marine, and rail.

Truck

Road transport is a key element in the movement of all kinds of goods. In comparison with other modes, truck transportation provides several valuable characteristics such as flexibility, high mobility, reliability and efficiency. Changes in the economy and the improvement of infrastructure have led the growth in demand for road transport in recent years. In addition, technology improvements have enabled more powerful trucks to carry manufactured goods efficiently, while lighter trucks can ensure timely and door-to-door delivery of high value-added goods (OECD 1999).

The trucking industry can operate engines based on gasoline or diesel. Today, most of the truck fleets around the world are powered by diesel engines. These engines are the most efficient of all known types of internal combustion, and their technology also promises progress to reduce combustion emissions in the future (Environment Canada 2001). However, diesel combustion currently still gives rise to high levels of pollutants. Factors such as vehicle use, fuel composition, engine condition, location (ambient conditions), usage patterns and driving characteristics determine the level and composition of these emissions. For example, emissions tend to increase under stop-and-go conditions and at very low and very high speeds.

As the major contributor of emissions of several pollutants, road transport has received greater attention from the research sector than any other mode.[145] Table 6.8 summarizes the emission levels per tonne-kilometre of trucking freight, which are obtained from various studies. As these sources undertook their studies at different times, with different test procedures and most probably under different circumstances, these figures may not allow a direct comparison with other regions. However they do give a rough idea of emissions from the trucking sector. From the limited information in Table 6.8 for Canadian CO_2 from freight trucks, Canadian fuel use per tonne-km is much lower than the European average. It is less clear, however, if that extends to the air pollutant

[145] Trucking external costs also include noise, accidents and several indirect impacts to public facilities. The latter have been dealt with in other chapters of the report.

emissions as the relevant Canadian data are not available. But this is likely because the longer distances and larger loads will result in lower emissions per tonne-km. Further, emission controls have been more stringent in North America and will become even more so with announced standards.

Table 6.8. Trucking Emission Factors, gm per tonne-km

Study	*Location*	*Air Pollutant*							*Notes*
		CO	**CO_2**	**HC**	**NO_x**	**SO_2**	**PM_{10}**	**VOC**	
OECD (1991)	**EU**	0.25	140	0.32	3	0.18	0.17		Long-distance trucks
Schoemaker and Bouman (1991)	**Netherlands**	2.24	451	1.57	5.65	0.43	0.9		Trucks
		0.54	109	0.38	1.37	0.1	0.22		Trucks & trailers
		0.34	127	0.34	2.3	0.11	0.19		Truck-tractors & Semi-trailers
		0.9	211	0.68	2.97	0.2	0.39		Road freight overall
Whitelegg (1993)	**EU**	2.4	207	0.3*	3.6			1.1	Road freight overall
Kurer (1993)	**Germany**	1.86	255	1.25	4.1	0.32	0.3		Local
		0.25	140	0.32	3	0.18	0.17		Long-haul
Befahy (1993)	**Belgium**	2.1		0.92	1.85		0.04		Trucks & semi-trailers > 10 tonne
RCEP (1994)	**UK**	2.4	207		3.6			1.1	
TTNCCP (1998)	**Canada**		114						Diesel trucks
ECMT (1998)	**EU**		100		1.2	0.03		0.05	Diesel truck, 35t gvw

			200		2.26	0.05		0.1	Diesel truck, 20t gvw
EEA (2001)	**EU**				0.31-0.88				Rural diesel truck
					0.24-1.15				Highway diesel truck

* Data for methane only.
HC: hydrocarbons.

Air

In estimating the air pollution cost from air transport, we follow steps similar to those used in road transport discussed above. The main difference is how the emissions from vehicles/aircraft are estimated. In road transport, air pollutants emitted during the whole journey are taken into account. In air transport, air pollution at the ground level resulting from flights' landing and takeoff (LTO) is distinguished from the cruise-level impact. Furthermore, Lu and Morrell (2002) suggested that differences in aircraft operations, engine types, emission rates and airport congestion are considered as important parameters influencing the damage level of pollutants. We will focus on the emissions from aircraft during the LTO, which are more relevant to local air pollution. The effects of GHG emissions at cruise level will be discussed in Chapter 7.

Perl et al. (1997) divided the LTO cycle into four operations: approach, taxi-idle-queue, takeoff, and climb-out. To obtain the total LTO emissions for each engine, the emission rate, or emission index (EI), is multiplied by the amount of time in each operation of the LTO cycle, and then the results from the four operations are summed up. The quantity of the LTO emission per engine is multiplied by the number of engines that are fitted on the particular model of aircraft under examination and then summed for all movements made by that type of aircraft annually.

UNITE (2000) calculated the changes in the concentration and deposition of pollutants due to the additional emissions by air quality models, including the Gaussian dispersion model ROADPOL, the Windrose Trajectory Model (WTM), and the Source-Receptor Ozone Model (SROM). These models are applicable for emissions up to the mixing layer height, which is typically around 800 meters. Emission calculations were based on International Civil Aviation Organization (ICAO) emission data (ICAO/CAEP 2002), complemented by other sources.

Following a similar approach, ICAO/CAEP (2004) estimated the emission in air transportation by the Emissions and Dispersion Modeling System (EDMS), developed by the U.S. Federal Aviation Administration (FAA). EDMS is a LTO cycle model for global estimates of local emissions, and is the FAA required model for performing air quality analyses of aviation sources associated with airport development projects in the U.S. It is designed to assess the air quality impacts of airport emission sources, particularly aviation sources, which consist of aircraft, auxiliary power units and ground support equipment. It includes emissions and dispersion calculations, the latest aircraft engine emission factors from the ICAO Engine Exhaust Emissions Data Bank, and EPA-validated dispersion algorithms. EDMS can be used to create an emissions inventory for an individual source (such as aircraft), or combination of sources. To create an emissions inventory, the user enters fleet and activity data. EDMS then combines these inputs with default or user-specified emission factors to calculate total emissions in tons.

The air pollution costs of air transport have been estimated in some recent studies. Levinson et al. (1998) divided the value of pollution damages into three components: health effects of local pollution, material and vegetation effects of local pollution, and global warming. Combining the unit cost estimated by other studies, the cost of air pollution caused by air travel is $0.0012/pkt. (All the figures in this paragraph are in terms of 2002 $C.) Here the cost basically is due to the health damages from particulates, sulfur oxides, hydrocarbons, carbon monoxide and nitrogen dioxide, plus the climate change damages due to carbon dioxide. UNITE (2002) quantified marginal external costs due to a Boeing 737-400 operated between Berlin and London. The estimated marginal cost is $203 per flight from Berlin Tegel to London Heathrow. Lu and Morrell (2002) estimated that the average social cost at ground level resulting from the standard LTO procedures is $347 per landing. The weighted average cost of emissions from 30-minute cruise either before landing or following take-off is $988 per landing, where NO_x is the only cruise emission included owing to the higher uncertainties of other emissions.

Table 6.9 shows estimates of emission factors for air transportation. These are all European estimates, which reflect their fleet mix of type and age of aircraft, as well as airport congestion. We suspect these figures are too high for Canada, e.g., longer stage lengths in Canada. There is a need to develop Canadian-based figures. There is also "uncertainty" over whether these are emissions during the full flight, or are adjusted to reflect only the low-level (takeoff and landing) emissions.

Table 6.9. Aircraft Emission Factors, gm per tonne-km

Study	***Location***	***Air Pollutant***					***Notes***
		CO	**CO_2**	**NO_x**	**SO_2**	**VOC**	
RCEP (1994)	**UK**	1.4	1,206	5.5		3	
ECMT (1998)	**EU**		1,420	4.33	0.42	0.65	Short haul (500 kms)
			800	2.66	0.23	0.25	Long haul (1500 kms)
EEA (2001)	**EU**			8.48-18.2			Short haul (232 kms)
				0.47-2.35			Long haul (232-4,630 kms)

Marine

In general, there is relatively little known about global air pollution produced by the marine industry. However, shipping emits substances that have an effect on air pollution problems (and global climate change). Large ships generate 14% of global nitrogen emissions and 16% of sulphur emissions from all petroleum sources (Talley 2003).

Further, ship emissions also account for 5% of sulphur emitted by all fuel combustion sources and 2% of carbon dioxide emitted from fossil fuel use (Corbett and Fishbeck 1997). See also Table 6.14 for air contaminant emissions for Canada. Note that air pollution is primarily an issue near population centres hence much of ship emissions would not have a high cost attached to them. The International Maritime Organization (2000) reported that 74-83% of ships are within 200 nautical miles (370.4 km) of land at all times, and that approximately 80% of shipping exhaust gases is emitted near the coast.

One of the main reasons for ship emissions is the type of fuel used by the shipping industry. Most of large vessels use the least expensive diesel available in the market. This fuel is usually the residual product left after producing higher grade fuels or the result of using secondary refining technologies (Bluewater Network 2003). In addition, it is noted that main vessel engines are not the only source of air pollution from shipping. Auxiliary engines used mainly for berth operations have also become an important source of vessel emissions within port areas (Cooper 2003).

Table 6.10 lists shipping air-pollution emission factors from several studies. Although most of the data did not specify the emission circumstances (e.g., ship docked or underway), the European Environment Agency (2001) information did differentiate between bulk carrier vessel and container ship emissions. Statistics Netherlands (1997) provided a set of emissions data explicitly for inland vessel traffic. Similarly, US EPA (1985) estimated detailed emission factors for inland vessel traffic; however, the study was based on kilograms per 10^3 liters of fuel and thus is difficult to compare with other results.

Table 6.10. Marine Emission Factors, gm per tonne-km

Study	***Location***	***Air Pollutant***							***Notes***
		CO	**CO_2**	**HC**	**NO_x**	**SO_2**	**PM_{10}**	**VOC**	
OECD (1991)	**EU**	0.018	40	0.08	0.5	0.05	0.03		
Whitelegg (1993)	**EU**	0.12	30	0.04	0.4			0.1	
Befahy (1993)	**Belgium**	0.2		0.08	0.58		0.04		
RCEP (1994)	**UK**	0.12	30		0.4			0.1	
SN (1997)	**Netherlands**	0.11	33	0.05	0.26	0.04	0.02		Inland waterways
ECMT (1998)	**EU**		13		0.26	0.02		0.01	Fuel: diesel
			12		0.32	0.24		0.01	Fuel: oil
EEA (2001)	**EU**				0.11-0.22				Bulk carrier
					0.19-0.4				Container ship

Marine Emission Factors, $kg/10^3$ liters of fuel

Study	*Location*	*Air Pollutant*					*Notes*
		CO	HC	NO_x	SO_2	PM_{10}	
EPA (1985)	**US**	12	6.0	33	3.2	470 g/hour	Rivers
		13	7.0	31	3.2	470 g/hour	Great Lakes
		13	6.0	32	3.2	470 g/hour	Coastal

Rail

Table 6.11 reports several sets of emission factor estimates for freight carried by rail locomotives. As can be seen, the study reported to the European Conference of Ministers of Transport (1998) shows that diesel engine locomotives are less environmental friendly than locomotives powered by electric engines. It should also be obvious from the limited information in Table 6.11 for Canadian CO_2 from freight rail that Canadian fuel use per tonne-km is much lower than the European average. It is less clear, however, if that extends to the air pollutant emissions as the relevant Canadian data are not available. European rail often employs electric propulsion; on the other hand Canadian freight operations are long-haul and large volume movements.

Table 6.11. Rail Emission Factors, gm per tonne-km

Study	*Location*	*Pollutant*							*Notes*
		CO	CO_2	HC	NO_x	SO_2	PM_{10}	VOC	
OECD (1991)	**EU**	0.15	48	0.07	0.4	0.18	0.07		
Schoemaker & Bouman (1991)	**Netherlands**	0.02	102	0.01	1.01	0.07	0.01		
Whitelegg (1993)	**EU**	0.05	41	0.06	0.2			0.08	
Kurer (1993)	**Germany**	0.15	48	0.07	0.4	0.18	0.07		
Befahy (1993)	**Belgium**	0.06		0.02	0.4		0.08		
RCEP (1994)	**UK**	0.05	41		0.2			0.08	
TTNCCP (1998)	**Canada**		20						
ECMT (1998)	**EU**		69		1.22	0.08		0.07	Diesel-electric engine train
			38		0.07	0.21		0	Electric engine train
EEA (2001)	**EU**				0.20-1.36				

A comparison between Table 6.11 and Table 6.8 shows that rail emission factors are in general lower than trucking emission factors. This is confirmed by Ellwanger (2002) as can be seen from Table 6.12, which shows a summary of external environmental costs per 1,000 tonne-km and per 1,000 passenger-km, respectively, for rail and road transport. We are unsure of the relevance of European figures for Canada because of the enormous difference in productivity of Canadian rail freight operations compared to Europe. However, rail passenger operations are another matter. On the other hand, rail tends to have higher emission factors than marine transportation (see Tables 6.11 and 6.10) as the technologies, friction, speeds and load factors produce different outputs (tonne-km) per unit of fuel.

Table 6.12. External Environmental Costs of Transport from European Estimates

	Passenger (ECU/1,000 Pkm)		Freight (ECU/1,000 Tkm)	
	Road	Rail	Road	Rail
IWW/INFRAS	50.1	10.0	58.4	7.3
ECMT, 1996	50-65	10-19	18-30	4-7.5
ECMT, 1998	49	12	62	9
EU-Greenbook	35.5	8.0	33.2	5.3
ZEW-QUITS	44.3	4.9	30.6	2.8

Source: Ellwanger (2002).
ECU: European Currency Unit.

6.5.3 Emission Factors

Table 6.13 provides the emission factors of major pollutants for each transport mode, which will, in Section 6.7, be used in deriving our estimates of air pollution costs.[146] For freight transport, the emission factors given in the table are based on the ranges of emission factors of above Tables 6.8-6.11. Because our recommended estimates are values for Canada whilst the low and high estimates here are calculated by taking non-Canadian values, comparison between them should be done carefully, recognizing the differences between Canadian and non-Canadian conditions.

Intercity emission estimates were much harder to obtain. Neither Mayeres nor KPMG made any estimates for intercity transport. Figures for Canadian intercity bus were obtained from Transport Canada, and checked with GHG emissions compiled for the Transportation Table (1999).

[146] Note that the pollutant CO is not included in the calculation of the marginal costs. This is because the air dispersion models, Tables 6.6-6.7 above, do not contain estimates for CO. With the dose-response approach that we are using, this means that the costs of CO emission could not be calculated (see Section 6.9 for the calculation procedure). We note, however, that this omission won't significantly change our overall results since CO is considered a relatively minor pollutant (especially as compared to PM_{10}). In Mayeres et al. (1996), for instance, the marginal cost (per vehicle-km) of PM_{10} is more than 500-1,300 times than that of CO for different modes of road transportation.

For intercity "private vehicle", Mayeres' estimates are not appropriate, as they are for urban car use, as well as being European. And the KPMG estimates are for urban operations. We developed estimates by adjusting urban-based figures in proportion to urban versus intercity GHG emission rates, as well as adjusting differences in vehicle occupancy.

Table 6.13. Emission Factors

PM_{10}				
Interurban passenger transport (gm per passenger-km)				
	Source	Low estimate	High estimate	Recommended estimate
Private vehicle	Mayeres et al. (1996), KPMG (1992)[147]	0.000	0.040	0.036
Aircraft		N/A	N/A	N/A
Bus	Transport Canada	N/A	N/A	0.041
Train[2]		N/A	N/A	0.192
Ferry[2]		N/A	N/A	0.446
Urban passenger transport (gm per passenger-km)				
Private vehicle	Mayeres et al. (1996), KPMG (1992)	0.000	0.079	0.071
Urban transit	Mayeres et al. (1996), KPMG (1992)	N/A	N/A	0.024
Freight transport (gm per tonne-km)				
Truck	Befahy (1993), Schoemaker and Bouman (1991)	0.040	0.900	0.205
Rail	Schoemaker and Bouman (1991), Befahy (1993)	0.010	0.080	0.070
Marine	SN (1997), Befahy (1993)	0.020	0.040	0.030
Aircraft		N/A	N/A	N/A

SO_x				
Interurban passenger transport (gm per passenger-km)				
	Source	Low estimate	High estimate	Recommended estimate

[147] Assume that PM_{10} was used in the study.

Private vehicle	Mayeres et al. (1996), KPMG (1992)	0.000	0.058	0.026
Aircraft		N/A	N/A	N/A
Bus	Transport Canada	N/A	N/A	0.011
Train[2]		N/A	N/A	0.050
Ferry[2]		N/A	N/A	0.117
Urban passenger transport (gm per passenger-km)				
Private vehicle	Mayeres et al. (1996), KPMG (1992)	0.000	0.114	0.050
Urban transit	Mayeres et al. (1996), KPMG (1992)	N/A	N/A	0.361
Freight transport (gm per tonne-km)				
Truck	ECMT (1998), Schoemaker and Bouman (1991)	0.030	0.430	0.180
Rail	Schoemaker and Bouman (1991), ECMT (1998)	0.070	0.210	0.180
Marine	ECMT (1998)	0.020	0.240	0.045
Aircraft	ECMT (1998)	0.230	0.420	0.325

NO_x				
Interurban passenger transport (gm per passenger-km)				
	Source	Low estimate	High estimate	Recommended estimate
Private vehicle	Mayeres et al. (1996), KPMG (1992)	0.058	0.803	0.696
Aircraft	Levinson et al. (1998)	N/A	N/A	0.130
Bus	Transport Canada	N/A	N/A	0.899
Train[2]		N/A	N/A	4.253
Ferry[2]		N/A	N/A	9.855
Urban passenger transport (gm per passenger-km)				
Private vehicle	Mayeres et al. (1996), KPMG (1992)	0.114	1.571	1.364
Urban transit	Mayeres et al. (1996), KPMG (1992)	N/A	N/A	0.232
Freight transport (gm per tonne-km)				
Truck	EEA (2001), Schoemaker and Bouman (1991)	0.240	5.650	2.635

Rail	ECMT (1998), Schoemaker and Bouman (1991)	0.070	1.010	0.305
Marine	EEA (2001), Befahy (1993)	0.110	0.580	0.320
Aircraft	EEA (2001)	0.470	18.200	4.330

VOCs				
Interurban passenger transport (gm per passenger-km)				
	Source	Low estimate	High estimate	Recommended estimate
Private vehicle	Mayeres et al. (1996), KPMG (1992)	0.004	0.186	0.095
Aircraft	Levinson et al. (1998)	N/A	N/A	0.093
Bus	Transport Canada	N/A	N/A	0.045
Train[2]		N/A	N/A	0.215
Ferry[2]		N/A	N/A	0.499
Urban passenger transport (gm per passenger-km)				
Private vehicle	Mayeres et al. (1996), KPMG (1992)	0.007	0.364	0.186
Urban transit	Mayeres et al. (1996), KPMG (1992)	N/A	N/A	0.002
Freight transport (gm per tonne-km)				
Truck	ECMT (1998), Whitelegg (1993)	0.100	1.100	0.600
Rail	ECMT (1998), Whitelegg (1993)	0.070	0.080	0.075
Marine	ECMT (1998), Whitelegg (1993)	0.010	0.100	0.055
Aircraft	ECMT (1998), RCEP (1994)	0.250	3.000	0.650

CO				
Interurban passenger transport (gm per passenger-km)				
	Source	Low estimate	High estimate	Recommended estimate
Private vehicle	Mayeres et al. (1996), KPMG (1992)	0.095	1.553	8.418
Aircraft		N/A	N/A	N/A

Bus	Transport Canada	N/A	N/A	0.485
Train[2]		N/A	N/A	2.294
Ferry[2]		N/A	N/A	5.315
Urban passenger transport (gm per passenger-km)				
Private vehicle	Mayeres et al. (1996), KPMG (1992)	0.186	3.036	16.836
Urban transit		N/A	N/A	N/A
Freight transport (gm per tonne-km)				
Truck	OECD (1991) and Whitelegg (1993)	0.250	2.400	1.380
Rail	OECD (1991) and Whitelegg (1993)	0.018	0.200	0.120
Marine	Schoemaker & Bouman (1991) and OECD (1991)	0.020	0.150	0.055
Aircraft	RCEP (1994)	N/A	N/A	1.400

Note: As only the emission factor of bus is available from Transport Canada, we use an indirect way to estimate the emission factors of train and ferry. Air pollutant emissions are fairly proportional to those GHG emissions for the transportation modes using the same fuel, for example, diesel. We calculate the ratio of GHG emissions among different modes from Table 7.21, which suggests that the GHG emissions from train and ferry are 4.73 and 10.96 times more than bus. We apply these ratios to estimate the emission factors of train and ferry.

As the estimation of emission factors plays a critical role in the calculation of marginal costs, we also suggest an alternative way to arrive at emission factors. Specifically, emission factors comparable to those in Table 6.14 could be calculated if passenger-km and tonne-km were obtained for each type of vehicle/craft. That is, emission factors are obtained by dividing the total emissions of different modes of transportation (e.g., Table 6.14) by the total traffic volume, in terms of passenger-km or tonne-km, in a specific year. Unfortunately, consistent estimates of the traffic volumes are not available and as a result, this method could not be implemented.

Table 6.14. 2000 Criteria Air Contaminant Emissions for Canada (tonnes)

	PM_{10}	$PM_{2.5}$	SO_x	NO_x	VOCs	CO
Air Transportation	1,319	1,013	3,504	57,556	9,726	57,219
Heavy-Duty Diesel Vehicles	15,542	14,350	9,706	514,518	23,417	124,895
Heavy-Duty Gasoline Trucks	249	191	408	15,386	8,512	134,844
Light-Duty Diesel Trucks	887	818	554	7,162	3,425	6,107
Light-Duty Diesel Vehicles	296	272	95	1965	843	1,927

Light-Duty Gasoline Trucks	1,179	992	6,131	120,116	148,494	2,302,568
Light-Duty Gasoline Vehicles	1,038	986	8,500	190,091	219,152	3,150,457
Marine Transportation	16,876	15,608	18,301	706,574	243,412	3,277,279
Motorcycles	19,191	17,609	25,394	849,238	403,843	5,720,798
Off-Road Use of Diesel	5,610	5,361	32,976	111,416	9,349	13,613
Off-Road Use of Gasoline	2,567	2,365	4,193	109,481	5,400	20,776
Rail Transportation	1319	1,013	3,504	57,556	9,726	57,219
Tire Wear & Brake Lining	15,542	14,350	9,706	514,518	23,417	124,895
Total Transportation	81,623	72,157	82,875	1,553,074	727,142	8,374,986

Source: Environment Canada Website.

6.6 Economic Valuation of Damages

The fourth step in the damage-function approach is the valuation or monetization of the impacts of emissions from transportation, drawing results from the economics literature.

6.6.1 Monetary Valuation of Mortality and VSL

A common approach to the valuation of premature mortality is to estimate the value of a risk reduction using CVM or hedonic methods, and then convert this estimate to the value of a statistical life (VSL). Chapter 3 of this report contains a detailed examination of the methodologies and estimates of VSL based largely on road transportation. Below we first briefly review the VSL found in environmental studies, and discuss the relationship between the VSL of road safety and the VSL to be used later in the present chapter.

McCubbin and Delucchi (1999) have estimated the health cost of motor-vehicle-related air pollution and assigned different values of mortality, depending on the degree of prematurity as well as the timing of the death. Table 6.15 lists the values of mortality reported by them.

Table 6.15. Value of Mortality (For Motor-vehicle-related Air Pollution, US$)

	Lower-bound estimate	Upper-bound estimate
Cancer from toxics	$0.5 million	$2 million
Death that would have occurred within a few days without exposure	$10,000	$50,000
Death that would not have occurred otherwise	$1 million	$4 million
Present value of chronic death	$0.513 million	$3.8 million

Source: McCubbin and Delucchi (1999, p. 266).

Based on an analysis of 26 studies (five CVM studies, 21 wage-risk studies), US EPA (1999) provided a mortality risk valuation estimate. Specifically, the analysis used the best estimate from each of the 26 studies to construct a distribution of mortality risk valuation estimates. A Weibull distribution, with a mean of $6.07 million (in 2002 $C) and standard deviation of $4.09 million, provided the best fit to the 26 estimates.

In a report to Environment Canada on the Air Quality Valuation Model (AQVM), Chestnut et al. (1999) reviewed the literature on WTP for changes in risk of death and estimated VSL to be used in the economic evaluation of environmental issues. They concluded that the VSL of people over 65 years of age is $3.9 million (in 1996 $C), with a high value of $7.8 million and a low value of $2.3 million. For people under 65 years of age, the VSL is $5.2 million, with a low value of $3.1 million and a high value of $10.4 million. Taking a weighted average of these estimates and assuming that 85% of air particulate-related deaths are to those members of the population aged 65 and older, Environment Canada recommended a central, age-weighted estimate of $4.1 million with a high value of $8.2 million and a low value of $2.4 million. These results are summarized in Table 6.16, with the figures being converted to 2002 $C.

Table 6.16. Selected Monetary Values for Mortality Risks in AQVM 3.0 (2002 $C million)

Population Group	Low value	Central value	High value
65 years and older	$2.50	$4.24	$8.49
<65 years old	$3.37	$5.66	$11.32
Age-weighted average VSL[1]	$2.61	$4.46	$8.92

Notes: 1. Assuming 85% of deaths due to air pollutants are individuals aged 65 and over.

In Chapter 3, we have, after a comprehensive study, recommended that a reasonable point estimate of the VSL for Canada is $4.25 million (in 2002 $C), with a high value of $7.5 million and a low value of $2.0 million. These values are certainly consistent with the values given in Table 6.16. They are smaller than the US EPA (1999) values. One contributing factor is the role of income elasticity in transferring VSL estimates between different countries. Miller (2000) found a range of income elasticity from 0.85 to 0.96, whereas Mrozek and Taylor (2002) found very inelastic estimates of 0.46 to 0.49. On the other hand, in their meta-analysis of wage-risk studies, Bowland and Beghin (2001) reported a median income elasticity of 1.95 and a range of income elasticity from 1.7 to 2.3, and de Blaeij et al. (2003) also found elastic effects of income on the VSL (1.67). Viscusi and Aldy (2003) replicated the meta-analyses undertaken by Miller (2000), Bowland-Beghin (2001), and Mrozek and Taylor (2002) with their own wage-risk data set. They found a range of the income elasticities between 0.52 and 0.61.[148] They further noted, under various specifications, that the 95% confidence interval's upper bound never exceeds 1.0. The issue is discussed in detail in Chapter 3.

The next issue is: Do we need to do any conversion for the VSL estimates recommended in Chapter 3, to the context of the present chapter, and if so, how do we undertake the conversion? Jones-Lee et al. (1998) proposed a factor of two to transfer the VSL for road accidents to the air pollution context, arguing that the WTP for reducing environmental mortality risks is higher than the WTP for reducing traffic accident risks. This would mean, in the context of the present chapter, that the VSL for road accidents is multiplied by 2 to account for the environmental context. This practice, however, ignores the point of whether the much lower average number of years of life lost through death from environmental emissions (rather than road accidents) means that the former should have a much lower value. This has been the major debate between transport and environmental analysts, and was also the issue addressed by Krupnik et al. (2002) in their Canadian study. As mentioned in Chapter 3.5.3, Krupnik et al. (2002) found that the VSL is constant up to 70 years of age but falls 30 % for those over 70 years. This finding is consistent with the one reported in Table 6.16, and was interpreted by Krupnik et al. (2002) and others to suggest environmental deaths should be valued lower than the

[148] Although the income elasticity of 0.52 calculated using Mrozek and Taylor's (2002) specification is not statistically significant at the 5% level, both estimates using Miller's (2000) and Bowland and Beghin's (2001) specifications (0.53 and 0.61 respectively) are significant at the 5% level.

average.[149] Also, physical health status has no impact on the WTP, but mental health does. People with fewer symptoms of psychological distress are willing to pay more to reduce their chance of dying. Given these uncertainties involved, we will not undertake the conversion suggested by Jones-Lee et al., and will, instead, use the VSL of $4.25 million recommended in our Chapter 3, with the $2.0-$7.5 million range for sensitivity analysis.

6.6.2 Monetary Valuation of Morbidity

There are generally two approaches to the estimation of the social cost of morbidity: the "observed market" approach and the "constructed market" approach. The observed-market approach gives a "cost of injury" (COI) measure, which includes medical costs and lost income as a proxy for work loss. The estimation relies on the demand and cost functions, market prices, and observed behavior and choices. However, it does not reflect the total welfare impact of an adverse health effect, and so results in a downward bias to what we want to value. On the other hand, the approach has a practical advantage, as the market and expenditure data are relatively easily accessible.

The constructed-market approach attempts to measure the value of health effects by WTP. It involves the CVM techniques that ask people's WTP (or WTA) for a postulated change and analyze how their behavior would change, or how they would rank alternative situations involving different combinations of health and income or consumption. In theory, this measures more precisely and explicitly what is to be valued, but it is reliable only insofar as people respond realistically to the constructed market.

For the damage-function approach adopted in this chapter, monetary valuations of illness and loss of productivity are required. Recall that as a part of the damage-function approach, we have, after reviewing the relevant medical literature, arrived at the dose-response functions of Tables 6.1-6.4, which provide the risk factors of air pollutants for various illnesses and productivity losses. Since Tables 6.1-6.4 are based on AQVM 3.0, for consistency we shall in this chapter use the AQVM valuations of these illnesses and productivity losses. Note that in our report, Chapter 4 has provided estimates of the cost of injuries and accidents. Conceivably, productivity losses (days of work missed) would be valued similarly between Chapter 4 and the approach used here, but one might debate whether the valuations of subjective pain and suffering are similar between the two. In any case, since Chapter 4 has used somewhat different approaches in estimating the illness costs, there are no corresponding estimates to the ones to be employed in the present chapter. Consequently, unlike the case of VSL, we are unable to import the estimates of Chapter 4 directly in the case of morbidity.

[149] They were referring to an average derived primarily from the risk premium studies, just as we have done in Chapter 3.

The AQVM valuations are discussed below.

Valuing chronic bronchitis

Air pollutants can particularly affect susceptible people with diseases such as asthma, chronic bronchitis and emphysema, referred to as a group as airway obstructive disease. Research indicates that people are willing to pay large amounts of money to avoid chronic illnesses. PM-related chronic bronchitis is expected to last from the initial onset of the illness throughout the rest of the individual's life. The WTP to avoid chronic bronchitis would, therefore, be expected to incorporate the present discounted value of a potentially long stream of costs – e.g., medical expenditures and lost earnings – and pain and suffering associated with the illness.

The valuation of chronic bronchitis is based on Viscusi et al. (1991), which is summarized below. The study described to the respondents a severe case of chronic bronchitis. On the other hand, US EPA (1999) employed an estimate of WTP to avoid a pollution-related case of chronic bronchitis that is based on adjusting the WTP to avoid a severe case, as estimated by Viscusi et al. (1991). The expected value is about $260,000.

Valuing hospital admissions

The value to society of an individual's avoidance of hospital admissions has two components: i) the COI to a society, including the total medical costs plus the value of the lost productivity; and ii) the WTP of the individual and others to avoid the pain and suffering resulting from the illness (McCubbin and Delucchi 2003). In the absence of estimates of the social WTP to avoid hospital admissions for specific illnesses or of the value of pain and suffering, the estimates of total COI are typically used as lower-bound estimates of the total social cost. Some analyses (Rowe et al. 1984, Rowe and Chestnut 1986, Rowe and Neithercut 1987, and Chestnut 1988) adjust COI estimates upward by multiplying by an estimate of the ratio of WTP to COI to better approximate the total WTP (see further discussion below).

Valuing chronic asthma

US EPA (1994) derived this valuation estimate from two studies that solicit values from individuals diagnosed as asthmatics. Blumenstein and Johannesson (1998) generated an estimate of monthly WTP, while O'Connor and Blomquist (1997) generated an annual WTP estimate. The mean estimate of WTP over an individual's lifetime to avoid a case of chronic asthma resulting from this method is approximately $25,000.

Summary of the estimates of value of morbidity in AQVM 3.0

Table 6.17 summarizes the monetary values for morbidity effects in AQVM 3.0 (adjusted to 2002 $C). The WTP-estimated values are used if they are available. When WTP estimates are not available, the monetary estimates are based on COI information, and the

COI values are inflated to the WTP estimates with a WTP/COI factor of 2.[150] (The COI information used here reflects medical costs and lost productivity due to illness.) The average daily Canadian wage for 1996 is used as a measure of lost productivity for days when all normal activities are prevented because of illness.

Table 6.17. Selected Monetary Values for Morbidity Effects in AQVM 3.0 (2002 $C)

Morbidity Effect	Estimate per Incident			Primary Source	Type of Estimate
	Low	Central	High		
Adult chronic bronchitis	$190,424	$289,445	$505,985	Viscusi et al. (1991), Krupnick and Cropper (1992)	WTP
Respiratory hospital admission	$3,591	$7,182	$10,664	Canadian Institute for Health Information (1994)	Adjusted COI
Cardiac hospital admission	$4,570	$9,140	$13,711	Canadian Institute for Health Information (1994)	Adjusted COI
Emergency room visit	$316	$620	$936	Rowe et al. (1986)	Adjusted COI
Child bronchitis	$163	$337	$501	Krupnick and Cropper (1989)	Adjusted COI
Restricted activity day	$40	$79	$120	Loehman et al. (1979)	WTP and Adjusted COI
Asthma symptom day	$18	$50	$82	Rowe and Chestnut (1986)	WTP
Minor restricted activity day	$22	$36	$62	Krupnick and Kopp (1988)	WTP
Acute respiratory symptom day	$8	$16	$24	Loehman et al. (1979), Tolley et al. (1986)	WTP

Monetary valuations in UNITE and US EPA

Although we will be using AQVM estimates, it is useful to take a look at the valuations at UNITE and US EPA. Based on Friedrich and Bickel (2001) and UNITE (2001a), UNITE

150 Across the four studies, namely Rowe et al. (1984), Rowe and Chestnut (1986), Rowe and Neithercut (1987) and Chestnut (1988), the individual WTP/COI ratios range from 1.3 to 2.4. Based on these results, a WTP/COI ratio of 2 is selected for morbidity effects.

(2001b) estimated the monetary values for morbidity. Table 6.18 summarizes the estimates.

Table 6.18. Selected Monetary Values for Morbidity Effects in UNITE (2002 $C)

Impact	Avg. Europe	Austria	Denmark	Spain	France	Ireland	Netherlands	Sweden	UK
Year of life lost (chronic effects)	108,418	121,480	129,463	87,518	107,402	117,997	122,787	110,885	110,160
Year of life lost (acute effects)	186,502	208,999	222,642	150,653	184,761	202,903	211,176	190,711	189,550
Chronic bronchitis	199,710	223,803	238,462	161,248	197,968	217,271	226,125	204,209	203,048
Cerebrovascular hospital admission	20,174	22,612	24,093	16,299	19,985	21,945	22,845	20,624	20,508
Respiratory hospital admission	5,239	5,878	6,255	4,238	5,196	5,704	5,936	5,356	5,327
Congestive heart failure	3,962	4,441	4,731	3,193	3,933	4,311	4,485	4,049	4,020
Chronic cough in children	290	319	334	232	276	305	319	290	290
Restricted activity day	145	160	174	116	145	160	160	145	145
Asthma attack	100	112	119	81	99	109	113	103	102
Cough	49	55	60	39	49	54	55	51	51
Minor restricted activity day	49	55	60	39	49	54	55	51	51
Symptom day	49	55	60	39	49	54	55	51	51
Bronchodilator usage	46	52	55	38	46	51	52	48	48
Lower respiratory symptom	10	12	12	9	10	12	12	10	10
Source: UNITE 2003, Additional Information to Appendix 2: Monetary values used, Page 145									

1. Assume 1C$ = €0.689.

Comparing these estimates with those from AQVM 3.0, most estimates in UNITE (2001b) are within the range of those from AQVM 3.0. It is no surprise to see that UNITE and AQVM have similar estimates for most of the valuations, for UNITE used values from ExternE (Friedrich and Bickel 2001), which in turn used EPA values for the morbidity effects, so does AQVM essentially.[151] However, the values for cardiac hospital admission and restricted activity day (RAD) in UNITE (2001b) are beyond the upper boundary of the AQVM estimates. AQVM 3.0 used the COI method to calculate the value of cardiac hospital admissions, since the WTP value was not available. Resource

[151] Some discussions regarding EPA and related studies have been discussed in section 6.6.2 and in Chapter 3 on VSL.

intensity weight, an index of relative demand of hospital resources, for heart diseases related to PM_{10} and ozone were multiplied by the unit value of $2,500 to derive illness specific costs. The weighted averages of the hospitalization costs and lengths of stay were calculated based on admission rates for various cardiac diagnoses as reported by Burnett et al. (1994, 1995) and supplemented by Canadian hospital admissions data. Lost productivity is measured as the average daily wage multiplied by the length of stay. Summing hospital and lost productivity costs and multiplying by the WTP/COI ratio of 2 gives an approximation to the value required.

RAD, defined by the Health Interview Survey (HIS), is a day on which illness prevents an individual from engaging in some or all of his or her usual activities. As for cardiac hospital admission, WTP estimates are not available. AQVM 3.0 used available COI data and WTP estimates for days with symptoms. Data from the HIS indicate that about 40% of all RADs are bed-disability days. The results of Ostro (1987) suggest that RADs associated with air pollution exposure may be less severe on average than all RADs. AQVM 3.0 presumed a lower proportion of bed-disability days for this analysis than the national average for all RADs.

In US EPA (1999), whenever possible, the report uses mean WTP estimates. When WTP estimates are not available, the costs of treating or mitigating the effect are used as an alternative estimate. Table 6.19 summarizes the valuations of mortality and morbidity effects from US EPA (1999). The estimated figures are similar to that from AQVM 3.0.

Table 6.19. Selected Monetary Values for Morbidity Effects in US EPA (2002 $C)

Impact	Valuation
Chronic Bronchitis	398,549
Chronic Asthma	38,322
Respiratory Hospital Admissions	10,577
Cardiovascular Hospital Admissions	14,562
Emergency Room Visits for Asthma	297
Acute Bronchitis	69
Asthma Attack or Moderate or Worse Asthma Day	49
Acute Respiratory Symptoms	28
Upper Respiratory Symptoms	29
Lower Respiratory Symptoms	18
Shortness of Breath, Chest, Tightness, or Wheeze	8
Work Loss Days	127
Mild Restricted Activity Days	58

Source: US EPA (1999) Table 6, p. 70.

6.6.3 Monetary Valuation of Cancer Risk

As indicated in Tables 6.3-6.4, toxic pollutants such as benzene and diesel particulates increase the risk of developing cancer. Cancers often have a long latency period, and are expensive and time-consuming to treat. The chance of recovery depends on many factors. For fatal cancer cases, McCubbin and Delucchi (1999, 2003) suggested assigning the VSL at the point when the cancer is discovered, and ignoring costs incurred between the time of discovery and death. The omission of post-discovery costs understates the present value of the cost of cancer, but the failure to consider the time lag between discovery and death overstates the present value, so that these two simplifications tend to cancel out with each other.

Table 6.20 summarizes the estimates of valuation of cancer risk that are used by AQVM 3.0. The approach here is to combine WTP estimates for mortality risks in general with adjusted COI estimates for non-fatal cancers according to the average cancer survival rates. WTP estimates for reducing the risk for developing a new cancer case are, thus, calculated by combining cancer survival rate information with VSL estimates and estimates of the value of nonfatal cancer cases using the following equation:

$$Cancer\ WTP = \left[\left(1 - survival\ rate\right) \times\ fatal\ case\ value\right] + \left(survival\ rate \times nonfatal\ case\ value\right)$$

Table 6.20. Monetary Values for Cancer Effects (2002 $C)

	Value per non-fatal cancer case	Value per fatal cancer case	Average value for all cancer cases
Values for Cancers Associated with Acetaldehyde, 1,3 Butadiene, and Formaldehyde			
Low	$166,485	$2.8 million	$1.7 million
Central	$331,882	$4.7 million	$2.9 million
High	$663,765	$9.4 million	$5.9 million
Values for Cases of AML Associated with Benzene[1]			
Low	$156,692	$2.9 million	$2.6 million
Central	$312,296	$4.9 million	$4.4 million
High	$624,591	$9.7 million	$8.6 million

Source: AQVM 3.0.
Notes: 1. AML: Acute myelogenous leukemia.

6.6.4 Valuation of Material Damage

US EPA (1988) reported that the soiling portion of total damage costs due to PM_{10} is $0.48 in 1990 U.S. dollars. After adjusting for exchange rate and purchasing power parity (PPP), the damage value becomes $0.73 in 2002 $C. It is plausible that at least half of the costs of household cleaning are for the time value of do-it-yourselfers, which was not included in the analysis by Manuel et al. (1982). A central value of $1.46 (in 2002 $C) per person per g/m^3 is, therefore, selected by AQVM 3.0. This central estimate is consistent with the results obtained in McClelland et al. (1991). An upper estimate of $3.66 is selected by AQVM 3.0 as five times the estimate in Mathtech et al. (1982) based on the results of Watson and Jaksch (1982). These three values are reported in Table 6.21 as the low, central, and high estimates, respectively.

The material damage cost due to SO_2 includes household expenditures and galvanized steel material damage. Citing from AQVM and adjusting for PPP, the central estimate of the cost is $1.05 (see Table 6.21) with low and high estimates of $0.50 and $1.59, respectively.

Table 6.21. Material Damage Cost (2002 $C) per person per g/m^3

	Low estimate	Central estimate	High estimate
PM_{10}	0.73	1.46	3.66
SO_2	0.50	1.05	1.59

Source: AQVM 3.0.

6.7 Our Estimates

6.7.1 Calculation Procedure and Basic Results

As discussed above we follow the damage-function approach in our estimation of full costs of air pollution. First, important air pollutants are identified. Second, relevant literature is reviewed to establish the relationship between the emissions of air pollutants identified and damage effects on such targets as human being and materials. In particular, the dose-response functions adopted, namely, Tables 6.1-6.5, are based on AQVM 3.0, which generally fulfills some desirable criteria and has done adjustments for Canada. Third, an air dispersion model is identified and used to estimate how the emission of a specific pollutant under consideration changes its atmospheric concentration. Fourth, emission factors – the amount of air pollutants emitted per passenger-km or per tonne-km – are estimated and summarized in Table 6.13. Since emission factors may differ across countries, depending on the technology used and operating conditions, we prefer, whenever possible, using the figures from Canadian studies to using those from other countries.

After obtaining the emission factors, we can use Tables 6.6-6.7 to calculate the increases in mortality/morbidity cases due to the change in concentration of each pollutant. Taking PM_{10} and passenger transport as an example, the method of calculating the annual cases due to transportation is as follow:

Increases in mortality/morbidity cases due to passenger transport (per passenger-km)
= Damage Coefficient * Emission Factor * Rural/Urban Indices
(Table 6.1) (Table 6.13) (Tables 6.6-6.7)

Next, we need to estimate the monetary valuation of different impacts due to air pollution. We adopt the VSL estimate of C$4.25 million from Chapter 3 of the report, to capture the cost of mortality. For morbidity, our evaluations of illness and productivity loss have evolved somewhat separately from the valuations of injury, which are examined in Chapter 4. Since Chapter 4 did not have estimates corresponding to individual health impacts of this chapter, we are unable to employ its estimates directly in our calculation. Instead, we use the morbidity valuations from AQVM 3.0 (Table 6.17); this is also consistent with the dose-response functions based on AQVM 3.0.

Finally, the results from the epidemiological and engineering literature are merged with the results from the economic literature to arrive at marginal social costs of air pollution for each transportation mode. Our final estimates are given in Table 6.22. (All the figures in this section are in terms of 2002 $C.)

Table 6.22. Our Recommended Estimates of Full Costs of Air Pollution (in 2002 $C)

Interurban passenger transport (per passenger-km)	
Private vehicle	0.00088
Aircraft	0.00008
Bus	0.00100
Train	0.00471
Ferry	0.01091
Urban passenger transport (per passenger-km)	
Private vehicle	0.00842
Urban transit	0.00331
Freight transport (per tonne-km)	
Truck	0.00503
Rail	0.00173
Marine	0.00074
Aircraft	0.00003

As emission factors of passenger transport by air are not available, the marginal air pollution cost of air is calculated on the assumption that the marginal air pollution costs of passenger and freight transportation are proportional between rail and aircraft. This is an arbitrary and dubious assumption but no better data were available. Also of concern is that the relatively low figures for aircraft air pollution apparently reflect an assumption that only local emissions (takeoff and landing) are relevant. This is inconsistent with the treatment of other modes, although note that the valuation of intercity emissions of other modes are much lower than for urban areas, as population density and distance from the source reduce the exposure hence the costs of emissions.

We note that aircraft configuration presents a challenge when allocating the externalities of air transportation between air cargo transport and passenger transport. An estimated two thirds of airfreight is carried in the belly compartment of passenger aircraft. For the one third of airfreight carried in all-cargo freighters, allocating air pollution costs is straightforward. However, for the two-thirds carried in passenger flights, it may be hard to know which costs should attribute to cargo and which to passenger travel (OECD, 1997a). Furthermore, the average age of the fleet is of importance for specific emissions of air transport, as it reflects the technology level. According to Boeing (2002), more than 70% of worldwide freighter fleet additions are coming from conversions of passenger aircraft to all-cargo freighters. This produces a freighter fleet with an older average age, as only a small portion of them are new factory-built aircraft. Thus, as a lower level of engine technology and older aircraft are utilized, the emission factors from the freighter fleet tend to be higher than those from the passenger aircraft fleet. Unfortunately, the data necessary for adjusting for these two factors are not available to us. As a result, our calculation for air passenger travel is based on freight emission factors, given in Table

6.9, assuming that the marginal costs of passenger and freight transportation are proportional to each other.

Our estimates are towards the lower end estimated in the existing range. However, if we were to use the values of UNITE (Table 6.18) and U.S. EPA (Table 6.19), then our recommended estimates would be revised upward by, on average, about 4% and 5%, respectively.

6.7.2 Sensitivity Analysis

In our calculation of the full costs of air pollution, we have made a number of assumptions regarding:

- value of mortality
- value of morbidity
- passenger occupancy rates per vehicle
- emission factors.

It is important to see how sensitive our recommended estimates are with respect to alternative values of the above variables.

Value of Mortality

In calculating our recommended estimates, we have applied the central estimate of VSL in road transportation, i.e., $4.25 million derived from Chapter 3 of this report. As examined in detail in Chapter 3, there are many factors that can affect the valuation of mortality (age, income, voluntarily vs. involuntarily incurred risks, lagged mortality, etc.). So it is warranted to conduct sensitivity analysis with respect to VSL. We thus re-calculate the marginal social costs of air pollution using the range of $2.5-$7.0 million for VSL provided by Chapter 3 while holding all the other variables (e.g., emission factors) at their base-case values. The results are given in Table 6.23, with the recommended estimates being re-produced from Table 6.22.

Given that the low VSL ($2.5 million) and high VSL ($7.0 million) represent, respectively, a -40% decrease and 65% increase as compared to the base value ($4.25 million), the deviations of low and high estimates from the recommended estimates in Table 6.23 are smaller than those percentages, suggesting that our cost estimates do not seem to be very sensitive to the valuation of mortality. Relative to other modes, the estimates of road transportation appear to be somewhat sensitive to the choice of VSL. This may be due to road transport's high emission of PM_{10} (see Table 6.13) which is crucial to the change in mortality (see Table 6.1). Also note that the marginal costs for air transportation are insensitive to the values of mortality; however, low, recommended and high estimates are all the same due to rounding errors.

Table 6.23. Sensitivity Analysis: VSL (in 2002 $C)

	Low estimate: VSL = 2.5 million	High estimate: VSL = 7.0 million	Recommended estimate: VSL = 4.25 million
Interurban passenger transport (per passenger-km)			
Private vehicle	0.00065	0.00126	0.00088
Aircraft [a]	0.00008	0.00008	0.00008
Bus	0.00073	0.00142	0.00100
Train	0.00344	0.00671	0.00471
Ferry	0.00796	0.01554	0.01091
Urban passenger transport (per passenger-km)			
Private vehicle	0.00617	0.01196	0.00842
Urban transit	0.00257	0.00448	0.00331
Freight transport (per tonne-km)			
Truck	0.00367	0.00716	0.00503
Rail	0.00126	0.00245	0.00173
Marine	0.00054	0.00105	0.00074
Aircraft	0.00003	0.00003	0.00003

a) See Table 6.22.

Value of Morbidity

Similarly, we conduct a sensitivity analysis with respect to the valuations of morbidity. As shown in Table 6.17, apart from the central values of morbidity, AQVM 3.0 also provided a range of the values for each individual impact. The low and high estimates given in Table 6.24 below are calculated by the lower and upper boundaries of the AQVM values in Table 6.17, while holding all the other variables (e.g., VSL, emission factors) at their base-case values.

The results show that the variations in the monetary valuations of morbidity do not seem to affect the base values very much, and that our estimates are much tighter in the morbidity case than the VSL case. Similarly to the VSL case, the costs for air transportation are insensitive to the values of morbidity.

Table 6.24. Sensitivity Analysis: Value of Morbidity[152] (in 2002 $C)

	Low estimate	High estimate	Recommended estimate
Interurban passenger transport (per passenger-km)			
Private vehicle	0.00077	0.00109	0.00088
Aircraft [a]	0.00008	0.00008	0.00008
Bus	0.00087	0.00122	0.00100
Train	0.00410	0.00579	0.00471
Ferry	0.00949	0.01342	0.01091
Urban passenger transport (per passenger-km)			
Private vehicle	0.00734	0.01034	0.00842
Urban transit	0.00296	0.00394	0.00331
Freight transport (per tonne-km)			
Truck	0.00438	0.00618	0.00503
Rail	0.00150	0.00212	0.00173
Marine	0.00064	0.00091	0.00074
Aircraft	0.00003	0.00003	0.00003

a) See Table 6.22.

Occupancy Rates

As indicated earlier, since some emission factors in the literature are reported in terms of vehicle-km, vehicle occupancy rates are needed in the computation of the emission factors for passenger transport. Recall that we have used the following average occupancy rates in computing our recommended estimates: 2.15 passengers per interurban private vehicle, 1.4 passengers per urban private vehicle, 31 passengers per interurban bus and 17 passengers per urban transit. These figures are updates of the Transportation Table (1999), obtained from Transport Canada. Alternatively, based on KPMG (1992), the average occupancy rates may be assumed as: 1.5 passengers per private vehicle, 30 passengers per bus, and 30 passengers per urban transit. The full estimates with this set of alternative passenger occupancy rates are given in the second column of Table 6.25.

[152] The low and high estimates given in the table are calculated by the lower and upper boundaries of the AQVM values in Table 6.17, while holding all the other variables (e.g., VSL, emission factors) at their base-case values.

Table 6.25. Sensitivity Analysis: Passenger Occupancy Rates (in 2002 $C)

	Estimates with Alternative Occupancy Rates*	Recommended estimate
Interurban passenger transport (per passenger-km)		
Private vehicle	0.00163	0.00088
Bus	0.00103	0.00100
Urban passenger transport (per passenger-km)		
Private vehicle	0.00786	0.00842
Urban transit	0.00188	0.00331

*: 1.5 passengers per private vehicle, 30 passengers per bus, and 30 passengers per urban transit.

Table 6.25 shows that our cost estimates are roughly proportional, indirectly, to the occupancy rates assumed. For example, when the occupancy rate for urban private vehicle increases by 7.1%, from 1.4 to 1.5 passengers per vehicle, the cost estimate is reduced by 6.6%: from $0.00842 to $0.00786 per passenger-km. Similar results are observed for other modes, suggesting that our estimates are quite sensitive to the passenger occupancy rate.[153]

Emission Factors

As can be seen above, our calculation relies on knowledge of emission factors. Tremendous uncertainties exist regarding the accuracy of emission factors, however. First, there exist a number of factors affecting the estimation of damages using a dose-response function:

- Selection bias: For example, US EPA (1999) argued that the published literature may collectively overstate the health impacts of pollution, because scientific journals tend to publish research reporting significant associations between pollution and disease more often than research that fails to find such associations;
- Uncertain shape of the dose-response function: The two most common functional forms in the epidemiological literature on health effects are the log-linear and linear relationships; as a consequence, the analysis has assumed the cost recovery function to have a linear form;
- Regional differences: There may be variations in regional-specific dose-response functions; this is due to the physical and chemical composition of air pollutants at a particular location with a given topography;
- Sample bias: Dose-response functions may be applied to sub-populations that so not match the original study population.

[153] In the table, when the occupancy rate for urban transit doubles, from 17 passengers per urban transit to 30 passengers per urban private transit, the cost estimates are reduced by half: from $0.00331 to $0.00188 per passenger-km. This result needs to be interpreted with caution, as the increase from 17 to 30 passengers per vehicle represents a large increase. Note here that pollution is implicitly assumed as a function of vehicle rather than the number of passengers.

Second, there are factors affecting the measurement of emissions caused by transportation. As transportation activities are not the only source of air pollution, we need to isolate the change in emission due to transportation activities. This implies being able to reflect and isolate the additive, sub-additive, and/or multiplicative effects of the different sources of pollution from transportation activities. Although this issue has been addressed in some of the studies (Delucchi and McCubbin 1996, UNITE 2001c, Fisher 2002), it remains as a major challenge related to the estimation of air pollutant emissions.

These uncertainties are reflected in the variations of emission factors reported in Table 6.13 – in certain instances, the variations are quite large. Based on the low and high estimates of Table 6.13, we conduct a sensitivity analysis of emission factors. The results are reported in Table 6.26 – again, the recommended estimates are re-produced from Table 6.22. The low (high) estimates are calculated by the lower (upper) boundaries of Table 6.13, while holding all the other variables (e.g., VSL, value of morbidity, occupancy rates) at their base-case values. Notice that the use of "low" and "high" estimates may be a bit misleading, since our recommended estimates are values for Canada whilst the low and high estimates here are calculated by taking non-Canadian values. The table illustrates possible ranges of our estimates with respect to emission factors. It shows that the ranges of the estimates are fairly large for some transport modes, suggesting that the choice of emission factors may be crucial for such modes.

Table 6.26. Sensitivity Analysis: Emission Factors (in 2002 $C)

	Low estimate	High estimate	Best estimate
Interurban passenger transport (per passenger-km)			
Private vehicle	0.00000	0.00095	0.00088
Aircraft [a]	N/A	N/A	0.00008
Bus	N/A	N/A	0.00100
Train	N/A	N/A	0.00471
Ferry	N/A	N/A	0.01091
Urban passenger transport (per passenger-km)			
Private vehicle	0.00000	0.00936	0.00842
Urban transit	N/A	N/A	0.00331
Freight transport (per tonne-km)			
Truck	0.00099	0.02213	0.00503
Rail	0.00026	0.00202	0.00173
Marine	0.00049	0.00105	0.00074
Aircraft	N/A	N/A	0.00003

a) See Table 6.22.

N/A: Not available.

6.7.3 Ecological Systems

The above discussion and calculation have focused on the health costs (mortality and morbidity) and material damages of air pollution. Costs due to air toxics, crop loss and damages to ecological systems have not been included because of the lack of information. The impacts on ecosystem services include natural purification of water, erosion control and habitat for wildlife, which are public goods that have value to society but no relevant markets where their values are expressed (Xu et al. 2003). Stephen et al. (2002) discussed the economic concepts in the valuation of ecological system services. First, economic valuations can be welfare-based or impact-based. Welfare-based valuations determine the difference that environmental services make to well-being, incomes, or costs to people, while impact-based valuations reflect how services change the economic or social context. Second, valuations in the literature are measured in the context of partial and general equilibrium. Third, they suggested that large-scale services, such as climate change, are not likely to be easily quantified on a partial valuation basis. The examples include energy-based approaches of Costanza and Neil (1981) and Odum (1983), and a special issue on this topic in *Ecological Economics* (1995). Annex 2 provides further discussion specifically on ecology and biodiversity.

6.7.4 Marginal Cost and Average Cost

As indicated in Chapter 1, it is important to distinguish between marginal values and average values for our estimates of the full costs of transportation. We have used the damage function approach in our estimation of full costs of transport emissions, in which dose-response functions and various other externality estimates have been used. Unfortunately, the literature on the costs of externalities often is unclear on whether marginal or average costs are being estimated. We believe that our estimates are marginal costs, in the sense that they are estimated at the current levels of environmental conditions. For the purpose of identifying what policy actions such as pricing policy (Pigouvian tax) would bring about a more efficient use of transportation and mix of transport modes, a marginal cost estimate is useful.

While our estimates, as marginal costs, are applicable to small reductions in those levels, the question remains whether they are also applicable to large reduction, or complete elimination of the damage. Further, it is not clear how to use these estimates to compile total national costs of transportation. These two questions hinge on the shape of the damage cost functions. In the literature, the underlying mathematical form for the cost function is almost never specified. But without the mathematical function, it is not possible to answer these questions. In some cases there may be no difference between average and marginal costs. In such a case the total externality cost curve would be a straight line, i.e., rising at a constant rate with output.

In the context of the present chapter (air pollution), there are several reasons to suspect that marginal externality costs increase with the volume of output, i.e., total externality costs are rising at an increasing rate. First, in Section 6.4.2, we have implicitly assumed that the dose-response functions are linear in the incidence of the effects. Hence, the change in relative risk factor is constant when the concentration of air pollutant changes. However, the literature does not have consensus about the shape of the dose-response functions, although most studies we reviewed used linear functions. For instance, US EPA (1994) suggested that the dose-response functions of PM_{10} are log-linear as follow:

$$\ln y = \alpha + \beta PM_{10}$$

where y is the health effect, PM_{10} denotes the concentration of PM_{10}, which is the major pollutant in transport emission, and α, β are two positive constant parameters. Alternatively, the functions can be written as:

$$y = e^{\alpha} e^{\beta \text{ PM10}}$$

That is, the health impact is an increasing function in the concentration of PM_{10}. Applying the monetary valuation of health effects (and the positive relationship between the concentration and transport output) then gives rise to the result that the value of damage losses is increasing functions of transportation activities.

Second, related to the first point, there is some evidence that for low levels of emissions, damage from air pollutants has lower or even zero values. Health Canada (1994, 1998, 1999) has examined the nature of the dose-response functions for CO, particulates and ozone when it set the National Ambient Air Quality Objectives (NAAQOs).[154] There are extensive discussions about the levels at which the health effects become evident, as well as specific considerations on whether there are "thresholds" below which the effects do not exist. The studies suggest that there are no proven thresholds for the health effects of ozone and particulates, although there is more likely one for CO, and also apparently thresholds for effects of the pollutants on vegetation. Instead of thresholds, they propose levels at which statistical significance of health effects disappears – and Health Canada does decide upon the NAAQOs in terms of "tolerable" and "desirable" levels, effectively judging the relative environmental risks. Thus, the discussion indicates that the extent to which the health effects are non-linear with doses, and that more generally, externality marginal costs may increase with volume of output.

Third, in Section 6.4.3, we used a relatively simple method ("point estimate") to compute the change in concentration of pollutants due to the emissions. If a more sophisticated air dispersion model is used, however, it might be the case that at different levels of concentration, a specific amount of pollutants emitted would have different effects on the change in concentration. This could be another channel through which an increasing marginal cost function arises.

By the nature of valuation research we are estimating the values at the current point in the damage loss function. If indeed the marginal costs are rising, or the marginal values

[154] http://www.hc_sc.gc.ca/hecs-sesc/air_quality/generalpubs.htm.

would decline with declining damage, then we would overestimate the total costs if we multiply the marginal cost by total output. To obtain total externality costs, one must compute the area beneath a marginal cost curve or calculate an average externality cost associated with the observed level of output. While the relationship between average and marginal externality costs are well recognized for road congestion, this subtlety in estimating total costs of pollution is overlooked in the air pollution literature. We consider this as an important research area in the future.

6.7.5 Internal vs. External Costs

After estimating the social costs of air pollution, it is also important to identify if any of the current "total costs of air pollution" are actually borne by transport users as distinct from borne by society as a whole. Our discussion and calculation have focused on the health costs (mortality and morbidity) and material damages of air pollution. In the economic valuations of mortality and morbidity, we have used the WTP of the individual and others to avoid the loss of life or the pain and suffering resulting from the illness, and added the full WTP values as parts of the total social costs.

The discussion in Chapter 2 has divided the total congestion costs into three components: costs imposed by users of transport on themselves, costs imposed by users on each other (other users), and costs imposed on non-users. The conclusions about congestion (Chapter 2) and safety (Chapter 3) categorise the non-monetary costs of delays and risks imposed by users on themselves as internal, while the costs imposed on other users and on non-users are external. Applying this analysis to emissions, we have that all vehicle users will bear the costs of air pollutant emission, which include health bills and some prevention costs (the latter could be substantial, such as the costs of emission controls on automobiles; these costs are borne internally in the costs of ownership and operation of vehicles). Part of the effects that are imposed by users on themselves is internalized, whereas the other part imposed by users on other users – just as with congestion delays – is external. Finally there are the effects imposed on non-users, which are clearly external. The relative amounts of total damage to users and non-users will depend on their numbers, the concentrations to which they are exposed, and lengths of time they are exposed. However, individual users will only internalize the cost imposed on themselves. We suggest that the internalized part of the social cost might be small. For example, if we assume that all citizens in a city with 100,000 people have the same exposure to air pollution, the internalized cost is only 1/100,000 of the social cost.

This assumption, that all citizens in a city with 100,000 people have the same exposure to air pollution, may not be valid, however. For air pollution emitted from the transportation sector, it may be unreasonable to assume that all people in the population would experience the same concentration change. The exposure of road users while they are in traffic is likely to be greater than that of non-users, in that the concentrations of some transport-created toxics (carbon monoxide and inhalable particulates) are highest in or close to the traffic stream, and diminish away from it. However, the difference needs to be substantially large so as to make the internalized part being significant. For ozone, the issue may not be so important, for ozone is not emitted from the vehicle directly. Instead, it is formed at the atmosphere through the chemical reaction between NO_x and VOC emitted from vehicles. Hence, it is presumably more an issue of area-wide concentrations rather than proximity to sources of the precursor emissions.[155]

More generally, while the effects imposed on non-users are clearly external, the cost users impose on one another may be ambiguous – it is an externality but it is imposed on other users hence internalized by the user group. In effect, the inference that the delays and risks imposed on other users are not internalized has been the subject of debate in the congestion literature especially among some European researchers, with the alternative possibility being advanced that the costs are recognized and accepted by the users as a group in their decisions to participate, therefore being internalized rather than external. This clearly would pose a serious challenge to the conventional analysis of values of time savings, and of congestion pricing effects. It would also by extension have implications for the analysis of the internal/external components of accident, noise and emissions. In the case of air pollution, this would imply that the internalized part of the social cost is certainly non-trivial and hence the marginal social costs reported would overestimate the external costs.

The congestion discussion in Chapter 2 has also shown us how to identify the internal component of the total social costs, and provided an important consideration of the issue of measuring total congestion, arguing that it should ignore the parts of delays that would not be eliminated by optimal charges. An implication would be that the national "full cost" accounts should exclude the component of "total congestion" that would be internalized by a congestion charge. The same principle could apply to the case of environmental damage for the social cost accounting. Nevertheless, the magnitude of the adjustment is unclear and depends on the nature of environmental damage charges. Furthermore, considerations of internal and external costs will of course have implications for the eventual analysis of damage charges. Given the extraordinarily complex issues involved, both conceptual and empirical, in tackling the question of whether and to what extent the effects are already internalized in market decisions and in their policy implications for national full-cost accounting and optimal pricing, resolution of the issues is beyond the scope of the present chapter. It would nevertheless represent an important extension of this research.

[155] On the other hand, there is nothing to diminish the ozone inside a vehicle – the air's the same inside and outside the vehicle – so users are exposed.

Chapter 6 References

Airbus, (2003) "Global Market Forecast 2003 - 2022", Airbus S.A.S, France.. Available at: http://www.airbus.com

Archer, L. J., (1993) "Aircraft Emissions and the Environment: COx, SOx, HOx & NOx", *Oxford Institute for Energy Studies*

AQVM 3.0, Air Quality Valuation Model Version 3.0 Documentation, Stratus Consulting

Abbey, D.E., P.K. Mills, F.F. Petersen, and W.L. Beeson, (1991) "Long-Term Ambient Concentrations of Total Suspended Particulates and Oxidants as Related to Incidence of Chronic Disease in California Seventh-Day Adventists", *Environmental Health Perspectives*, 94, 43-50.

Abbey, D.E., F. Petersen, P.K. Mills, and W.L. Beeson, (1993) "Long-Term Ambient Concentrations of Total Suspended Particulates, Ozone and Sulphur Dioxide and Respiratory Symptoms in a Non-Smoking Population", *Archives of Environmental Health*, 48(1), 33-46.

Arndt, R., G. Carmichael, J. Roorda, (1998) "Seasonal source-receptor relationships in Asia, Atmospheric Environment", 32, pp.1397–1406.

Baedecker, P.A., E.O. Edney, T.C. Simpson, P.J. Moran, and R.S. Williams, (1990) *Acidic Deposition: State of Science and Technology, Report 19, Effects of Acidic Deposition on Materials*, prepared for the National Acid Precipitation Assessment Program, Washington, D.C.

Baumol and Oates (1971), "The use of Standard and prices for the protection of the environment", *Swedish Journal of Economics*, 73.

Befahy, F., (1993) "Environment, Global and Local Effects", cited in OECD 1997a.

Bein, Peter, (1997) "Monetization of Environmental Impacts of Road", Highway Planning and Policy Branch, Information Management Section, Ministry of Transportation and Highways, British Columbia.

Best, C, Fortes D, Krueger E, (2003) "Wisconsin's Proposed Regulation on Stationary Compression Ignition Internal Combustion Engines: A Cost-Benefit Analysis", Prepared by The Air Management Program Wisconsin Department of Nature Resources.

BeTa (Benefits Table database) Version E1.02a, "Benefits Table database: Estimates of the marginal external costs of air pollution in Europe", Created for European Commission DG Environment by netcen.

Bishop, R.C. and Romano, D., (1998) *Environmental Resource Valuation: Application of the Contingent Valuation Method in Italy*, Kluwer Academic Publisher, The Netherlands.

Bluewater Network, (2003) "Ship Emissions: Air Pollution Across the Ocean". Available at: http://bluewaternetwork.org/campaign_ss_ships.shtml.

Blumenchein, Karen and Magnus Johannesson, (1998) "Relationship between Quality of Life Instruments, Health State Utilities, and Willingness to Pay in Patients with Asthma", *Annals of Allergy, Asthma and Immunology*, 80, pp189-194, 1998

BMWE (Brotherhood of Maintenance of Way Employees), (2003) "Transport Concepts, External Costs of Truck and Train", (Ottawa), October 1994, http://www.bmwe.org, Cited at VTPI, 2003.

Boardman, A.E., D.H. Greenberg, A.R. Vining and D.L. Weimer, (2001) *Cost-Benefit Analysis: Concepts and Practice*, Prentice, New Jersey.

Boeing, "World Air Cargo Forecast 2002/2003", Boeing Commercial Airplanes, Seattle, WA. , 2002. Available at: http://www.boeing.com/commercial/cargo/flash.html

Bowland, Brad and Beghin, John. "Robust Estimates of Value of a Statistical Life for Developing Economies. An Application to Pollution and Mortality in Santiago", *Journal of Policy Modelling,* 23(4): 385-396, 2001.

Burnett, R.T., R.E. Dales, M.E. Raizenne, D. Krewski, P.W. Summers, G.R. Roberts, M. Raad-Young, T. Dann, and J. Brooke, "Effects of Low Ambient Levels of Ozone and Sulphates on the Frequency of Respiratory Admissions to Ontario Hospitals", *Environmental Research*, 65, 172-194, 1994.

Burnett, R.T., R.E. Dales, J.R. Brook, M.E. Raizenne, and D. Krewski, "Associations between Ambient Carbon Monoxide Levels and Hospitalizations for Cardiac Diseases in Ten Canadian Cities", Manuscript submitted for publication consideration, 1996.

Burnett, R.T., J.R. Brook, W.T. Yung, R.E. Dales, and D. Krewski, "Association between Ozone and Hospitalization for Respiratory Diseases in 16 Canadian Cities", *Environmental Research*, 72, 24-31, 1997.

Burnett, R.T., R. Dales, D. Krewski, R. Vincent, T. Dann, and J.R. Brook, "Associations between Ambient Particulate Sulphate and Admissions to Ontario Hospitals for Cardiac and Respiratory Diseases", *American Journal of Epidemiology*, 142(1), 15-22, 1995.

Capaldo K., Corbett, P., Kasibhatla, P., Fischbeck, P., and Pandis, S., "Effects of Ship Emissions on Sulphur Cycling and Radiative Climate Forcing over the Ocean", Nature, 400, 743-746, 1999.

Calori, G. and G. Carmichael, "An urban trajectory model for sulfur in Asian mega cities: model concepts and preliminary application", *Atmospheric Environment*, 33, pp. 3109–3117, 1999.

Canadian Institute for Health Information, *Resource Intensity Weights: Summary of Methodology 1994/95,* Don Mills, Ontario, 1994.

Chapman, R.S., D.C. Calafiore and V. Hasserlblad, "Prevalence of Persistence Cough and Phlegm in Young Adults in Relation to Long-term Ambient Sulfur Oxide exposure", *American Review of Respiratory Disease*, 132, 61-267, 1985.

Chestnut, L.G., S.D. Colome, L.R. Keller, W.E. Lambert, B. Ostro, R.D. Rowe, and S.L. Wojciechowski, Heart Disease Patients Averting Behavior, Costs of Illness, and Willingness to Pay to Avoid Angina Episodes. Final Report to the Office of Policy Analysis, U.S. EPA, Washington D.C. October, 1988.

Chestnut, Lauraine G., Mills, David and Rowe, Robert D., Air Quality Valuation Model Version 3.0 (AQVM 3.0) Report 2: Methodology, prepared for Environment Canada, Health Canada by Status Consulting Inc., Boulder, CO., 1999.

Coase, R.H., "The Problem of Social Costs", *Journal of Law and Economics*, 3, pp.1-44, 1960.

Cooper, D., "Exhaust Emissions from Ships at Berth", Atmospheric Environment, 37, 3817-3830, 2003.

Corbett, Capaldo K., P., Kasibhatla, P., Fischbeck, P., and Pandis, S., "Effects of Ship Emissions on Sulphur Cycling and Radiative Climate Forcing over the Ocean", *Nature*, 400, 743-746, 1999.

Costanza, Robert, Ralph d'Arge, Rudolf de Groot, Stephen Farber, Monica Grasso, Bruce Hannon, Karin Limburg, Shahid Naeem, Robert V. O'Neill, Jose Paruelo, Robert G. Raskin, Paul Sutton, and Marjan van den Belt, "The Value of the World's Ecosystem Services and Natural Capital", *Nature*, Vol. 387, 15 May 1997.

Costanza, Robert and Neil C., in Energy and Ecological Modeling (eds. Mitsch W.J., Bosserman, R.W. & Klopatek, J.M.), pp 745-755, Elsevier, New York, 1981

Cropper, M.L., and A.M. Freeman III, *Environmental Health Effects. Measuring the Demand for Environmental Quality* J.B. Braden and C.D. Kolstad (ed.). North-Holland, New York, 1991.

Cummings, R., H. Burness, and R. Norton, "Methods Development for Environmental Control Benefits Assessment", Volume V. *Measuring Household Soiling Damages from Suspended Air Particulates, A Methodological Inquiry,* Report prepared for the U.S. Environmental Protection Agency, Washington, D.C. , 1981.

Danielis, Romeo and Aline Chiabai, "Estimating the Cost of Air Pollution from Road Transport in Italy", *Transportation Research Part D*, No. 4, 249-258, 1998.

Davis, R, "Recreation planning as an economic problem", *Natural Resources Journal*, 3(2), pp 239-249, 1963.

De Blaeij, Arianne, Florax, Raymond J.G.M, Rietveld, Piet and Verhoef, Erik. "The Value of Statistical Life in Road Safety: A Meta-Analysis," *Accident analysis and Prevention,* 35: 973-986, 2003.

Delucchi, Mark A., and Donald R. McCubbin, "The Contribution of Motor Vehicles and other Sources to Ambient Air Pollution", the Annualised Social Cost of Motor-Vehicle Use in the Untied States, based on 1990-1991 Data, August, 1996.

Dockery, D.W., F.E. Speizer, D.O. Stram, J.H. Ware, J.D. Spengler, and B.G. Ferris, Jr., "Effects of Inhalable Particles on Respiratory Heath of Children", *American Review of Respiratory Disease*, 139, 587-94, 1989.

Dockery, D.W., J. Cunningham, A.I. Damokosh, L.M. Neas, J.D. Spengler, P. Koutrakis, J.H. Ware, M. Raizenne, and F.E. Speitzer, "Health Effects of Acid Aerosols on North American Children: Respiratory Symptoms", *Environmental Health Perspectives*, 104, pp500-505, 1996.

Dockery, D.W., C.A. Pope III, X. Xu, J.D. Spengler, J.H. Ware, M.E. Fay, B.G. Ferris, Jr., and F.E. Speizer, "An Association Between Air Pollution and Mortality in Six U.S. Cities", *The New England Journal of Medicine* 329(24), pp1753-9, 1993.

Dodge, L., Callahan, T., Ryan, T., "Humidity and Temperature Correction Factors for NOx Emissions from Engines", Final Report, ENVIRON International Corporation, Novato, CA, 2003. Available at: http://www.harc.edu/harc/Projects/AirQuality/Projects/Status/

ECMT (European Conference of Ministers of Transport), "Efficient Transport for Europe, Policies for Internalization of External Costs", OECD publication Service, Paris, 1998.

Ellwanger, G., "External Environmental Costs of Transport - Comparison of Recent Studies". Social Costs and Sustainable Mobility, ZEW, Physica-Verlag, pp. 15-20, 2002. cited in VTPI 2003

EPA (United States Environmental Protection Agency), "Compilation of Air Pollutant Emission Factors Volume II: Mobile Sources", AP-42, Fourth Edition, Office of Air and Radiation, Office of Mobile Sources, Test and Evaluation Branch, Ann Arbor, MI. , 1985. cited in OECD 1997a, Available at: http://www.epa.gov/otaq/ap42.htm, EEA (European Environment Agency), "Emissions per passenger-kilometre and per tonne-kilometre for NOx, NMVOCs, PM10 and SOx by mode", Indicator Fact Sheet, 2001. Available at: http://themes.eea.eu.int/Sectors_and_activities/transport/indicators/technology/emissions/Specific_emissions_TERM_2001.doc.pdf

Escher, J., "Diesel Exhaust Poses Huge Threat", Article online, 2002. Available at: http://www.shpna.org/old_site/caltrain/caltdiesel.htm

Evans, J.S., T. Tosteson, and P.L. Kinney, "Cross-Sectional Mortality Studies and Air Pollution Risk Assessment", *Environment International,* 10, 55-83, 1984.

ExternE, "External costs of transportation in ExternE", edited by P. Bickel, S. Schmid, W. Krewitt, R. Friedrich IER, Germany, Research funded in part by The European Commission in the framework of the Non Nuclear Energy Programme, 1996.

Eyre, N. J., E. Ozdemiroglu, D. W. Pearce and P. Steele, "Fuel and Location Effects on the Damage Costs of Transport Emissions," *Journal of Transport Economics and Policy*, 31(1), 5-24, 1997.

Friedrich, R. and Bickel, P. (eds.), "Environmental External Costs of Transport", Springer Verlag, Heidelberg, 2001.

Fisher G.W. K. A. Rolfe, T. Kjellstrom, A. Woodward, S. Hales, A. P. Sturman, S. Kingham, J. Petersen1, R. Shrestha, D. King., "Health effects due to motor vehicle air pollution in New Zealand, 2002", Report to the Ministry of Transport, New Zealand, 2002.

Gerking, Shelby and William Schulze, "What do we know about Benefits of Reduced Mortality from Air Pollution Control?" *American Economic Review*, 71 (2), 228-234, 1981.

Giannias, Dimitrios A., "Consumer Benefit from Air Quality Improvements", *Applied Economics*, 21, 1099-1108, 1989.

Hall, Jane V., Arthur M. Winer, Michael T. Kelinman, Frederick W. Lurmann, Victor Brajer, and Steve D. Colome, "Valuing the Health Benefits of Clean Air", *Science*, 255(5046), 812-817, 1992.

Heagle, H.S., L.W. Kerss, P.J. Temple, R.J. Kohut, J.E. Miller, and H.E. Heggestad, 1988, "Factors Influencing Ozone Dose-Yield Response Relationships in Open-Top Field Chamber Studies", *Assessment of Crop Loss Yield from Air Pollutants*, W.W. Heck, O.C. Taylor, and D.T. Tingey (eds.). Elsevier Applied Science. London, 141-179, 1988.

Health Canada (1994), "National Ambient Air Quality Objectives for Carbon Monoxide," Executive Summary, Prepared by the CEPA/FPAC Working Group on Air Quality Objectives and Guidelines, Health Canada, Ottawa, November 1994.

Health Canada (1998), "National Ambient Air Quality Objectives for Particulate Matter," Executive Summary, Prepared by the CEPA/FPAC Working Group on Air Quality Objectives and Guidelines, Health Canada, Ottawa, 1998.

Health Canada (1999), "National Ambient Air Quality Objectives for Ground-Level Ozone," Summary, Prepared by the Federal-Provincial Working Group on Air Quality Objectives and Guidelines, Health Canada, Ottawa, July 1999.

Heffter, J.L., Branching atmospheric trajectory (BAT) model, Technical memorandum of the National Oceanic and Atmospheric Administration, ERLARL-121, 1983.

Hoehn, J. and Randall, A., 1989, "Too many proposals pass the benefit–cost test", *American Economic Review*, 79, pp. 544–551

Holguin, A., P. Buffler, C. Contant, T. Stock, D. Kotchmar, B. Hsi, D. Jenkins, B. Gehan, L. Noel, and M. Mei, "The Effects of Ozone on Asthmatics in the Houston Area", *Evaluation of the Scientific Basis for Ozone/Oxidants Standards* (Transactions). Si Duk (ed.) Lee (ed.) Air Pollution Control Association, Pittsburgh, 262-281, 1985.

Holmen, B., and Niemeier, D., "Air Quality", Handbook of Transport and the Environment, Chapter 4, 61-79, 2003.

Hrebenyk, Bohdan W., James. W.S. Young, and Zivorad R. Radonjic, "Guidelines for Air Quality Dispersion Models Critical Review & Recommendation, Prepared for: Water, Air & Climate Change Branch, Ministry of Water, Land & Air Protection, SENES Consultants Limited, May 2003.

ICAO, "ICAO Engine Exhaust Emissions Data Bank. Doc 9646-AN/943", International Civil Aviation Organisation, 1995.

ICAO/CAEP, Database of aircraft jet engine emissions certification data, QuinetiQ on behalf of International Civil Aviation Organisation (ICAO), Committee on Aviation Environmental Protection (CAEP), 2002. http://www.qinetiq.com/aviation-emissionsdatabank/DBCOMPA7.xls

ICAO/CAPE, "Economic Analysis of NOx Emissions Stringency Options", CAEP/6-IP/13, 2004.

IIASA (International Institute for Applied Systems Analysis), User instruction and manual for RAINS-ASIA version 7.52, ASA, Laxenburg, 2001.

IMO (International Maritime Organization), "Study of Greenhouse Gas Emissions from Ships", MT Report: MT00 A23-038, Trondheim, Norway, 2000. Available at: http://unfccc.int/issues/imoghgmain.pdf

IPCC, "Aviation and the Global Atmosphere", Cambridge University Press for the Intergovernmental Panel on Climate Change, 1999.

Jones-Lee, M., Loomes, G., Rowlatte, P., Spackman, M. and Jones, S., "Valuation of Deaths from Air Pollution", Report for the Department of Environment, Transport and the Regions and the Department of Trade and Industry, London, 1998.

Kinney, P.L., and H. Ozkaynak, "Associations of Daily Mortality and Air Pollution in Los Angeles", *Environmental Research*, 54, 99-120, 1991.

Kinney, P.L., K. Ito and G.D. Thurston, "A Sensitivity Analysis of Mortality/PM10 Associations in Los Angeles", *Inhalation Toxicology*, 7, 59-69, 1995.

Knight, F.H., "Some Fallacies in the Interpretation of Social Cost", *Quarterly Journal of Economics*, 37, pp 582-606, 1924.

KPMG, GVRD Air Quality Management Plan: Stage 2 Draft Report: Priority Emission Reduction Measures, Greater Vancouver Regional District (Vancouver), Table 5-8, p.5-43, May 1992.

Krupnick, A.J., "The Implementation and Enforcement of the Clean Air Act Amendments pf 1990,"Testimony before the Subcommittees on Oversight and Investigations and on Health and the Environment of the Committee on Commerce, U.S. House of Representatives, Thursday, November 9, 1995.

Krupnick, A.J., and M.L. Cropper, "Valuing Chronic Morbidity Damages: Medical Costs, Labour Market Effects, and Individual Valuations. Final Report to U.S", EPA, Office of Policy Analysis, 1989.

Krupnick, A.J., and M.L. Cropper, "The Effect of Information on Health Risk Valuations", *Journal of Risk and Uncertainty*, 5, 29-48, 1992.

Krupnick, A.J., W. Harrington, and B. Ostro, "Ambient Ozone and Acute Health Effects: Evidence from Daily Data", *Journal of Environmental Economics and Management*, 18(1), 1-18, 1990.

Krupnick, A.J., and R. Kopp, "The Health and Agricultural Benefits from Reductions in Ambient Ozone in the United States", Resources for the Future, Washington, D.C. Discussion Paper QE88-10, 1988.

Krupnik, Alan, Alberini, Anna, Cropper, Maureen, Simon, Nathalie, O'Brien, Bernie, Goeree, Ron and Heintzelman, Martin. "Age, Health and the Willingness to Pay for Mortality Risk Reductions: A Contingent Valuation Survey of Ontario Residents", *Journal of Risk and Uncertainty,* 24(2): 161-186, 2002.

Levinson, David M., David Gillen, and Adib Kanafani, "The Social Cost of Intercity Transportation: a Review and Comparison of Air and Highway", *Transport Reviews*, 18(3), 215-240, 1998.

Link, Heike, Louise Helen Stewart (DIW), Claus Doll (IWW), Peter Bickel, Stephan Schmid, Rainer Friedrich, Roland Krüger, Bert Droste-Franke, Wolfgang Krewitz (IER), UNITE (UNIfication of accounts and marginal costs for Transport Efficiency) Working Funded by 5th Framework RTD Programme. ITS, University of Leeds, Leeds, April, 2001.

Lipfert, F.W., *Air Pollution and Community Health*. New York: Van Nostrand Reinhold, 1994.

Loehman, E.T., S.V. Berg, A.A. Arroyo, R.A. Hedinger, J.M. Schwartz, M.E. Shaw, R.W. Fahien, V.H. De, R.P. Fishe, D.E. Rio, W.F. Rossley, and A.E.S. Green, "Distributional Analysis of Regional Benefits and Cost of Air Quality Control", *Journal of Environmental Economics and Management*, 6, 222-243, 1979.

Loomis, John, Paula Kent, Liz Strange, Kurt Fausch and Alan Covich, "Measuring the total economic value of restoring ecosystem services in an impaired river basin: results from a contingent valuation survey", *Ecological Economics,* 33(1), pp 103-117, 2000.

Lu, Cherie H.Y. and Peter Morrell, "Evaluation and Implications of Environmental Charges on Commercial Flights", Transport Reviews, Vol. 21, No.3, pp377-395, 2001.

Manuel Jr., E., R.L. Horst Jr., K. Brennan, W. Lanen, M.C. Duff, and J.K. Tapiero, "Benefits Analysis of Alternative Secondary National Ambient Air Quality Standards for Sulfur Dioxide and Total Suspended Particulates", Volume II. Prepared by U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Research Triangle Park, North Carolina, 1982.

Mathtech, Inc., "Benefits of Reduced Materials Damage Due to Local Reductions in SO2 Concentrations: A Six State Study", report to the U.S. Environmental Protection Agency, Office of Policy Analysis, Washington, D.C., Contract No. 68-01-6596, November, 1983.

Mayeres, Inge, Sara Ochelen and Stef Proost, "The Marginal External Costs of Urban Transport", *Transportation Research Part D*, 2, 111-130, 1996.

McCubbin, Ronald R. and Mark A. Delucchi, "The Health Effects of Motor-Vehicle-Related Air Pollution", *Handbook of Transport and the Environment*, edited by D.A. Hensher and K. J. Button, Chapter 22, Elsevier Ltd., 2003.

McCubbin, Ronald R. and Mark A. Delucchi, "The Health Cost of Motor-Vehicle-Related Air Pollution", *Journal of Transport Economics and Policy*, 33(3), 253-86, 1999.

McClelland, G., W. Schulze, D. Waldman, J. Irwin, D. Schenk, T. Stewart, L. Deck, and M. Thayer, "Valuing Eastern Visibility: A Field Test of the Contingent Valuation (Draft)", Prepared for the U.S. Environmental Protection Agency, Washington, D.C. Cooperative Agreement #CR-815183-01-3, 1991.

Miller, Ted. "Variations between Countries in Values of Statistical Life", *Journal of Transport Economics and Policy,* 34(2), 2000.

Mitchell, R. and Carson, R.T., "Using surveys to value public goods: the contingent valuation method", *Resources for the Future*. Washington DC, 1989.

Moolgavkar, S.H., E.G. Luebeck, T.A. Hall and E.L. Anderson, "Air Pollution and Daily Mortality in Philadelphia", *Epidemiology*, 7, 420-8, 1995.

Morris, R. D., E. N. Naumoova and R. L. Munasubghe, "Ambient Air Pollution and Hospitalization for Congestive Heart Failure Among Elderly People in Seven Large Cities", *American Journal of Public Health*, 85, 1361-1365, 1995.

Mrozek, Janusz and Taylor, Laura. "What Determines The Value of Life? A Meta-Analysis", *Journal of Policy Analysis and Management*, 21(2): 253-70, 2002.

Nash, Chris, with contributions from partner: UNITE (UNIfication of accounts and marginal costs for Transport Efficiency) Final Report for Publication, Funded by 5th Framework RTD Programme, 2003

OECD, Environmental Policy: How to Apply Economic Instruments, 1991

OECD (Organization for Economic Co-operation and Development), "The Environmental Effects of Freight ", OECD, Paris, 1997a. Available at: http://www1.oecd.org/ech/pub/TRANSP4.PDF

OECD (Organization for Economic Co-operation and Development), "Freight and the Environment: Effects of Trade Liberasation and Transport Sector Reforms", OCDE/GD(97)213, 1997b. Available at: http://www1.oecd.org/ech/docs/envi.htm

OECD (Organization for Economic Co-operation and Development), "Freight and the Environment: Effects of Trade Liberasation and Transport Sector Reforms", OCDE/GD(97)213, 1997b. Available at: http://www1.oecd.org/ech/docs/envi.htm

OECD (Organization for Economic Co-operation and Development), "Transportation and Environment", OECD Working Papers, Vol VII, No. 90, Paris, 1999.

O'Conor, Richard M. and Glenn C. Blomquist, "Measurement of Consumer-Patient Preferences Using a Hybrid Contingent Valuation Method", *Journal of Health Economics*, 16, pp667-683, 1997

Odum, H.T., Systems Ecology: An Introduction. Wiley, New York, 1983.

Ostro, B.D., "Air Pollution and Morbidity Revisited: A Specification Test", *Journal of Environmental Economics and Management*, 14, 87-98, 1987.

Ostro, B.D., M.J. Lipsett, M.B. Wiener, and J.C. Selner, "Asthmatic Responses to Airborne Acid Aerosols", American Journal of Public Health, 81, 694-702, 1991.

Ostro, B.D., and S. Rothschild, "Air Pollution and Acute Respiratory Morbidity: An Observational Study of Multiple Pollutants", *Environmental Research*, 50, 238-247, 1989

Ozkaynak, H., and G. Thurston, "Associations between 1980 U.S. Mortality Rates and Alternative Measures of Airborne Particle Concentration", *Risk Analysis,* 7, pp 449-62, 1987.

Pearce, B., Pearce, D., "Setting Environmental Taxes for Aircraft: A Case Study of the UK, Centre for Social and Economic Research on the Global Environment", University College London and University of East Anglia (CSERGE), Working Paper GEC 2000-26, 2000.

Peng, Chaoyang, Xiaodong Wu, Gordon Liu, Todd Johnson, Jitendra Shah, and Sarath Guttikunda, "Urban Air Quality and Health in China", *Urban Studies*, Vol. 39, No. 12, pp. 2283-2299, 2002.

Perl, Anthony, Judith Patterson and Marc Perez, "Pricing Aircraft Emissions at Lyon-Satolas Airport", Transportation Research Part D, Vol. 2, No. 2, pp. 89-105, 1997.

Peper, J., In W. Fransen (ed.), "Atmospheric Effects of Aircraft Emissions and an Investigation of Some Operational Measures to Mitigate these Effects", Directorate General of Civil Aviation, The Netherlands, 1994.

Pezzey, Market mechanisms of pollution control" "polluter says", economic and practical aspects", in R. Kerry Turner (ed.) *Sustainable Environment Management: Principles and Practices*, Belhaven Press, London and Westview Press, Boulder ,1988

Pigou, A.C., *The Economics of Welfare*, London: Macmillian and Company, 1938.

Pope, C.A., III., "Respiratory Hospital Admissions Associated with PM10 Pollution in Utah, Salt Lake, and Cache Valleys", *Archives of Environmental Health*, 46(2), pp 90-97, 1991.

Pope, C.A., III, J. Schwartz, and M.R. Ransom, "Daily Mortality and PM10 Pollutant in Urah Valley", *Archives of Environmental Health*, 47, 211-217, 1992.

Pope, C.A., III, M.J. Thun, M.M. Namboodiri, D.W. Dockery, J.S. Evans, F.E. Speizer, and C.W. Heath, Jr., "Particulate Air Pollution as a Predictor of Mortality in a Prospective Study of U.S. Adults", *American Journal of Respiratory and Critical Medicine*, 151, 669-674, 1995.

Rowe, R.D., and T.N. Neithercut. 1987. Economic Assessment of the Impacts of Cataracts. Prepared for U.S. Environmental Protection Agency, Office of Policy, Planning, and Evaluation. Washington, D.C.

Rowe, R.D., L.G. Chestnut, and W.D. Shaw. 1984. Oxidants and Asthmatics in Los Angeles: A Benefits Analysis. Evaluation of the Ozone/Oxidants Standards. Si Duk Lee (ed.) Air Pollution Control Association. Pittsburgh.

Rowe, R.D., and L.G. Chestnut, "Oxidants and Asthmatics in Los Angeles: A Benefits Analysis", Prepared by Energy and Resource Consultants, Inc. Report to the U.S. Environmental Protection Agency, Office of Policy Analysis, Washington, D.C., March. EPA 230-09-86-018 , 1986.

Rowe, R.D., C.M. Lang, L.G. Chestnut, D. Latimer, D. Rae, S.M. Bernow, and D. White, *The New York Electricity Externality Study*, Dobbs Ferry, New York. Oceana Publications, 1995.

Richard S. J. Tol, "The Marginal Costs of Greenhouse Gas Emissions", *The Energy Journal*, 20(1), 61-81, 1999.

Schoemaker, T., and Bouman, P., "Facts and Figures on Environmental Effects of Freight Transport in the Netherlands", 1991, cited in OECD 1997a.

Schwartz, J., "Air Pollution and Hospital Admissions for Cardiovascular Disease in Tuscon", *Epidemiology*, 8, 371-77, 1997.

Schwartz, J., and D.W. Dockery, "Increased Mortality in Philadelphia Associated with Daily Air Pollution Concentrations", A*merican Review of Respiratory Disease*, 145, 600-604, 1992a.

Schwartz, J., and D.W. Dockery, "Particulate Air Pollution and Daily Mortality in Steubenville, Ohio", *American Journal of Epidemiology*, 135(1), 12-19, 1992b.

Schwartz, J., D.W. Dockery, and L.M. Neas, "Is Daily Mortality Associated Specifically with Fine Particles?", *Journal of the Air & Waste Management Association*, 46, 927-939, 1996.

Schwartz, J., and R. Morris, "Air Pollution and Hospital Admissions for Cardiovascular Disease in Detroit, Michigan", *American Journal of Epidemiology*, 142, 23-35, 1995.

Shah, J., T. Nagpal, T. Johnson Jitendra, Markus Amann, Gregory Carmichael, Wesley Foell, Collin Green, Jean-Paul Hettelingh, Leen Hordijk, Jia Li, Chao Peng, Yifen Pu, Ramesh Ramankutty, and David Streets, "Integrated assessment model for acid rain in Asia: policy implications and results of RAINS-Asia model", *Annual Review of Energy and Environment*, 25, pp. 339–375, 2000.

Simpson, D, Olendrzynski, K, Semb, A, Storen, E, Unger, S, "Photochemical oxidant modelling in Europe: multi-annual modelling and source-receptor relationships", EMEP/MSC-W Report 3/97, Oslo, 1997.

Small K. and Kazimi C., "On the Costs of Air Pollution from Motor Vehicles", *Journal of Transportation and Economic Policy*, 29, 7-32, 1995.

Smith, V. Kerry and Ju-Chin Huang, "Can Markets Value Air Quality? A Meta-Analysis of Hedonic Property Value Model", *Journal of Political Economy*, 103, 209-227, 1995.

SN, Statistics Netherlands/Centraal Bureau voor de Statistiek, Schoemaker and Bourmnan, p. 57. , 1997. cited in OECD 1997a.

Stephen, C. Farber, Robert Costanza, Matthew A. Wilson. Economic and Ecological Concepts for Valuing Ecosystem Services", Ecological Economics, 41, pp. 375-392, 2002

Stieb, D.M., R.C. Beveridge, J.R. Brook, R.T. Burnett, A.H. Anis, and R.E. Dales1995, "Measuring Health Effects, Health Costs and Quality of Life Impacts Using Enhanced Administrative Data: Design and Preliminary Results", *Particulate Matter: Health and Regulatory Issues*, VIP-49, 131-142, 1995.

Stock, T.H, B.M. Gehan, P.A. Buffler, C.F. Constant, B.P. Hsi, and M.T. Morandi, "The Houston Area Asthma Study: A Reanalysis", Paper presented at the Annual Meeting of the Air Pollution Control Association, Dallas, Texas, June 19-24, 1988.

Talley, W., "Environmental Impacts of Shipping", Handbook of Transport and the Environment, Chapter 15, 279-291, 2003.

Tolley, G.S., L. Babcock, M. Berger, A. Bilotti, G. Blomquist, R. Fabian, G. Fishelson, C. Kahn, A. Kelly, D. Kenkel, R. Kumm, T. Miller, R. Ohsfeldt, S. Rosen, W.

Webb, W. Wilson, and M. Zelder, ”Valuation of Reductions in Human Health Symptoms and Risks”, Prepared at the University of Chicago. Final Report for the U.S. EPA, Grant #CR-811053-01-0. January, 1986a.

Toman, M, “Why not to calculate the value of the world's ecosystem services and natural capital”, *Ecological Economics*, 25(1), pp. 57–60, 1998.

Turvey, Ralph, “On Divergences between Social Cost and Private Cost”, *Economica*, 30 (119), pp 309-313, 1963.

Transportation Table, National Climate Change Process, “Foundation Paper on Climate Change – Transportation Sector”, December, 1998.

Trukenmüller, A, Friedrich, R, “Die Abbildung der großräumigen Verteilung, chemischen Umwandlung und Deposition von Luftschadstoffen mit dem Trajektorienmodell WTM, in: Jahresbericht 1995”, ALS Universität Stuttgart, pp. 93 -108, 1995.

TTNCCP (Transportation Table National Climate Change Process), “Foundation Paper on Climate Change”, Transportation Sector, Ottawa, ON., 1988. Available at: http://www.wlu.ca/~wwwsbe/faculty/dgillen/UBC_social_cost/Studies/trans.pdf.pdf

UNITE, (UNIfication of accounts and marginal costs for Transport Efficiency), “Valuation Conventions for UNITE”, Working Funded by 5th Framework RTD Programme. ITS, University of Leeds, Leeds, April 2001a.

UNITE, “Deliverable 5: The Pilot Accounts of Austria - Annex Report”, Working Funded by 5th Framework RTD Programme. ITS, University of Leeds, Leeds, October 2001b.

UNITE, “Deliverable 5: The Pilot Accounts of Germany - Annex Report”, Working Funded by 5th Framework RTD Programme. ITS, University of Leeds, Leeds, April 2001c.

UNITE, “Deliverable 11, Appendix Marginal Cost Case Study 9a: Urban Passenger Car for Finland”, Funded by 5th Framework RTD Programme, ITS, University of Leeds, Leeds.

UNITE, “Deliverable 11: Environmental Marginal Cost Case Studies - Marginal Costs Case Study 9F: Air Transport Case Study”, Working Funded by 5th Framework RTD Programme. ITS, University of Leeds, Leeds, 2002.

US DOT, Addendum to the 1997 Federal Highway Cost Allocation Study Final Report, 2000.

US EPA, "The Benefits and Costs of the Clean Air Act 1990 to 2010", EPA Report to Congress, November, Environmental Protection Agency, 1999.

US EPA, "Methane and Other Gases" 2001.
Available at: http://www.epa.gov/ghginfo/topics/topic2.htm

US EPA, "Regulatory Impact Analysis on the National Ambient Air Quality Standards for Sulfur Oxides Sulfur Dioxide", prepared by the Office of Air and Radiation, Research Triangle Park, NC. March, 1988.

US EPA, "Health Effects Notebook for Hazardous Air Pollutants", Prepared for U.S. Environmental Protection Agency by Air Risk Information Support Center, Research Triangle Park, NC, USA, 1994.

Vincent, B., and Walsh, B., "The Electric Rail Dilemma: Clean Transportation from Dirty Electricity?", Breakthrough Technologies Institute, Washington D.C. , 2003. Available at: http://www.gobrt.org/RailBRTAirQualityAnalysis.pdf

Viscusi, W Kip and Aldy, Joseph. "The Value of a Statistical Life: A Critical Review of Market Estimates Throughout the World", *Journal of Risk and Uncertainty,* 27(1): 5-76, 2003.

Viscusi, W.K., W.A. Magat, and J. Huber, "Pricing Environmental Health Risks: Survey Assessments of Risk-Risk and Risk-Dollar Trade-offs for Chronic Bronchitis. *Journal of Environmental Economics and Management*, 21(1), 32-51, 1991.

Watson, W., and J. Jaksch, "Air Pollution: Household Soiling and Consumer Welfare Losses", *Journal of Environmental Economics and Management*, 9, 248-262, 1982.

Whitelegg, J., "Transport for a Sustainable Future: The Case for Europe", Paperback, John Wiley and Sons Ltd, N: 0471947911, 1993, cited in OECD 1997a.

Whittemore, A., and E. Korn, "Asthma", *American Journal of Public Health*, 70(7), 687-689, 1980.

Xu, Zhongmin, Cheng Guodong, Zhang Zhiqiang, Su Zhiyong and John Loomis, "Applying contingent valuation in China to measure the total economic value of restoring ecosystem services in Ejina region", *Ecological Economics*, 44(2-3), pp. 345-358, 2003.

Chapter 7: Greenhouse Gas Emissions

7.1 Introduction

This chapter initially describes the potential impacts of greenhouse gas (GHG) emissions, specifically climate change effects. To move towards costing these impacts, how climate change effects can be quantified is explored. The global climate system is a very large system and there are decades of lag between emissions now and impacts that may take effect in the future. How these impacts can be forecast is examined, together with the particular economic and environmental modelling issues which arise in trying to assess the impact of those climate change effects. As any policy development associated with GHG emissions must operate within a substantial body of international regulation, economic aspects of GHG reduction agreements, regulations and policies are outlined. This then allows future impacts from current emissions to be monetized, and current price estimations can be suggested.

7.2 What Do We Mean by Global Climate Change and its Impacts?

The composition of the Earth's atmosphere is a primary determinant of the planet's temperature, which in turn affects all life on earth. Greenhouse gases occur naturally and trap heat within the atmosphere, helping to keep the planet hospitable to life. The main greenhouse gases are water vapor (H_2O), carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and halocarbons (such as chlorofluorocarbons, or CFCs).

Global climate change, often referred to as "global warming," involves an increase in the average atmospheric temperature of the Earth. This does not mean that temperatures will rise by a few degrees in all locations around the world. Rather, were global warming to occur, increases in atmospheric and oceanic temperatures might raise sea levels and alter associated weather patterns, which in turn could increase the frequency and severity of extreme weather worldwide. Such changes would likely alter current patterns of land use and human activity, as well as ecosystems and natural habitat.

Reliable prediction of the effects of climate change is difficult. We do not really know what the consequences are (and even if we know about the outcomes, there remain significant uncertainties with regard to the probabilities of each outcome). On the other hand, the extent of global warming may be indicated by the global average surface air temperature, which has continuously risen since Industrial Revolution with an accelerated rate of increase in the last three decades. For example, the early studies by Hansen and Lebedeff (1987, 1988) indicated that the rate of increase in the global average surface air temperature has increased from -0.5°C in 1880 to 0.2°C in 1980 on the 5-year moving average basis. And, IPCC (2001a, d) predicted that the global average surface air temperature would most likely increase by 1.4-5.8°C from 1990 to 2100.

If global warming of such magnitude occurs, it could bring about changes in rainfall patterns and other climatic conditions, resulting in serious ecological disequilibrium. An immediate impact is a rise in sea level. IPCC (2001a) predicted a sea level rise of 9-88cm during the period from 1990 to 2100. A sea level rise on the order of 20-60cm would have a significant impact on human life, affecting more than half a billion people worldwide, since the majority of human settlements are located either near the seashore or by rivers.

Other foreseeable effects from global warming are suggested in some studies. However, it is noted that the effects are still highly controversial among scientists. Some models suggest there may be more extreme weather events such as hurricanes and typhoons, and unstable rainfall distribution. Furthermore, the spread of diseases, affecting crops and forests as well as human populations, can accelerate under changed climate conditions as the lifecycle and distribution of insect vectors is changed.

The principal cause for global warming is the atmospheric concentration of radiative forcing agents, which keep infrared radiation from the Earth's surface and warm the surface air temperature. The radiative forcing agents are often referred to as greenhouse gases. Usually, GHGs are converted from one to another using their global warming potentials (GWP). The GWP of a gas is defined as the time integral of radiative forcing per unit emission divided by the same integral for carbon dioxide. The Intergovernmental Panel on Climate Change (IPCC)[156] considers that the increase in atmospheric concentrations of GHGs can, in part, be attributed to human activities, such as emissions of GHGs and deforestation. IPCC and many scientists believe that global climate change and its potentially disruptive effects are likely to occur unless we reduce GHG emissions.

Emissions of GHGs are usually reported in terms of metric tonnes of carbon dioxide equivalent (tCO2E). However, carbon units, or metric tonnes of carbon equivalent (tCE) are a common measure in the scientific community when considering energy issues since not all carbon from combustion is emitted in the form of carbon dioxide and carbon units are more convenient. Carbon units are defined as the molecular weight of the carbon content in carbon dioxide (i.e., just the "C" in CO_2) for comparisons with data on fuel consumption and carbon sequestration.

Carbon dioxide units at full molecular weight can be converted into carbon units by dividing by 3.67, or multiplying by 12/44 (the ratio of the weight of the carbon content of CO_2 to the total CO_2 molecular weight). Emissions of other gases, such as methane, can also be measured in "carbon equivalents" by multiplying their emissions (in metric tonnes) by their global warming potential and then dividing by 3.67.

[156] IPCC was established by the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP) in 1988, in recognizing the problem of potential global climate change. IPCC attempts to assess on a comprehensive, objective, open and transparent basis the scientific, technical and socio-economic information relevant to understanding the scientific basis of risk of human-induced climate change, its potential impacts and options for adaptation and mitigation. IPCC does not carry out research nor does it monitor climate related data or other relevant parameters. It bases its assessment mainly on peer reviewed and published scientific/technical literature.

Carbon dioxide is estimated to be responsible for 64% of the greenhouse effect, whereas methane accounts for 19%, nitrous oxide for 6%, and CFCs for 10%. Neftel et al. (1985), and several other studies in the 1980s found that the atmospheric concentration of CO_2 has increased from 280 parts per million (ppm) just prior to the Industrial Revolution to 360 ppm in the 1980s. Keeling et al. (1976), Komhyr et al. (1985), and Conway et al. (1988), among others, reported findings that the atmospheric concentration of carbon dioxide increased from 315 ppm in 1959 to 335 ppm in 1978. It increased at the annual rate of 0.3-0.5 ppm from 1880 to 1958. From 1958 to 1988, however, it increased at the annual rate of 1.3 ppm, which is a significant increase over a 30-year period. If the current trend were to persist, carbon dioxide would reach the level of 540-970 ppm by 2100.

The extent to which the atmospheric concentration of carbon dioxide contributes to the increase in global temperature has been extensively analyzed. Ramanathan et al. (1985) calculated that an increase of 0.52°C is due to the atmospheric concentration of CO_2 from 1880 to 1980. According to Dickinson (1986), the atmospheric concentration of CO_2 would reach a level twice as high as the pre-industrial level, and the resulting equilibrium warming would be 2.5-4.5°C. These findings have been reinforced by the recent studies published in IPCC (2001a, b, d).

In the past, a major difficulty in developing appropriate government policy in response to climate change threats has been the scientific uncertainty about the likely extent of change, and its specific regional effects. A small number of scientists argue that global warming is not fully supported by empirical evidence, mostly as a result of an inadequate understanding of atmospheric and weather patterns. Another, much larger, group of scientists assert that human activity is altering the chemical makeup of the Earth's atmosphere. These scientists also assert that the time lag between emissions of greenhouse gases and their full impact is on the order of decades to centuries, as is the time needed to reverse any effects. Finally, these scientists, including those of the IPCC, feel that the potential risks are so great that some action is warranted.

7.2.1 Transportation Sector and Global Warming[157]

The most recent Canadian data shows that the transportation sector is a principal source of GHG emissions, in particular CO_2 emissions, and is therefore a main contributor to potential climate change.

In 2001, total GHG emissions from Canada were estimated to be approximately 720 million tonnes, expressed on a carbon dioxide equivalent basis. Table 1 presents a breakdown of sources of GHG emissions in Canada. The emissions are shown in tonnes CO_2 equivalent, which take into account the combined impact of CO_2, methane and nitrous oxide and other greenhouse gases. The CO_2 equivalent is 21 tonnes for 1 tonne of methane and 310 tonnes for 1 tonne of nitrous oxide. CO_2 is by far the largest component of GHG emissions from transportation, and accounts for about 92% of total GHG

[157] All the data in this sub-section are from Environment Canada (2003).

emissions from the sector. As shown in Table 1, transportation is the second largest single source of GHG emissions in Canada, accounting for 26% of these emissions.

Table 7.1. GHG emissions for Canada, by sector
(Sum of CO_2, CH_4, N_2O, HFCs, PFCs, SF_6, in mt CO2 eq)

GHG Source	1990	1995	2001	2001 share
Energy:				
Stationary Combustion Sources	282	294	342	47.5%
Transportation Combustion Sources	153	169	187	26.0%
Fugitive Sources	38	50	55	7.6%
Industrial Processes	52.9	56.2	49	6.8%
Solvent & Other Product Use	0.42	0.44	0.47	0.1%
Agriculture	59	61	60	8.3%
Land Use Change and Forestry	2.3	4.7	2.1	0.3%
Waste	20	22	25	3.5%
Total	608	658	720	100.0%

Source: Environment Canada (2003).

It is not surprising that the largest single source of GHG emissions from transportation is the automobile. As shown in Table 2, in 2001 gasoline automobiles and light trucks accounted for 47% of GHG emissions from transportation sources. When the other transportation modes are taken into account, road transportation accounts for approximately 71.7% of all GHG emissions from transportation sources.

Table 7.2. Total GHG emissions by transportation mode, 2001 (kilo tonnes CO_2 equivalent)

Mode	GHG Emissions	2001 Share
Domestic Aviation	12,100	6.5%
Road Transportation		
Gasoline Automobile	48,700	26.0%
Light Duty Gasoline Trucks	39,400	21.1%
Heavy Duty Gasoline Vehicles	4,130	2.2%
Motorcycles	242	0.1%
Diesel Automobiles	596	0.3%
Light Duty Diesel Trucks	643	0.3%
Heavy Duty Diesel Vehicles	38,600	20.6%
Propane & Natural Gas Vehicles	1,140	0.6%
Road Transportation Total	134,000	71.7%
Railways	6,550	3.5%
Domestic Marine	5,510	2.9%
Others		
Off Road	19,500	10.4%

Pipelines	10,300	5.5%
Transportation Total	187,000	100.0%

Source: Environment Canada (2003).

7.2.2 Transportation and Biodiversity

The description of issues above has focused on the effects of climate change on human economic activity. A related issue is the impact of transportation, and of climate change, in biodiversity, the range of ecosystems that form the natural resource support for human systems. A description of the issues here, and the economic questions which arise, together with the tools used to research answers to those questions, is explored at Annex 2 to this report.

7.3 Identifying and Quantifying the Effects of Greenhouse Gas Emissions

This section summarizes approaches adopted by IPCC (2001b) to understand:

- How can current effects of climate change be detected?
- How can the future effects of climate change be anticipated, estimated, and integrated?
- How can impacts and adaptations be valued and costed?
- How can uncertainties be expressed and characterized?

7.3.1 Detecting Responses to Climate Change using Indicator Species or Systems

Climate change may cause responses in many human and natural systems, influencing human health (disease outbreaks, heat/cold stress), agriculture (yield, pest outbreaks, crop timing), physical systems (glacier, icepack, stream flow), and biological systems (distributions/abundances of species, timing of events). In intensively human-managed system, the direct effects of climate change may be either buffered or so completely compounded with other factors that they become impossible to detect. Conversely, in systems with little human manipulation, the effects of climate change should be most transparent. Systems for which we have a good process-based understanding of the effects of climate and weather events, and have had minimal human intervention, may act as indicators for the more general effects of climate change in other systems and sectors.

An important component of this detection process is the search for systematic patterns of change across many studies, based on observed or predicted changes in climate. Confidence in attributing these observed changes to climate change increases as studies are replicated across diverse systems and geographic regions. Although studies now number in the hundreds, some regions and systems remain underrepresented.

To investigate possible links between observed changes in regional climate and biological or physical processes in ecosystems, IPCC (2001b) gathered more than 2,500 articles on climate and one of the following entities: animals, plants, glaciers, sea ice, and ice on lakes or streams. To determine if these entities have been influenced by changing climate, only studies meeting at least two of the following criteria were included:

- A trait of these entities (e.g., range boundary, melting date) shows a change over time.
- The trait is correlated with changes in local temperature.
- Local temperature changed over time.

At least two of these three criteria had to exhibit a statistically significant correlation. Only temperature was considered because it is well established in the literature how it influences the entities examined, and because temperature trends are more globally homogeneous than other locally varying climatic factors, such as precipitation changes. Selected studies must also have examined at least 10 years of data. More than 90% had a time span of more than 20 years.

These stringent criteria reduced the number of studies used in the analysis to 44 animal and plant studies that cover more than 600 species. Of these species, about 90% (more than 550) show changes in traits over time. Of these 550+ species, about 80% show changes in a direction expected given the scientific understanding of known mechanisms that relate temperature to each of the species traits. The probability that more than 450 species of 550+ would show changes in the directions expected by random chance is negligible.

Sixteen studies examining glaciers, sea ice, snow cover extent/snow melt, or ice on lakes or streams included more than 150 sites. Of these 150+ sites, 67% show changes in traits over time. Of these 100+ sites, about 99% exhibited trends in a direction expected, given the scientific understanding of known mechanisms that relate temperatures to physical processes governing change in that trait. The probability that 99+ of 100+ sites would show changes in the directions expected by chance alone is negligible.

7.3.2 Appropriate Scales of Analysis for Impact Assessment

Climate change impact assessments must begin with decisions about the scope and scale of the assessment: What are the main policy issues? What and who are exposed to climate change impacts? What is the appropriate scale, in time frame and geographical extent, and resolution?

Methods of identifying policy issues include checklists and inventories, document analysis, surveys and interviews, and simulations. The process of determining the scope of assessment should be iterative. Design of the impact assessment should specify what and who is exposed to climate change impacts, for example, economic sectors, firms, or individuals.

The choice of temporal scales, regional extent, and resolution should be related to the focus of the assessment. Often, more than one scale is required, under methods such as strategic scale cycling (Root and Schneider, 1995) or multi-level modeling (e.g., Easterling et al., 1998). Linkage to global assessments may be necessary to understand the policy and economic context (e.g., Darwin et al., 1995).

The most common set of methods and tools remains various forms of dynamic simulation modeling, such as crop-climate models or global vegetation dynamic models. Data for running and validating models is a recurrent issue. Inter-model comparisons have been undertaken in some areas (e.g., Mearns et al., 1999), but much remains to be done.

Climate change is likely to have multiple impacts across sectors, showing combined effects with other socioeconomic and environmental stresses, such as desertification, water scarcity, and economic restructuring. Most studies have focused on single-sector impacts.

Vulnerability assessment may be one way of integrating the various stresses on populations and regions arising from climate change (see Briguglio, 1995; Clark et al., 1998; Huq et al., 1999; Kaly et al., 1999; Downing et al., 2001). There are some areas in which formal methods for vulnerability assessment have been well developed (e.g., famine monitoring and food security, human health) and applied to climate change. However, methods and tools for evaluating vulnerability are in formative stages of development.

7.3.3 Baseline for Comparison

Climate change impacts are generally agreed to be the difference in conditions with and without climate change. However, there is controversy among researchers about how to set the baseline for estimating impacts. Most studies apply scenarios of future climate change but estimate impacts on the basis of current environmental and socioeconomic baselines. Although this approach is expedient and provides information about the sensitivity of current systems, it skirts the issue of evolving sensitivity to climate variations (Parry and Carter, 1998). Even without climate change, the environment and societal baselines will change because of ongoing socioeconomic development. With climate change, the baselines will change because of system responses and autonomous adaptation. Therefore, the effects of climate change should be evaluated by taking a moving baseline into account.

Given the uncertainty of the future and the complexity of systems involved, a wide range of different assumptions about future baselines is plausible. The emission scenarios in IPCC (2000) reflect this perspective and are based on multiple projections of “alternative futures.” For vulnerability and adaptation assessment, there is little apparent consistency regarding elements or procedures for developing these future baselines, including who is exposed, how to select sensitive sectors and the drivers of social and institutional change at the stakeholder level.

A researcher who wants to estimate the costs or benefits of changing conditions must define as fully as possible the socioeconomic, political, institutional, and cultural environments within which the change will be felt. A "first best" analysis assumes that everything works efficiently in response to changing conditions in the context of all of the right information; results of first-best analyses reflect benchmarks of "best-news" scenarios. Second-best analyses assume that distortions caused by the failure to hold by some or all of these assumptions, will diminish the efficiency of the first-best world; second-best analyses can produce dramatically different answers to cost and valuation questions. Indeed, baselines that are constructed to reflect the global externalities of climate change by definition reflect second-best circumstances.

It may be reasonable to assume that distortions will persist as changes occur over the short run. Making the same assumption over the long run could be a mistake, however. Will information not improve over time? If distortions are costly, they may persist over the long term if the beneficiaries have sufficient power to preserve their advantage. There is no right way to do second-best analysis; it is simply incumbent on the researcher to report precisely what assumptions define the baseline.

7.3.4 Integrated Assessment

Integrated assessment is an interdisciplinary process that combines, interprets and communicates knowledge from diverse scientific disciplines from the natural and social sciences to investigate and understand causal relationships within and between complicated systems. Methodological approaches employed in such assessments include computer-aided modeling, scenario analysis, simulation gaming and participatory integrated assessment, and qualitative assessments that are based on existing experience and expertise.

However, the progress to date, particularly with regard to integrated modeling, has focused largely on mitigation issues at the global or regional scale, and only secondarily on issues of impacts, vulnerability and adaptation. Greater emphasis on the development of methods for assessing vulnerability is required, especially at national and sub-national scales where impacts of climate change are felt and responses are implemented.

7.4 Towards Current Prices of Future Climate Change Effects

7.4.1 Market Impacts

Cost and valuation exercises work best when competitive markets exist. Even when markets are distorted, cost and valuation exercises provide some useful information.

These concepts have already been outlined in Chapter 1 of this report. This section offers brief additional insights into how the elements described can be applied to climate change effects**.**

7.4.2 Pre-existing Distortions

Market-based exercises that evaluate the costs and benefits of change must carefully account for pre-existing distortions in markets. In the presence of one distortion, in fact, creation of another might actually improve welfare. Changes may or may not work to reduce pre-existing distortions, so they actually can produce benefits that would be missed entirely if analyses were confined to competitive conditions. Goulder and Schneider (1999), for example, have noted that pre-existing subsidies to conventional energy industries reduce the costs of climate policies, but that pre-existing subsidies to alternative energy industries would increase costs. Moreover, they pointed out that the opportunity costs of research and development (R&D) could be reduced or even reversed if there were an ample supply of R&D providers rather than a scarcity.

7.4.3 The Cost of Uncertainty

This sub-section reviews the primary methods for incorporating uncertainty into analyses of climate impacts. Here we look at how to judge the cost associated with uncertainty. Cost and valuation depend, in general, on the entire distribution of the range of outcomes.

Insurance and the cost of uncertainty: Risk-averse individuals who face uncertainty try to buy insurance to protect themselves from the associated risk (e.g., different incomes next year or over the distant future, depending on the situation that actually occurs). Assuming the availability of “actuarially fair” coverage (i.e. coverage available from an insurance provider for which the expected cost of claims over a specified period of time equals the expected income from selling coverage), individuals try to insure themselves fully so that the uncertainty would be eliminated.

For a risk-averse person, the certainty-equivalent income is less than the expected income, so the difference can be regarded as “willingness to pay” (WTP, see Chapter 1) to avoid risk. In a real sense, willingly paid insurance premiums represent a measure of the cost of uncertainty. Therefore, willingly paid insurance premiums can represent the society’s WTP for the assurance that non-diversifiable uncertainty would disappear (if that were possible). Thus, this is a precise, utility-based measure of economic cost. The cost of uncertainty would be zero if the objective utility function were risk-neutral; indeed, the WTP to avoid risk is positive only if the marginal utility of economic activity declines as income increases. Moreover, different agents could approach the same uncertain circumstance with different subjective views of the relative likelihoods of each outcome and/or different utility functions. The amount of insurance that they would be willing to purchase would be different in each case. Application of this approach to a society therefore must be interpreted as the result of contemplating risk from the perspective of a representative individual.

The value of information: A straightforward method of judging the value of information in an uncertain environment has been developed and applied (see Manne and Richels, 1992, for an early and careful description, and Boardman, et al. 2001, for a general discussion). The idea is simply to compute the expected cost of uncertainty with and without information and compare the outcomes. For example, it might be that improved information about the range of uncertainty would change the mean and the variance of associated costs. If the researcher were interested only in the resulting change in costs, however, the value of information would simply be the difference between expected cost with and without the new information, and only the mean would matter. However, if the researcher wanted to represent the value of information in terms of welfare that displays some degree of risk aversion so that variance also plays a role, a comparison of insurance-based estimates of the WTP to avoid uncertainty would be more appropriate.

Uncertainty and discounting: Uncertainty about costs and/or values that are incurred or enjoyed over time can be handled in two ways. One method calculates the present value across the full range of possibilities; means and distributions of present values are the result. The second method, reported in Arrow et al. (1996), converts outcomes at each point in time into their certainty equivalents and then applies discounting techniques. This approach raises the possibility of including risk aversion into the calculation.

The situation is quite different when uncertainty surrounds the selection of the discount rate itself. It may not be appropriate, in these cases, to use a certainty-equivalent discount rate (or an average over the range of possible rates). Weitzman (1998) has noted, in particular, that the "lowest possible" discount rate should be used for discounting the far-distant future. The reason is that the expected value of present value over a range of discount rates is not equal to the present value calculated with an average rate. Moreover, the difference between the two is exaggerated in the distant future. Present values computed with low rates can be orders of magnitude greater than those computed with high rates when the future is extended.

7.4.4 Alternative Metrics for Measuring Costs

Economic thinking focuses on cost measures denominated in currency, but practitioners have been criticized on the grounds that such measures inadequately recognize non-market costs. Schneider et al. (2000), for example, have listed five metrics with which the costs of climate change might be captured. Their list includes monetary losses, loss of life, changes in quality of life (including a need to migrate, conflict over resources, cultural diversity, loss of cultural heritage sites, etc.), species or biodiversity loss, and distributional equity. When all is said and done, however, costs denominated in one metric must be weighed, at least subjectively, with costs denominated in another – and there are no objective quantitative methods with which to do so. A survey conducted by Nordhaus (1994a), however, offered some insight into 15 researchers' subjective views of the relative importance of several different measures along three different "what if" scenarios. Table 7.3 displays some of the results in terms of the anticipated cost denominated in lost gross world product, the likelihood of high-consequence impacts, the distribution of costs across the global population, and the proportion of costs that would be captured by national income accounts.

Table 7.3. Subjective expert opinion on climate change (Nordhaus, 1994a)

Cost Metric	Scenario A[a]	Scenario B[b]	Scenario C[c]
a) Loss in gross world product[d]			
— Mean	1.9	4.1	5.5
— Median	3.6	6.7	10.4
— High	21.0	35.0	62.0
— Low	0.0	0.0	0.8
b) Probability of high-consequence event[e]			
— Mean	0.5	3.0	5.0
— Median	4.8	12.1	17.5
— High	30.0	75.0	95.0
— Low	0.0	0.2	0.3
c) Top to bottom ratio of impacts[f]			
— Mean	4.2		
— Median	3.5		
— High	10.0		
— Low	1.0		
d) Percentage of total in national accounts			
— Mean	62.4	66.6	65.6
— Median	62.5	70.0	80.0

Notes:

a) Scenario A postulated 3°C warming by 2090.
b) Scenario B postulated scenario A continuing to produce 6°C warming by 2175.
c) Scenario C postulated 6°C warming by 2090.
d) Percentage of global world product lost as a result of climate change.
e) Likelihood of a high-consequence event (a loss of 25% of gross world product, comparable to the Great Depression).
f) Proportion of loss felt by the poorest quintile of income distribution relative to the loss felt by the richest quintile; a value of 1 signifies an equal distribution of burden.

As can be seen from the table, the survey results show wide disagreement across the first three metrics; this disagreement generally can be explained in terms of a dichotomy of views between mainstream economists and natural scientists. Nonetheless, Nordhaus (1994a) reports that a majority of respondents held the view that a high proportion of costs would be captured in national accounts. It would seem, therefore, that natural scientists think that mainstream economists not only underestimate the severity of non-market impacts but also do not translate the implications of those impacts into the monetized economy.

7.4.5 Treatment of Uncertainties

Uncertainty, or, more generally, debate about the level of certainty required to reach a "definitive" conclusion, is a perennial issue in science. Difficulties in explaining uncertainty have become increasingly salient as society seeks policy advice to deal with global environmental change. How can science be useful when evidence is incomplete or ambiguous, the subjective judgments of experts in the scientific and popular literature differ, and policymakers seek guidance and justification for courses of action that could cause, or prevent, significant environmental and societal changes? How can scientists improve their characterization of uncertainties so that areas of slight disagreement do not become equated with paradigmatic disputes, and how can individual subjective judgments be aggregated into group positions? In short, how can the full spectrum of the scientific content of public policy debates be fairly and openly assessed?

The term "uncertainty" implies anything from confidence just short of certainty to informed guesses or speculation. Lack of information obviously results in uncertainty. Often, however, disagreement about what is known or even knowable is a source of uncertainty. Some categories of uncertainty are amenable to quantification, whereas other kinds cannot be expressed sensibly in terms of probabilities (see Schneider et al., 1998, for a survey of literature on characterizations of uncertainty). Uncertainties arise from factors such as lack of knowledge of basic scientific relationships, linguistic imprecision, statistical variation, measurement error, variability, approximation, and subjective judgment (see Box 7.1). These problems are compounded by the global scale of climate change, and local scales of impacts, long time lags between forcing and response, low-frequency variability with characteristic times that are greater than the length of most instrumental records and the impossibility of before-the-fact experimental controls also come into play. Moreover, it is important to recognize that even good data and thoughtful analysis may be insufficient to dispel some aspects of uncertainty associated with the different standards of evidence (Morgan, 1998; Casman et al., 1999).

Two approaches to evaluate uncertainties are applied in IPCC (2001b). A quantitative approach is adopted to assess confidence levels in instances for which present understanding of relevant processes, system behaviour, observations, model simulations, and estimates is sufficient to support broad agreement among authors of the report about Bayesian probabilities associated with selected findings. A more qualitative approach is used to assess and report the quality or level of scientific understanding that supports a conclusion (see Box 7.2). These approaches, and the rationale for them, are explained in more detail in Third Assessment Report: Cross-Cutting Issues Guidance Papers (http://www.gispri.or.jp).

Box 7.1. Examples of Sources of Uncertainty

Problems with Data

1. Missing components or errors in the data
2. "Noise" in data associated with biased or incomplete observations
3. Random sampling error and biases (non-representativeness) in a sample

Problems with Models

4. Known processes but unknown functional relationships or errors in structure of model
5. Known structure but unknown or erroneous values of some important parameters
6. Known historical data and model structure but reasons to believe parameters or model structure will change over time
7. Uncertainty regarding predictability (e.g., chaotic or stochastic behavior) of system or effect
8. Uncertainties introduced by approximation techniques used to solve a set of equations that characterize the model

Other Sources of Uncertainty

9. Ambiguously defined concepts and terminology
10. Inappropriate spatial/temporal units
11. Inappropriateness of/lack of confidence in underlying assumptions
12. Uncertainty resulting from projections of human behavior (e.g., future consumption patterns or technological change), as distinct from uncertainty resulting from "natural" sources (e.g., climate sensitivity, chaos)

Box 7.2. Confidence Levels and State of Knowledge

Quantitative Assessment of Confidence Levels

In applying the quantitative approach, authors of the report assign a confidence level that represents the degree of belief among the authors in the validity of a conclusion, based on their collective expert judgment of observational evidence, modeling results, and theory that they have examined. Five confidence levels are used. In the tables of the Technical Summary, symbols are substituted for words:

Very High (*****)	95% or greater
High (****)	67-95%
Medium(***)	33-67%
Low (**)	5-33%
Very Low (*)	5% or less

Qualitative Assessment of the State of Knowledge

In applying the *qualitative* approach, authors of the report evaluate the level of scientific understanding in support of a conclusion, based on the amount of supporting evidence and the level of agreement among experts about the interpretation of the evidence. Four qualitative classifications are employed:

- *Well-established:* Models incorporate known processes, observations are consistent with models, or multiple lines of evidence support the finding.
- *Established but incomplete:* Models incorporate most known processes, although some parameterizations may not be well tested; observations are somewhat consistent but incomplete; current empirical estimates are well founded, but the possibility of changes in governing processes over time is considerable; or only one or a few lines of evidence support the finding.
- *Competing explanations:* Different model representations account for different aspects of observations or evidence or incorporate different aspects of key processes, leading to competing explanations.
- *Speculative:* Conceptually plausible ideas that are not adequately represented in the literature or that contain many difficult-to-reduce uncertainties.

7.4.6 Selected Estimators of the Impacts of the Climate Change

As discussed earlier, insight into the impact of climate change is crucially important for evaluating the total externality of transportation, and for deciding on a proper course for GHG emission reduction policies. This sub-section will introduce the estimation results of some relevant literature on the damage cost of climate change.

7.4.6.1 IPCC (1996)

Pearce et al. (1996) discussed and summarized estimates of the damage costs of climate change in the IPCC (1996) report.

As we have discussed in Section 7.3, the level of sophistication in socioeconomic assessments of climate change impacts is still rather modest. Damage estimates are tentative and based on a number of simplifying and often controversial assumptions. Most estimates are for equilibrium climate change associated with a doubling of the pre-industrial CO_2-equivalent concentration of all greenhouse gases (referred to as $2xCO_2$). Best-guess central estimates of global damage, including non-market impacts, are in the order of 1.5-2.0% of world GDP for $2xCO_2$ concentrations and equilibrium climate change. This means that if a doubling of CO_2 occurred now, it would impose this much damage on the world economy now. The figures are best-guess results, and several impact categories could not be assessed for lack of data. Moreover, the range reflects variations in the best-guess estimates and cannot be interpreted as a confidence interval. Particularly vulnerable sectors include agriculture, the coastal zones, human mortality and natural ecosystems. The possibility of catastrophes (low probability/high impact events) and surprises cannot be ignored.

The regional variation in damage is substantial. The available studies in Pearce et al.'s summary estimate the damage for developed countries at between 1% and 2% of GDP for a $2xCO_2$ climate. Central estimates of the damage in different developing regions range from a minimum of 2% of GDP to a maximum of 9%. For individual nations, or if alternative assumptions are used about the value of statistical life (VSL), the figure could be even higher. Small island states and low-lying coastal areas are especially vulnerable. Most impact work is confined to developed nations, however. The confidence in estimates for developing countries is much lower.

The $2xCO_2$ damage estimates usually form the basis for the calculation of marginal damage – the extra damage done by one extra tonne of carbon emitted. The marginal damage is estimated by different studies at US$5-$125 per tonne of carbon emitted now. This wide range reflects variations in model assumptions, as well as the high sensitivity of figures to the choice of discount rate. Although the estimates based on a social rate of time preference of the order of 5% tend to be about US$5-$12, the figures assuming a rate of 2% or less can be almost an order of magnitude higher. The authors argue that models are simplistic and provide poor representations of dynamic processes. The effect of climate change adaptation in particular is poorly understood.

Tables 7.4-7.6 summarize the principal damage estimates of climate change impacts for major regions of the world, which were outlined in Pearce et al. (1996). In the United States, the losses from benchmark $2xCO_2$ equivalent warming reach over 1% of GDP in the Cline, Fankhauser and Tol compilations, and some 2.5% of GDP in the central Titus estimates. Titus specifies a lower and upper end of his range of estimates, at 0.8% and 5.4% of GDP, respectively. It should also be noted that the Titus estimates are based on climate models with average warming projections of about 4°C, 1.5°C higher than the IPCC's best guess of 2.5°C.

Table 7.4. Monetized 2xCO_2 damage to present US economy (base year 1990; billion $ of annual damage; 2002 $C values in brackets)

Damage Category	Cline (2.5°C)	Fankhauser (2.5°C)	Nordhaus (3°C)[a]	Titus (4°C)	Tol (2.5°C)[b]
Agriculture	17.5 (26.8)	8.4 (12.9)	1.1 (1.7)	1.2 (1.8)	10.0 (15.3)
Forest loss	3.3 (5.0)	0.7 (1.1)	Small	43.6 (66.9)	--
Species loss	4.0+a [c] (6.1)	8.4 (12.9)	[c]	--	5.0 (7.7)
Seal level rise	7.0 (10.7)	9.0 (13.8)	12.2 (18.7)	5.7 (8.7)	8.5 (13.0)
Electricity	11.2 (17.2)	7.9 (12.1)	1.1 (1.7)	5.6 (8.6)	--
Non-elec. heating	-1.3 (-2.0)	--	d	--	--
Human amenity	+b [c]	--	d	--	12.0
Human morbidity	+c [c]	--	d	--	--
Human life	5.8 (8.9)	11.4 (17.5)	d	9.4 (14.4)	37.4 (57.4)
Migration	0.5 (0.8)	0.6 (0.9)	d	--	1.0 (1.5)
Hurricanes	0.8 (1.2)	0.2 (0.3)	d	--	0.3 (0.5)
Construction	±d [c]	--	d	--	--
Leisure activities	1.7 (2.6)	--	d	--	--
Water supply			d		
Availability	7.0 (10.7)	15.6 (23.9)	d	11.4 (17.5)	--
Pollution	--	--	d	32.6 (50.0)	--
Urban infrastructure	0.1 (0.15)	--	d d	--	--
Air pollution			d		
Trop. O3	3.5 (5.4)	7.3 (11.2)	d	27.2	--
Other	+e [c]	--	d	--	
Mobile air cond.	--	--		2.5	--
Total	61.1 (93.7)	69.5 (106.6)	55.5 (85.1)	139.2 (213.5)	74.2 (113.8)
(% of GDP)	+a+b+c±d+e [c] (1.1)	(1.3)	(1.0)	(2.5)	(1.5)[b]

Notes:

a) Transformed to 1990 base.
b) US and Canada, base year 1988.
c) Costs that have been identified but not estimated.
d) Not assessed categories, estimated at 0.75% of GDP.

Figures represent best guesses of the respective authors. Although none of the studies reports explicit confidence intervals, figures should be seen as reflecting orders of magnitude only.

Sources: Cline (1992a), Fankhauser (1995), Nordhaus (1991), Titus (1992) and Tol (1995).

Table 7.5. 2xCO_2 damage in physical units: different world regions (2.5°C warming)

Type of Damage	Damage Indicator	EU	USA	Ex-USSR	China	Non-OECD	OECD	World
Agriculture	Welfare loss (% of GDP)	0.21	0.16	0.24	2.10	0.28	0.17	0.23
Forestry	Forest area loss (km^2)	52	282	908	121	334	901	1235
Fishery	Reduced catch (1,000t)	558	452	814	464	4,326	2,503	6,829
Energy	Rise in elec. demand (TWh)	54.2	92.0	54.6	17.1	142.7	211.2	353.9
Water	Reduced water availability (km^3)	15.3	32.7	24.7	32.2	168.5	62.2	230.7
Coastal protection	Annual capital cost (million $US/yr) (2002 $C values in brackets)	133 (180)	176 (238)	51 (69)	24 (32)	514 (695)	493 (666)	1,007 (1361)
Dryland loss	Area lost (1,000 km^2)	1.6	10.7	23.9	0	99.5	40.4	139.9
Wetland loss	Area lost (1,000 km^2)	9.9	11.1	9.8	11.9	219.1	33.9	253.0
Ecosystem loss	Number of protected habitats lost, (assuming 2% loss)	16	8	n/a	4	53	53	106
Health/ mortality	Number of deaths (1,000)	8.8	6.6	7.7	29.4	114.8	22.9	137.7
Air pollution								
Trop O_3	(1,000 t NO_x)	566	1,073	1,584	227	2,602	1,943	4,545
SO_2	(1,000 t sulphur)	285	422	1,100	258	1,864	873	2,737
Migration	Additional immigrants (1,000)	229	100	153	583	2,279	455	2,734
Hurricane								
Casualties	number of deaths	0	72	44	779	7,687	313	8,000
Damages	million $US (2002 $C values in brackets)	0 (0)	115 (155)	1 (1)	13 (18)	124 (168)	506 (684)	630 (851)

Source: Fankhauser (1995).

Table 7.6. Monetized 2xCO_2 damage in different world regions (annual damage; 2002 $C values in brackets [e])

	Fankhuaser (1995)		Tol (1995)	
Region	bn$	%GDP [a]	bn$	%GDP [a]
European Union	63.6 (85.9)	1.4		
United States	61.0 (82.4)	1.3		
Other OECD	55.9 (75.5)	1.4		
OECD America			74.2 (100.3)	1.5
OECD Europe			56.5 (76.4)	1.3
OECD Pacific			59.0 (79.7)	2.8
Total OECD	180.5 (243.9)	1.3	189.5 (256.1)	1.6
E. Europe / former USSR	18.2 [b] (24.6)	0.7 [b]	-7.9 (-10.7)	-0.3
Centrally planned Asia	16.7 [c] (22.6)	4.7 [c]	18.0 (24.3)	5.2
South and Southeast Asia			53.5 (72.3)	8.6
Africa			30.3 (40.9)	8.7
Latin America			31.0 (41.9)	4.3
Middle East			1.3 (1.8)	4.1
Total non-OECD	89.1 (120.4)	1.6	126.2 (170.5)	2.7
World [d]	269.6 (364.3)	1.4	315.7 (426.6)	1.9

Notes:

a) Note that the GDP base may differ between the studies.
b) Former Soviet Union only.
c) China only.
d) Percentage of GDP figures are based on market exchange rate GDP.
e) Assumed 1995 US$ is used in the studies.

The order of magnitude of estimates does not change if uncorrected damage categories are purchasing-power-parity (PPP) adjusted and expressed as a fraction of PPP-corrected GDP.

Less comprehensive estimates by Nordhaus (1991), again for the US, arrive at a direct calculation of only 0.26% of GDP, primarily from sea level rise; but Nordhaus also sets 1% of GDP as a reasonable central estimate. However, these damage figures are likely to deviate from the "true" impacts, for three main reasons. First, several effects are not adequately quantified (e.g., non-tropical storms, droughts, floods, morbidity). Second, adaptation – the system responses to react and adapt to climate change – is not fully taken into account. Third, the figures are far from exact, and one should allow for a considerable margin of error. Many are deliberately kept conservative. Species loss valuation in particular could be far higher. The economic figures presented also suffer from the fact that they are based on earlier climate and impact research.

It should also be emphasized that the estimates in Tables 7.4-7.6 refer to central warming expectations. The corresponding damages for upper-bound warming would be higher, and more than linearly so. Also, when moving from the question of damage estimation to that of abatement benefits, a number of benefits not related to climate change need to be taken into account.

There is a distinction between climate change impacts and the benefits of policy measures to abate CO_2 emissions, although the two concepts are related. In general, the benefits of policy measures to abate CO_2 emissions are at least equal to the amount of damage avoided, that is, to the extra damage which would have occurred in the absence of action. This principal rule is complicated somewhat by the dynamic character of climate change. In addition, there may also be ancillary benefits (or costs) from those actions that are not related to climate change.

Table 7.7 provides a list of estimates of the marginal benefits of CO_2 abatement. Two types of marginal cost estimation methods are distinguished. One is based on the average additional cost of a small perturbation of an exogenous "business-as-usual" scenario (commonly IPCC (1992a) or something very similar). The other is based on the shadow value of carbon dioxide emissions along an optimal emission path. Since optimal and no-control trajectories lie very close to one another (e.g., Manne et al., 1995; Nordhaus and Yang, 1996; Peck and Teisberg, 1994; Tol, 1997), the difference is small in practice.

Table 7.7. The marginal costs of GHG emissions, measured in tCO2E [a] (2002 $C values in brackets)

Study	Type [b]	1991-2000	2001-2010	2011-2020	2021-2030
Nordhaus (1991) [c]	MC		7.3 (11.2) 0.3-65.9 (0.5-101.1)		
Ayres and Walter (1991)[c]	MC		30-35 (46.0-53.7)		
Nordhaus (1994b) - best guess - expected value	CBA	 5.3 (8.1) 12.0 (18.4)	 6.8 (10.4) 18.0 (27.6)	 8.6 (13.2) 26.5 (40.6)	 10.0 (15.3) n.a.
Cline (1992b, 1993)	CBA	5.8-124 (8.9-190.2)	7.6-154 (11.7-236.2)	9.8-186 (15.0-285.3)	11.8-221 (18.1-339.0)
Peck and Teisberg (1992)	CBA	10-12 (15.3-18.4)	12-14 (18.4-21.5)	14-18 (21.5-27.6)	18-22 (27.6-33.7)
Fankhauser (1995)	MC	20.3 (31.1) 6.2-45.2 (9.5-69.3)	22.8 (35.0) 7.4-52.9 (11.3-81.1)	25.3 (38.8) 8.3-58.4 (12.7-89.6)	27.8 (42.6) 9.2-64.2 (14.1-98.5)
Maddison (1995)	CBA MC	5.9 (9.0) 6.1 (9.4)	8.1 (12.4) 8.4 (12.9)	11.1 (17.0) 11.5 (17.6)	14.7 (22.5) 15.2 (23.3)

Notes:

a. Current (1990) value $/tC; figures in brackets denote 90% confidence intervals; net present values are discounted to the period of emission.
b. MC = marginal cost study, i.e., estimate is based on a slight perturbation of a baseline;
   CBA = cost-benefit analysis study, i.e., estimate is based on a shadow value.
c. Time of emission not explicitly considered.

The estimates of Table 7.7 show a wide range. The upper bound of Cline can be explained by: (i) high benchmark estimates of climate change; (ii) a long time horizon combined with a low discount rate; and (iii) constant vulnerability to climate change. Ayres and Walter's estimate is on the high side, because they use a low discount rate and OECD values for the whole world in areas such as valuing health risks. Nordhaus shows that the expected value of marginal costs is higher than the best guess value, because uncertainties are asymmetric and relationships non-linear. Fankhauser's estimates are expected values, centered around a discount rate of 3%.

Using the base case in DICE (Dynamic Integrated Climate Economy model of global warming), which is a globally aggregated model integrating a general-equilibrium model of the global economy with a climate system including emissions, concentrations, climate change, impacts and optimal policy, Nordhaus (1993a, b) finds that the shadow price begins at about US$5 (or $6.8 at 2002 $C) per tonne of carbon in 1995, rises to about $10 ($13.6) by 2025, and reaches $21 ($28.4) by 2095 at 1990 prices. Peck and Teisberg (1992) find values of a similar order of magnitude. Tol's (1995) alternative specification of DICE yields shadow prices of $13 ($17.6 at 2002 $C) for 1995, rising to $89 ($120.3) for 2095. These model runs assume that parameter values are known with certainty. In case of DICE, expected shadow prices more than double once uncertainty is added to the model. This result arises because of the skewedness in the damage distribution, which allows for low probability/high impact events (Nordhaus, 1994b). In contrast, Cline (1992b, 1993) finds significantly higher shadow prices by using a zero utility discount rate. His reproduction of the DICE model generates a path of shadow prices beginning at about $45 ($69.0 at 2002 $C) per tonne, reaching about $243 ($372.3) by 2100. Other parameter specifications provide even higher values.

In comparison, Fankhauser (1995) identifies a lower and flatter trajectory for the shadow price of carbon, rising from $20 ($31.1 at 2002 $C) per tonne in the decade 1991-2000 to $28 ($42.6) per tonne by 2021-2030, with confidence intervals of $6-$45 ($9.5-$69.3 at 2002 $C) and $9-$64 ($14.1-$98.5) respectively. Fankhauser uses a probabilistic approach to the range of discount rates, in which low and high discount rates are given different weights. His sensitivity analysis of the discount rate suggests that moving from high (3%) to low (0%) discounting could increase marginal costs by a factor of 9, from $5.5 to $49 ($7.4-$64.2 at 2002 $C) per tonne of carbon emitted now.

7.4.6.2 Bein (1997)

Directed by Dr. Peter Bein, the Ministry of Transportation and Highways at British Columbia carried out a study of monetization of environmental impacts of highway and transportation investments. The original research was conducted from 1992 to 1995. The evaluation framework is Social Cost Benefit Analysis (SCBA), in which as many criteria as possible are valued in monetary units, and non-monetized and intangible factors are considers in a Multiple Account Evaluation (MAE) framework. SCBA is a natural extension of CBA, which has been firmly established in transportation appraisals analysis. Agency and user costs are standard in transportation appraisals, whereas many environmental impacts can be monetized as rigorously as the value of travel time or the costs of accidents. The major challenge is how to include the non-monetizable values, or intangibles.

The MAE framework could provide a suitable basis for including tangible, monetizable environmental impacts side by side with unmonetized and intangible ones. With such an approach, existing environmental cost information, however imperfect, can be assembled and included in a monetary SCBA. This form of SCBA incorporates a weak sustainability approach by:

- allowing uncertain cost estimates to be considered;
- using sensitivity analysis for decision makers to understand the impact of unit prices;
- erring on the safe side by choosing the high end of the uncertain estimates; and,
- listing and qualifying the intangibles that cannot be captured by monetary values, so that the decision maker can apply precautionary value judgments.

Bein (1997) is interesting in that it was carried out in a Canadian context, which makes the findings of particular relevance to the present study. In general, it has provided higher cost estimates than other studies.

7.4.7 Estimating the impacts and prices of GHG emissions from transportation

To develop a cost estimate of climate change impacts, Bein and Rintoul (1996a) use the Cline (1992) and Cline (1995a) model, with minor adaptations, but run it over a longer horizon (to the year 2500), and with a set of more precautionary inputs to reflect a worse-case scenario (Table 7.8). They use the following inputs:

- CO_2 doubling leads to warming of 2.5°C to 4.5°C;
- benchmark damage corresponding to 2.5°C warming due to CO_2 doubling is 4% for developed countries and 8% for developing countries;
- analysis period is 500 years, rather than 300 years used by Cline;
- SRTP (the Social Rate of Time Preference) is allowed to vary around 1.5%; and
- Damage function exponent ranges from 2.0 to 3.0.

Table 7.8. Comparison of model assumptions (2002 $C values in brackets)

Assumption	Cline (1995a)	Bein and Rintoul (1996a)
Analysis period	300 years	500 years
Benchmark warming	1.5°C to 4.5°C	2.5°C to 4.5°C
Benchmark damage		
o Developed world	1.4%-2.5% GDP	1.4%-4.0% GDP
o Developing world	1.8%-4.0% GDP	1.8%-8.0% GDP
Value of human life	US$ 0.6 million ($0.81 million)	$C 3 million ($3.3 million) [a]
SRTP	0%-4%	0%-4%
Damage function exponent	1.3-3.0	2.0-3.0
Long-term damage limit	100% GDP	No limit

Notes: a. Assumed that 1996 $C is used in the original study.

Bein and Rintoul (1996a) assumed 4% and 8% of GDP for the developed and developing countries' benchmark damage, respectively. The estimate of damage from global warming, expressed as a fraction of GDP, is a crucial independent variable for shadow price estimation. A number of published estimates of the damage corresponding to CO_2 equivalent doubling "agree" on about 1% to 2% of GDP for developed countries, and 2% to 4% for developing countries (Pearce et al., 1995). Bein and Rintoul pointed out that this agreement does not necessarily demonstrate the reliability of the estimate for benchmark damage. There are several reasons for the similarity of the estimates:

- They largely draw upon the same study (EPA, 1989) or parametric extensions of its results to areas other than the United Sates.
- Nordhaus (1994) discovered that scientists consistently estimated significantly higher damage, higher probabilities of catastrophic impacts and higher likelihood of faster warming, compared with economists. Since the economic analysis of global warming has been conducted by economists rather than by global warming scientists, there may be a bias toward lower damage estimates.
- Cline's estimates of damage expressed as a GDP percentage are based on a relatively low value of human life and a disregard for the ecological economic value of goods and services produced by habitats. More up-to-date values increase previously monetized damages substantially.

Table 7.9 presents the shadow prices for selected sets of assumptions in Bein and Rintoul (1996a). The "average shadow price" is calculated over the 500-year period, while the "peak shadow price" is the maximum value within that period. The average price is 60-70% of the peak price.

Table 7.9. Average/peak shadow price for global warming ($C per tonne of carbon equivalent) [a]

Base Damage	Λ=2.5 γ=1.2	Λ=2.5 γ=2	Λ=2.5 γ=3.2	Λ=3.5 γ=1.2	Λ=3.5 γ=2	Λ=3.5 γ=3.2	Λ=4.5 γ=1.2	Λ=4.5 γ=2	Λ=4.5 γ=3.2
SRTP=2%									
Low	3/5	4/7	11/17	5/8	9/14	32/51	6/11	14/23	72/114
Medium	6/11	9/15	23/36	10/17	18/29	67/107	13/22	30/48	150/238
High	12/21	17/28	43/69	18/31	34/54	127/202	25/42	56/90	284/452
SRTP=1.5%									
Low	6/9	10/14	29/47	8/13	19/28	86/137	11/17	31/46	193/305
Medium	12/18	20/30	62/97	18/27	39/58	181/286	24/36	65/97	404/639
High	22/33	38/57	117/185	33/50	74/111	343/543	45/68	123/183	767/1215
SRTP=1.0%									
Low	12/17	25/36	94/163	18/25	48/71	277/478	25/34	80/118	619/1068
Medium	25/35	52/76	198/342	38/53	101/149	580/1002	51/97	167/318	1296/2240
High	48/67	98/145	376/650	72/100	192/284	1103/1908	97/135	318/469	2464/4264

Notes:
a. The values can be converted into 2002 $C by dividing 0.919.
X/Y means: X = average price over analysis horizon; Y = peak price in analysis horizon.
SRTP: Social Rate of Time Preference
Λ: climate sensitivity, which denotes warming associated with CO_2 doubling
γ: damage function exponent
Damage at CO_2 doubling in terms of world GDP:
Low: 1.4% developed countries; 1.8% developing countries.
Medium: 2.5% developed countries; 4.0% developing countries.
High: 4.0% developed countries; 8.0% developing countries.
Source: Bein and Rintoul (1996a).

The shadow prices depend strongly on the SRTP. As SRTP increases from 1.5% by 0.5% to 2.0%, the shadow price reduces two to four times. A reduction of the SRTP to 1.0% increases the shadow price two to four times. A high damage-function exponent affects the shadow price strongly, while the degree of warming due to CO_2 doubling (the climate sensitivity parameter) has a weaker effect by comparison. The Bein and Rintoul study selects a shadow price of $1,000 ($1,088 at 2002 $C) per tonne of carbon equivalent, favoring the peak price value over the average price and adopting a high value of damage function exponent as a precautionary approach. The chosen value corresponds to high-damage with high-climate-sensitivity scenario at SRTP equal to1.5%. At SRTP equal to 1%, the chosen value corresponds to low to medium-damage with medium to high-climate-sensitivity.

It is evident that the choice of the shadow price must depend ultimately on assessments of what input values are reasonable, and on value judgments concerning how assertive the policy maker should be in establishing decision incentives.

7.4.8 Cost estimates of stratospheric ozone depletion

Bein and Rintoul (1996b) use a method similar to that employed in their shadow pricing of greenhouse gases to estimate the costs associated with stratospheric ozone depletion. The shadow price is calculated as the ratio of present value of future damages to the cumulative emissions over the analysis horizon. Discounting future damage costs to present values is based on considering the effects on future generations (intergenerational effects) and using an SRTP in the range 0% to 5%. The higher end of the range overlaps with the discount rate based on the opportunity cost of capital, which is commonly used in cost benefit analysis of public projects.

A range of emission scenarios are considered. Under the Optimistic Scenario, emission of ozone depleting substances (ODS) peak in 1995 and then drop to nil by year 2000. This scenario is purely hypothetical. The strictest reductions in ODS emissions negotiated so far under the Montreal Protocol will produce a scenario worse than the Optimistic Scenario. It is apparent that the emission reduction targets currently set may not be achieved. At the other extreme (the Pessimistic Scenario), ODS emissions continue for 50 years at the 1995 level and drop to nil by 2050. The actual scenario is likely to fall between these assumed limits.

The benchmark damage was assumed to be 1.0% of global GDP in 1995. For other values of damage, the results can be scaled by proportion. The atmospheric life cycle of ODSs is assumed to be 100 years, based on a weighted average of 10 species of ODS lifespan ranging from 6 to 550 years.

The analysis is run over a range of SRTP, while ODS emission levels range from the Optimistic to the Pessimistic Scenarios. Table 7.10 summarizes the shadow prices for the range of assumptions. The shadow price is less sensitive to the SRTP in this case than in the case of global warming, probably because of the shorter horizon over which ODSs are assumed to inflict damage, compared with greenhouse gases. Within each SRTP, the results are only moderately sensitive to the scenario chosen.

Table 7.10. Shadow prices of ozone depletion, assuming 1% GDP damage in 1995 (US$ per kg of CFC-equivalent)

	Number of Years ODS Production Continues at 1995 Level					
Discount Rate	0	10	20	30	40	50
0%	978	1,062	1,159	1,268	1,388	1,517
1%	736	766	798	828	858	886
2%	595	597	596	593	588	581
3%	512	497	480	462	443	423
4%	467	441	413	387	362	338
5%	447	411	377	346	318	292

Notes: a. The values can be converted into 2002 $C by dividing 0.74.
Source: Bein and Rintoul (1996b).

Based on the results, a preliminary shadow price of about US$600 (C$800) per kg of CFC-11 equivalent is selected. This value assumes SRTP of 2%. The value corresponds to damage of the order of 1% of global GDP. For damage amounting to 4% of world GDP in 1995, the shadow price would be about US$3,200 per kg of CFC-11 equivalent. For the proponents of discounting based on the opportunity cost of capital, the shadow price value is about US$400 (C$500) per kg of CFC-11 equivalent.

The attribution of these CFC damage costs to a unit of transportation in a project appraisal requires estimation of the mass of ODS per vehicle from both vehicle manufacture and vehicle air conditioners, including recharging. The total mass of ODS in the vehicle fleet at any future time depends strongly on the effectiveness of new regulations governing the automotive industry and ODS disposal and recycling. Per-kilometer unit costs must assume the quantity of ODS consumed by transportation activities, and then spread out the consumption over annual vehicle kilometers and vehicle life.

This is straightforward for the existing situation, that is, the base case in social cost benefit analysis. Changes to the quantities of ODS used by transportation and changes to future vehicle utilization are more difficult to predict, but the unit costs would depend strongly on the assumptions. Possible changes in travel behavior, with less distance driven as a result, would increase the ODS contribution per kilometer. The total emissions depend on distance driven only to the extent that driving vibrations contribute to leakage and to the need to replenish CFC. Even if left in a garage and never driven, a vehicle is a contributor to the ozone-depletion problem if it contains CFC and if ODS are used to make the vehicle and its parts.

7.4.9 Tol (2000) and FUND 1.6

Tol (2000) provides a set of marginal costs of GHG emissions, based on version 1.6 of the Climate Framework for Uncertainty, Negotiation and Distribution (FUND). FUND is a model that closes the loop of:

> population – economy – technology – GHG emissions – atmospheric composition – climate – climate change impacts – emission abatement

It is a simulation model consisting of a set of exogenous scenarios and endogenous perturbations, specified for nine major world-regions. Using simple representations of the components above, the model runs in time steps of one year from 1950 to 2200. The nine major world regions it covers are OECD-America, OECD-Europe, OECD-Pacific, Central and Eastern Europe and the former Soviet Union, Middle East, Latin America, South and South-East Asia, Centrally Planned Asia, and Africa. Scenarios for the period 1950-1990 are based on historical observation, namely the IMAGE 100-year database (Batjes and Goldewijk, 1994). The period 1990-2100 is based on the IS92a scenario, with

IS92d and IS92f as alternatives (Leggett et al., 1992). The period 2100-2200 is based on extrapolation of the population, economic and technological trends in 2050-2100, that is, a gradual shift to a steady state of population, economy and technology. The model and scenarios are so far extrapolated that the results for the period 2100-2200 are not be relied upon.

The endogenous parts of FUND consists of the atmospheric concentrations of carbon dioxide, methane and nitrous oxide, the global mean temperature, and the impact of climate change on coastal zones, agriculture, extreme weather, natural ecosystems and malaria.

I. Methane and nitrous dioxide are taken up in the atmosphere, and then geometrically depleted:

$$C_t = C_{t-1} + \alpha E_t - \beta\left(C_{t-1} - C_{pre}\right)$$

where C denotes concentration, E emissions, t year, and *pre* pre-industrial. The coefficients are chosen as follows:

Table 7.11. Parameters chosen in FUND 1.6

Gas	α [a]	β [b]	Pre-industrial concentration
Methane (CH_4)	0.3597	1/8.6	790 ppb
Nitrous oxide (N_2O)	0.2079	1/120	285 ppb

Notes:
a. The parameter α translates emissions (in million metric tonnes of CH_4 or N_2O) into concentrations (in parts per billion by volume).
b. The parameter determines how fast concentrations return to their pre-industrial (and assumedly equilibrium) concentration; $1/\beta$ is the atmospheric life-time (in years) of the gases.

II. The carbon cycle is a five-box model:

$$Box_{i,t} = \rho_i Box_{i,t-1} + 0.00047\alpha_i E_t$$

with $C_t = \sum_{i=1}^{5} \alpha_i Box_{i,t}$, where α_i denotes the fraction of emissions E (in million metric tonnes of carbon) that is allocated to box i (0.13, 0.20, 0.32, 0.25 and 0.10, respectively) and ρ the decay-rate of the boxes ($\rho = exp(-1/\text{lifetime})$), with average life-times of infinity, 363, 74, 17 and 2 years, respectively). Thus, 13% of total emissions remain forever in the atmosphere, while 10% has an average life-time of two years.

III. Radiative forcing factors for carbon dioxide, methane and nitrous oxide are based on Shine et al. (1990). The global mean temperature T is governed by geometric build-up to its equilibrium (determined by radiative forcing RF), with a life-time of 50 years. In the base case, global mean temperature rises in equilibrium by 2.5°C for a doubling of carbon dioxide equivalent, so

$$T_t = \left(1 - \frac{1}{50}\right) T_{t-1} + \frac{1}{50} \frac{2.5}{6.3 \ln 2} RF_t$$

IV. Global mean sea level is also geometric, with its equilibrium determined by the temperature and a life-time of 50 years. These life-times result from a calibration to the central estimates of temperature and sea level for the IS92a scenario. FUND also calculates hurricane activity, winter precipitation, and winter storm activity because these feed into the damage module.

V. The climate impact module is fully described in Tol (1996). Impacts include sea level rise, agriculture, heat stress, cold stress, malaria, tropical cyclones, extra-tropical storms, river floods, and unmanaged ecosystems. Each of these impacts is modeled separately. Damage is distinguished between tangible (market) and intangible (non-market) effects. Tangible damages affect investment and consumption; through investment, economic growth is affected; through consumption, welfare is affected. Intangible damages affect welfare. Relative vulnerability to climate change alters with economic development in many ways. The importance of agriculture falls with per capita income growth, and so does incidence of malaria and the inclination to migrate. Heat stress increases with urbanization. The valuation of impacts on non-market goods and services increases with per capita income. Impacts vary across regions, as do values. Impacts in one region are not valued in other regions. The one exception is the impact of climate change on ecosystems; regional monetary impacts are a function of global rather than regional changes in ecosystems.

Table 7.12 presents the marginal costs of climate change according to FUND 1.6, using a simple summation of the impacts across its nine regions. For a discount rate of 5%, the marginal costs of carbon dioxide emissions are comparable to those found in Table 7.7. Table 7.12 also presents marginal damage estimates for methane and nitrous oxide. Usually, GHG are converted from one to another using their global warming potentials (GWP). The GWP of a gas is defined as the time integral of radiative forcing per unit emission divided by the same integral for carbon dioxide. The global damage potential is defined similar to GWP, with radiative forcing replaced by impact and discounting introduced. In fact, the global damage potential is the ratio of the marginal damages. Table 7.13 displays global damage potentials as estimated with FUND 1.6 and as reported in the literature.

Table 7.12. Marginal damages for CO_2, CH_4 and N_2O emissions [a] (2002 $C values in brackets)

Discount Rate	0%	1%	3%	5%	10%
Carbon dioxide ($/tC)					

1995-2004	142 (217)	73 (112)	23 (35)	9 (14)	2 (3)
2005-2014	149 (229)	72 (110)	20 (31)	7 (11)	1 (2)
Methane (\$/tCH_4)					
1995-2004	147 (225)	141 (216)	89 (137)	52 (80)	16 (25)
2005-2014	264 (405)	186 (285)	87 (133)	41 (63)	8 (12)
Nitrous oxide (\$/t N_2O)					
1995-2004	15,468	7,559	2,201	817	140 (215)
2005-2014	(23,723)	(11,594)	(3,376)	(1,253)	71 (109)
	16,313	7,632	1,975	631 (968)	
	(25,020)	(11,706)	(3,029)		

Notes: a. Damages discounted to 1990; time horizon: 2100; model FUND 1.6; scenario: IS92a; simple sum; no higher order effects.
Source: Tol (2000).

Table 7.13. Global damage potential, impact per Tonne of CH_4 and N_2O relative to impact per tonne of CO_2

	FUND [a]	Kandlikar [b]	Fankhauser [c]	Hammitt [d]	GWP [e]
CH_4	14	12	20	11	25
N_2O	348	282	333	355	320

Notes:
a. Emissions between 1995 and 2004; time horizon: 2100; discount rate: 3%; model: FUND 1.6; scenario: IS92a; simple sum; no higher order effects.
b. Time horizon: 100 years; discount rate: 2%; scenario: IS92a; quadratic damages.
c. Emissions between 1991 and 2000; time horizon: 2100; GDP is calculated as ratio of mean marginal damages.
d. Emissions in 1995; time horizon: 2100; discount rate: 3%; scenario: IS92a; middle case.
e. Time horizon: 100 years.
Sources: Tol (2000), Kandlikar (1995, 1996), Fankhauser (1995), Hammitt et al. (1996), Schimel et al. (1996).

The estimates in Table 7.12 are based on different values in different regions of factors such as human mortality risks. This may be considered inequitable and may be inconsistent with the view of a global decision-maker (who would rather treat all equal, as regional decision-makers are assumed to do within their regions, and as national decision-makers commonly do within their countries). It is also inconsistent with basic welfare theory, since simply adding monetary values across disparate income levels assumes that utility is a linear function of monetary income. Following Fankhauser et al. (1997), equity-weights are used in aggregating regional impacts. Equity-weights express the relative importance of small changes in regional impacts in a hypothesized global welfare function. Regional welfare is the natural logarithm of per capita income – a mild form of risk aversion – and global welfare is the sum of regional welfare. Alternatively, global welfare may be interpreted as the product of regional welfare, a mild form of adversity to income inequality. The equity-weights are then the inverse of per capita income (relative to its global average), so

$$D_{world} = \sum_{regions} D_{region} \frac{Y_{world}}{Y_{region}}$$

where D denotes damage and Y per-capita income. Since per-unit values are generally assumed to be approximately linear in per-capita income, equity-weighted per-unit values are approximately the same for all regions, and equal to their global average. Table 7.14 shows the results of this for marginal damage of GHG emissions. Marginal impacts increase by a factor of slightly less than 3. This increase is solely due to the fact that, above, a "dollar to a rich man" is assumed equal to a "dollar to a poor man." With equity-weights, the welfare equivalents are compared, so that the "dollar to a poor man" counts more.

Table 7.14. Equity-weighted marginal damages for CO_2, CH_4 and N_2O emissions [a] (2002 $C values in brackets)

Discount Rate	0%	1%	3%	5%	10%
Carbon dioxide ($/tC)					
1995-2004	317 (486)	171 (262)	60 (92)	26 (40)	6 (9)
2005-2014	311 (477)	157 (241)	48 (74)	18 (28)	3 (5)
Methane ($/t$CH_4$)					
1995-2004	660	517 (793)	295 (452)	170 (261)	52 (80)
	(1,012)	556 (853)	252 (387)	120 (184)	24 (37)
2005-2014	831				
	(1,275)				
Nitrous oxides ($/t N_2O)					
1995-2004	32,735	16,862	5,459	2,217	434 (666)
	(50,207)	(25,862)	(8,373)	(3,400)	197 (302)
2005-2014	32,785	15,994	4,510	1,556	
	(50,284)	(24,531)	(6,917)	(2,387)	

Notes: a. Damages discounted to 1990; time horizon: 2100; model FUND 1.6; scenario: IS92a; equity-weighted; no higher order effects.
Source: Tol (2000).

Sensitivity Analysis

Table 7.15 presents Tol (2000)'s results of a sensitivity analysis around the equity-weighted marginal costs of emissions in the 1995-2004 decade discounted at 3% per annum. The discount rate is clearly the most important parameter. Postponing emissions by 10 years slightly reduces the marginal costs, primarily because they are discounted for 10 more years. However, the estimate for the 0% discount rate reveals that undiscounted marginal costs are also somewhat lower, because of a slower rate of climate change in the future and reduced vulnerability.

Table 7.15. Sensitivity analysis: Marginal damage of CO_2 emissions ($/tC) [a] (2002 $C values in brackets)

Case Discount Rate	0%	1%	3%	5%	10%
Base (Table 7.4.12)	317 (486)	171 (262)	60 (92)	26 (40)	6 (9)
Emissions in 2005-2014	311 (477)	157 (241)	48 (74)	18 (28)	3 (5)
Horizon: 2200	243 (373)	172 (264)	62 (95)	26 (40)	6 (9)
Simple sum (Table 7.4.10)	142 (218)	73 (112)	23 (35)	9 (14)	2 (3)
Higher order impacts	360 (552)	192 (294)	66 (101)	28 (43)	6 (9)
Climate sensitivity: 1.5°C	186 (285)	101 (155)	35 (54)	15 (23)	3 (5)
Climate sensitivity: 4.5°C	590 (905)	318 (488)	112 (172)	49 (75)	11 (17)
IS92f	348 (534)	187 (287)	65 (100)	28 (43)	6 (9)
IS92d	288 (442)	156 (239)	56 (86)	25 (38)	6 (9)

Notes: a. Damage discounted to 1990; emissions in 1995-2004; model: FUND 1.6; scenario: IS92a; time horizon: 2100; equity weighted; no higher order effects.
Source: Tol (2000).

Extending the horizon to 2200 makes little difference, except in the zero discount rate case. Equity weights matter a great deal as damage in poorer countries counts much more in the global total. Perturbing the climate sensitivity has an obvious and substantive influence on the marginal damages. If FUND runs with a higher (IS92f) or lower (IS92d) emission scenario, marginal costs are higher or lower. The effect is not large, partly because the difference in climate change only becomes substantial in the long run, and partly because IS92d leads to a more equitable income distribution than IS92a (so impact in developing countries is less – because of overall lower vulnerability – and counts less – because of lower equity weights) while IS92f has overall higher economic growth rates.

Uncertainty Analysis

Uncertainties abound in climate change. These are complicated by uncertainties about the scenarios (which expand through time) and about the mechanisms of the climate system

(Tol 2000). Uncertainty analysis is restricted to parametric uncertainty and tries to reflect the ranges found in the literature. Table 7.16 presents the results of a Monte Carlo analysis based on the uncertainty assumptions. The best guess (i.e., the marginal costs with all parameters set at their central estimate) is a conservative estimate of the marginal costs of CO_2. The mean estimate is higher than the best guess by some 35%, because uncertainties are asymmetric and relationships non-linear. The uncertainty about the marginal costs is also asymmetric (right-skewed) so that median and modal marginal costs are smaller than the mean. For smaller discount rates, the mode also lies above the best guess. Mode (the most likely value of the marginal costs) and best guess (the marginal costs if all parameters are set to their most likely value) deviate in a non-linear system. The uncertainty is large, as is revealed by the standard deviation and the confidence intervals. The coefficient of variation varies around 2 or 3. The upper bound of the 95% interval lies at more than 2.5 times the best guess, and more than 2 times the mean. The uncertainty is so large mainly because of the non-linearity in the system and the convoluted uncertainties.

Table 7.16. Characteristics of the uncertainty about marginal costs of carbon dioxide emissions (in $/tC) [a] (2002 $C values in brackets)

Discount rate	0%	1%	3%	5%	10%
Best guess	317 (486)	171 (262)	60 (92)	26 (40)	6 (9)
Mean	465 (713)	244 (374)	82 (126)	35 (54)	7 (11)
Median	405 (621)	210 (322)	70 (107)	29 (44)	6 (9)
Mode	340 (521)	190 (291)	54 (83)	22 (34)	5 (8)
Std. Deviation	267 (410)	143 (219)	51 (78)	22 (34)	5 (8)
1-percentile	106 (163)	54 (83)	17 (26)	7 (11)	1 (2)
5-percentile	158 (242)	81 (124)	26 (40)	11 (17)	2 (3)
95-percentile	962 (1,475)	512 (785)	178 (273)	77 (118)	17 (26)
99-percentile	1,390 (2,132)	744 (1,141)	259 (397)	114 (175)	26 (40)
Geometric mean	6.0 (9.2)	5.3 (8.1)	4.2 (6.4)	3.4 (5.2)	1.8 (2.8)
Geometric std.dev.	1.7 (2.6)	1.8 (2.8)	1.8 (2.8)	1.8 (2.8)	1.9 (2.9)

Notes: a. Damage discounted to 1990; emissions in 1995-2004; model: FUND 1.6; scenario: IS92a; time horizon: 2100; equity weighted; no higher order effects.
Source: Tol (2000).

7.4.10 Tol (2002a, b) and FUND 2.0

Tol (2002a, b) presents new estimates of the damage costs of emissions of carbon dioxide, methane and nitrous oxide, and discusses their sensitivities and uncertainties, based on version 2.0 of the Climate Framework for Uncertainty, Negotiation and Distribution (FUND).

The impact module of FUND 1.6 reflects the insights into the effects of climate change of the first half of the 1990's, as laid down in the Second Assessment Report of the IPCC (Pearce et al., 1996, Watson et al., 1996). These insights have substantially changed since then. Whereas earlier studies emphasized the negative impacts of climate change, later studies increasingly found positive aspects as well (Mendelsohn and Neumann, 1999), for example in energy consumption and agriculture. Other developments include the extension of studies to new sectors and new countries, better inclusion of adaptation, better integration of sectors, and the addition of more dynamics. These changes are reflected in the climate change impact module of FUND 2.0, which is a complete revision of the impact module of FUND 1.6. FUND 2.0 is described in Tol (2002a). There are some reasons why version 2.0 is placed alongside version 1.6, rather than replacing it. The revision of FUND 2.0 was so extensive that it is almost a completely different model; and, although FUND 1.6, reflecting earlier impact literature, may be too pessimistic about climate change, FUND 2.0, reflecting more recent literature, may be too optimistic.

Tol (2002a) provides climate change impact estimates for the following categories: agriculture, forestry, sea level rise, and human health. In each case, climate scenarios derive from General Circulation Models (GCMs). Table 7.17 summarizes the climate change impact estimates by aggregating the impacts on all the sectors. The estimates are the total annual impact of a 1°C increase in the global mean temperature, and a 0.2 meter sea level rise, changes that are expected to occur over the first half of the 21st century. In the OECD, Middle East and China, impacts are on balance positive. In other regions, impacts are on balance negative. In all cases, uncertainties are substantial, so that not even the sign of the impact can be known with reasonable confidence. Uncertainties as estimated here are really lower bounds of the 'true' uncertainty.

Table 7.17. Annual impact of a 1°C increase in the global mean temperature (Standard deviation in parenthesis)

Region	Billion US dollars	Percent of income
OECD-America	175 (107)	3.4 (2.1)
OECD-Europe	203 (118)	3.7 (2.2)
OECD-Pacific	32 (35)	1.0 (1.1)
Central and Eastern Europe and the former Soviet Union	57 (108)	2.0 (3.8)
Middle East	4 (8)	1.1 (2.2)
Latin America	-1 (5)	-0.1 (0.6)
South and Southeast Asia	-14 (9)	-1.7 (1.1)
Centrally Planned Asia	9 (22)	2.1 (5.0)
Africa	-17 (9)	-4.1 (2.2)

Source: Tol (2002a).

Table 7.18 displays the impact on the world as a whole. Simply aggregating estimated impacts across regions leads to a positive impact (i.e., a benefit) of about US$448 billion per year, equal to 2.3% of total world income. The standard deviation is a little less than half of that, at US$197 billion or 1.0% of income.

Table 7.18. Annual impact of a 1°C increase in the global mean temperature on the world: Three different rules of aggregation (Standard deviation in parenthesis)

	Billion US dollars	Percent of income
Simple sum	448 (197)	2.3 (1.0)
Average value	-522 (150)	-2.7 (0.8)
Equity-weighted sum	40 (257)	0.2 (1.3)

Source: Tol (2002a).

The interpretation of simple aggregation is not obvious. In fact, the estimate is a potential Pareto improvement, but compensation is unlikely. A global impact estimate is useful to a (non-existent) global decision maker, or a group of cooperating regional decision makers. In either case, the sum of regional estimates ignores the wide disparity between these regional estimates. Also, different monetary values are used for similar impacts, notably statistical life is valued differently.

One solution is to use globally averaged prices to value non-market goods and services. Table 7.18 displays the result of doing this. World impacts are estimated at a negative $522 billion, or 2.7% of income, with a standard deviation of $150 billion, or 0.8% of income. The sign switch is largely due to the impact of climate change on mortality. The reduction in mortality in OECD countries is smaller than the increase in mortality in developing countries. Using regionally differentiated values, the welfare gain in OECD countries is higher than the welfare loss in developing countries. This is not the case with globally averaged values, however. In addition, the standard deviation of the world impact decreases, as compared to that from the simple-sum aggregation, because the difference between regions is smaller when using globally averaged values.

Another solution is advocated by Fankhauser et al. (1997). When added, different regions' impact estimates should be given weights. These "equity weights" reflect the regions' risk aversion and the world inequality aversion. A mild version is to use the ratio of global to regional per capita income as equity weight. As can be seen from Table 7.18, world impact is again positive, at $40 billion or 0.2% of income. The standard deviation is substantially larger, at $257 billion or 1.3% of income. The difference compared to the simple summation is explained by the higher weight attached to the poorest regions, which are generally estimated to be negatively affected by climate. The increase in the standard deviation is due to the same reason, since impact estimates in developing countries rely more heavily on the extrapolation and are therefore more uncertain.

7.5 Some Policy Background Relevant to GHG Reductions

7.5.1 Developing an efficient policy for responding to climate change

How can nations cope with the potential effects of climate change? Table 7.19 lays out some of the options. The first option, taking preventive policies to slow or prevent greenhouse warming, has received the greatest public attention. Most policy discussion has focused on reducing energy consumption or switching to non-fossil fuels. A second option is to offset the climatic warming through climatic engineering. Among recent proposals are putting trace iron in the North Pacific and Antarctic oceans and shooting particulate matter into the stratosphere. One estimate finds that 100,000 kilograms of carbon can be offset by 1 kilogram of particles. Careful analysis of these proposals is only just beginning, but a number of cost-effective ones have already been identified.

Table7.19. Alternative responses to the threat of greenhouse warming

1. Slow or prevent greenhouse warming: reduce emissions and concentrations of greenhouse gases.
   - Reduce energy consumption.
   - Reduce GHG emissions per unit of energy consumption or GNP
     - Shift to low-CO_2 fuel
     - Divert CO_2 from entering atmosphere
     - Shift to substitutes for CFC
   - Remove greenhouse gases from atmosphere
     - Grow and pickle trees
2. Offset climatic effects
   - Climatic engineering
     - Shoot particles into the stratosphere
     - Fertilize the ocean with trace iron
3. Adapt to warmer climate
   - Decentralized/market adaptations
     - Movement of population and capital to new temperature zones
     - Corn belt migrates toward Canada and Siberia
   - Central/governmental policies
     - Build dikes to prevent ocean's invasion
     - Land-use regulations
     - Research on drought-tolerant crops

Source: Nordhaus (1991).

A final option is to adapt to the warmer climate. This could take place gradually on a decentralized basis through the automatic response of people, institutions, and markets as the climate warms and oceans rise. If particular areas become unproductive, labor and capital would migrate to more productive regions. If sea level rises, settlements would gradually retreat upland unless protected. In addition, governments could take steps to pre-empt possible harmful climatic impacts by land-use regulations or investing in research on living in a warmer climate.

Based on the model prediction, Nordhaus (1991) also provides estimates of an efficient policy for slowing greenhouse warming. In this analysis, he assumes a baseline in which there are no greenhouse policies in place. Table 7.20 tabulates the calculated costs and benefits. Column (1) shows the percentage reduction in GHGs from an uncontrolled level. Column (2) and (3) show, respectively, the marginal and total costs of GHG reductions estimated in the paper. The final column displays the estimated total discounted benefits associated with the given level of reduction of GHG emissions. For both costs and benefits, calculations used 1989 levels of world GHG emissions and world output.

Table 7.20. Calculation of costs and benefits for different levels of reduction of GHG emissions

(1) Reduction of GHG emissions (as % of base level)	(2) Marginal cost of reduction ($ per tC) [a]	(3) Total cost of reduction (billion $ / year) [a]	(4) Total benefit of reduction (billion $ / year) [a]
0	0.0	0.0	0.0
1	0.5	0.04	0.6
2	1.0	0.12	1.2
3	1.5	0.24	1.8
4	2.0	0.40	2.4
5	2.6	0.61	3.0
10	5.3	2.2	5.9
11[b]	8.0	2.9	6.5
15	16.3	6.8	8.9
20	28.0	16.3	11.9
25	40.2	30.7	14.8
30	53.3	49.5	17.8
40	89.9	108.0	23.7
50	120.0	191.0	29.6
60	171.0	309.0	35.6
75	285.0	581.0	44.4

Notes:
a. The values can be converted into 2002 $C by dividing 0.628.
b. Most efficient level of control of GHG emissions for medium damage level.
Source: Nordhaus (1991).

The efficient level of GHG reduction shown in Table 7.20 is for the middle level of damages and for a discount rate that is 1% above the growth rate (that is, $r\text{-}h=0.01$ per year). Equating the marginal damage with the marginal cost leads to an efficient level of control, shown with the superscript b in Table 7.20, of 11% of GHG emissions. At the efficient control level, the total cost of reducing emissions is around \$3 billion (\$4.78 billion at 2002 \$C) per year while the total benefit is estimated to be around \$6 billion (\$ 9.55 at 2002 \$C) per year.

7.5.2 International agreements on GHG reductions and climate changes

7.5.2.1 Montreal Protocol

Global cooperation for the protection of the stratospheric ozone layer began with the negotiation of the Vienna Convention for the Protection of the Ozone Layer, which concluded in 1985. The details of the international agreement were defined in the Montreal Protocol on Substances that Deplete the Ozone Layer. The Montreal Protocol was signed in September 1987 and became effective in 1989. It contains provisions for regular review of the adequacy of control measures that are based on assessments of evolving scientific, environmental, technical, and economic information.

At a meeting in London in 1990, the Parties to the Montreal Protocol agreed to a phase out of controlled substances. Another meeting of the Parties held in Copenhagen in 1992 accelerated the phase-out schedules of the controlled substances. Controlled substances include CFC, halons, carbon tetrachloride, methyl chloroform, HCFC, HBFC, and methyl bromide.

In addition to the Montreal Protocol, other bodies such as the U.S. Environmental Protection Agency and the European Community have imposed still more strict regulations and phase-out schedules.

Changes were made to the Montreal Protocol in Vienna in 1995. In developed countries, the phase out of CFC had been mandated for 1 January 1996 at the Copenhagen meeting (held in 1992). Halons had been required to be totally phased out by 1 January 1994, and carbon tetrachloride and methyl chloroform by 1 January 1996. The developing countries can continue to produce and purchase CFC and carbon tetrachloride for use until 2010 and methyl chloroform until 2015. Developed nations can continue to produce CFC up to 15% of their 1986 baseline to help developing countries meet their domestic needs and for essential uses such as medical devices.

The Copenhagen Amendments had called for a freeze of HCFC production in 1996 in developed countries to a baseline level calculated for each country using the formula: 3.1% of ODP weighted CFC consumption in 1989, plus 100% of ODP weighted HCFC consumption in 1989. The 3.1% cap was changed to 2.8% during the 1995 Vienna meeting. The basic phase-out schedule for HCFC in developed countries is as follows: 35% reduction in 2004, 65% reduction in 2010, 90% reduction in 2015, 99.5% reduction in 2020, and 100% phase-out in 2030. The final 0.5% is to be available only to service existing refrigeration and air conditioning equipment. Developing countries will freeze

HCFC consumption at 2015 levels (maximum) in 2016, and phase out completely by 2040.

7.5.2.2 Kyoto Protocol

The Kyoto Protocol is an international agreement that will commit industrialized countries to reduce emissions of the six greenhouse gases: carbon dioxide, methane, nitrous oxide, hydro fluorocarbons, perfluorocarbons, and sulfur dioxide, once the Protocol is ratified. Each of these gases has distinct properties, and the overall emissions reduction targets for the six gases are weighted by their global warming potential.

The agreement specifies that both developed and developing countries must follow a number of steps including: designing and implementing climate change mitigation and adaptation measures; preparing national inventories of emissions removals by "carbon sinks;" implementation and cooperation in development and transfer of climate friendly technologies; and partnerships in research and observation of climate science, impacts and response strategies. Developing countries are not legally bound to emissions reduction targets yet because, historically, they have been responsible for only a small portion of the GHG emissions.

Once adopted, the agreement will call for each country to remain within their assigned emissions quota over a five-year period, from 2008 to 2012, the first commitment period. Under the Kyoto Protocol, the overall emissions from industrialized countries would be reduced 5% below 1990 levels during this period, and negotiations on reduction commitments for subsequent periods must begin no later than 2005.

The target amounts for each country are listed as a percentage of their base-year emissions (1990 for most countries). Canada's target is to reduce its GHG emissions to 6% below 1990 levels by the period between 2008 and 2012. Most European countries have a target of 8%.

A provision in the agreement allows for a nation to meet its reduction quota by reducing emissions from power plants and automobiles; however, developed countries can also achieve their commitments by deducting the GHG emissions absorbed by carbon sinks (like forests) from their gross emissions in the commitment period. This provision includes emissions absorbed or emitted by certain land-use changes and forestry activities, such as reforestation.

After the Canadian signing the Kyoto agreement, the Transportation Table (composed of twenty-six representatives drawn from federal, provincial and municipal governments, transport sector private organizations, environmental groups and other stakeholders in Canada's transport system) submitted to Ministers of Transport and the National Climate Change Secretariat a Foundation Paper (Transportation Table 1998) and an Options Paper (Transportation Table 1999). The Options paper summarized the analysis undertaken, and presented options to reduce GHG emissions from the transportation sector. The paper analyzed the cost options for GHG reductions across the entire transportation sector in Canada or elsewhere. In 2002, the federal government published an action plan,[158] which, if fully implemented, would reduce carbon emissions from transportation by 100MT.

7.6 Estimating the Impacts and Prices of GHG Emissions from Transportation

Before we estimate the unit costs of GHG due to the emissions from different transportation modes, we need to estimate the emission factors (kg per passenger-km, per tonne-km, or per vehicle-km) for each transportation mode. In the literature a large range of emission factors has been reported. The high and low estimates given in Table 7.21 are taken from the literature referenced in the table. The precision of the figures quoted reflects the precisions with which the original studies quote their results.

Most of the studies that provide the "high-low" ranges of emission factors have focused on EU countries and, to a lesser extent, the US. However, substantial differences in emission rates might exist between Canada and those countries. This can arise from different technologies in Canada – e.g., the more stringent/earlier regulation of road vehicle emission control technology and fuels, but the inferior technology in urban transit and intercity rail – and differences in operating conditions, including lengths of haul, passenger occupancies/load factors, and operating speeds. As a consequence, the Canadian rates of petroleum fuel consumption, and therefore CO_2 emissions per passenger-km or per and tonne-km, are very different from Europe's, as was shown in the Options Paper (Transportation Table 1999). The Canadian ratios of emissions of the criteria air contaminants (CAC) to fuel use and CO_2 emissions are also different, owing to the differences in regulated controls and operating conditions.

This calls for estimates of emission factors for Canada. Although authoritative estimates are not easy to obtain, we obtain the Canadian figures for passenger transportation from the Options Paper (Transportation Table 1999), and the Canadian figures for freight transportation from Transport Canada. However, there is an issue of allocating ferry costs and emissions between passengers and freight. For estimating the emission factor for ferry passengers, the Transportation Table figures implicitly assign all emissions to passengers. We arbitrarily reduced the emission rate in half. This may be a high or low estimate. If ferry passengers all bring along a car, then the emission rates will be high per passenger-kilometre compared to other modes, in contrast to true passenger-only ferries. Similarly, we also reduced the emission rate for freight by ferry in half.

Reported in 1997, these figures may lie outside the "low-high" ranges reported in the literature. We consider these federal CO_2/GHG estimates are the best, as they are based on a more thorough compilation of national vehicle-km, passenger-km and tonne-km data than any other studies have done. The Canadian figures are reported in the last column of Table 7.21 and will be used to suggest our "best estimates" of full costs in the following Tables 7.22-7.23.

[158] http://www.climatechange.gc.ca/plan_for_canada/plan/chap_3_1.html.

Table 7.21. GHG emission factors

	Source	Low estimate	High estimate	Canadian figure
Interurban passenger transport (kg per passenger-km)				
Private vehicle [1]	Transportation Table (1999)	N/A	N/A	0.110
Aircraft	Transportation Table (1999), Levinson, et al (1998), OECD (1991)	0.150	0.465	0.150
Bus [1]	Transportation Table (1999)	N/A	N/A	0.026
Train	Transportation Table (1999), OECD (1991), Environment Canada	0.045	0.092	0.123
Ferry	Transportation Table (1999)	N/A	N/A	0.285[2]
Urban passenger transport (kg per passenger-km)				
Private vehicle [1]	Transportation Table (1999), Mayeres, et al (1996)	0.071	0.164	0.215
Urban Transit [1]	Transportation Table (1999), Mayeres, et al (1996)	0.091	0.091	0.077
Freight transport (kg per tonne-km)				
Truck	Transportation Table (1999), ECMT (1998), Schoemaker & Bouman (1991)	0.100	0.451	0.100
Rail	Transportation Table (1999), TTNCCP (1998), Schoemaker & Bouman (1991)	0.020	0.102	0.020
Marine	Transportation Table (1999), ECMT (1998), OECD (1991)	0.012	0.040	0.015[2]
Aircraft	ECMT (1998)	0.800	1.420	0.800[3]

Notes:

1. Assume, per vehicle, 2.15 passengers for interurban private vehicles, 1.4 passengers for urban private vehicles, 31 passengers for bus and 17 passengers for urban transit. This assumption on passenger occupancy rates is the same as the one in Chapter 6.
2. As noted in the text, we arbitrarily reduced the emission rate in Transportation Table in half to allocate emissions between freight and passenger operations.
3. Since the Canadian figure is not available, we used the lower end of the European figures in the literature, as we suspect these figures are too high for Canada, e.g., longer stage lengths in Canada..

To translate the emission factors into costs per passenger-km for passenger transport, or costs per tonne-km for freight transport, we use Tol (2000), which estimated the unit cost of emissions to be US$13/tC (in 1990 US$) during the period 2001-2010, by assuming a discount rate of 5% per year. Using the PPP adjustment, the unit cost then becomes $20/tC in 2002 $C. By multiplying the above figures by $20 we obtain our estimates of the unit costs of GHG emissions for Canada ("best estimates"), which are given in Table 7.22.

Table 7.22. Our estimates of unit costs of GHG emissions, in 2002 $C

	Best estimate
Interurban passenger transport (per passenger-km)	
Private vehicle	0.000599
Aircraft	0.000817
Bus	0.000142
Train	0.000670
Ferry	0.001553
Urban passenger transport (per passenger-km)	
Private vehicle	0.001172
Urban transit	0.000420
Freight transport (per tonne-km)	
Truck	0.000545
Rail	0.000109
Marine	0.000082
Aircraft	0.004360

We would consider the unit costs in Table 7.22 to be a marginal cost (as opposed to average cost) concept, in the sense that they are estimated at the current levels of environmental conditions, but this could be debated. Furthermore, as discussed above, reliable prediction of the effects of climate change is difficult, and there is a significantly high degree of uncertainties regarding, among other factors, the consequences of climate change, scenarios, and discount rates. As a result, we believe that the unit costs are highly uncertain in magnitude. Nonetheless, like the case of air pollution, the unit costs are thought to be increasing, at an unknown rate, in the volume of transportation output, i.e., total externality costs are rising at an increasing rate. If indeed these unit costs are the marginal costs which are rising, then we would overestimate the total costs if we multiply the marginal cost by total output. To obtain total externality costs, one must compute the area beneath a marginal cost curve or calculate an average externality cost associated with the observed level of output. While the relationship between average and marginal externality costs are well recognized for road congestion, this subtlety in estimating total costs of emissions is little discussed in the GHG emissions literature. We consider this as an important, but difficult, research area in the future.

It is also important to comment on whether the "total costs of emissions" identified in Table 7.22 are actually external costs. This question hinges on whether any of the current costs are borne by transport users as distinct from being borne by society as a whole. In principle, and for consistency with our earlier analysis of congestion costs, accidents, noise and air pollution, we could disentangle the climate change damage imposed by users on themselves, which they internalize, the damage imposed by users on other users, and the damage imposed on non-users. For GHG emissions, the fact that there are no direct effects of the emissions on human health or well-being may change the analysis, in that any climate changing effects of GHG emissions are borne by the world at large rather than borne by individual users. As a result, it may be reasonable to dismiss any consideration of internalized components, and to consider the costs identified as external costs.

"High-low" estimates based on different sets of emission factors

Finally, in Table 7.21 we have also given the "high-low" estimates of emission factors based on existing studies, most of which focused on EU countries. As indicated above, Canadian emission rates may differ in a substantial way from European emission rates, we have opted for Canadian figures and used them to derive our cost and damage estimates for Canada. Nonetheless, it is of some interest, e.g., for sensitivity analysis, to derive the corresponding cost estimates by using these high-low emission factors. The results are given in Table 7.23.

Table 7.23. High-low estimates of unit costs of GHG emissions based on non-Canadian emission factors, in 2002 $C

	Low estimate	High estimate
Interurban passenger transport (per passenger-km)		
Private vehicle	N/A	N/A
Aircraft	0.000817	0.002534
Bus	N/A	N/A
Train	0.000245	0.000501
Ferry	N/A	N/A
Urban passenger transport (per passenger-km)		
Private vehicle	0.000389	0.000895
Urban transit	0.000420	0.000420
Freight transport (per tonne-km)		
Truck	0.000545	0.002458
Rail	0.000109	0.000556
Marine	0.000065	0.000218
Aircraft	0.004360	0.007738

We again note that the ranges of high and low cost estimates in Table 7.23 are derived from the emission factors based mostly on EU countries and hence should not be regarded as the upper and lower bounds for the Canadian cost estimates which are based on Canadian emission rates.

Chapter 7 References

Arrow, K.J., W.R. Cline, K.G. Mäler, M. Munasinghe, R. Squitieri, and J.E. Stiglitz, (1996). "Discounting. In: Climatic Change 1995: Economic and Social Dimensions of Climate Change", in Second Assessment of the Intergovernmental Panel on Climate Change [Bruce, J.P., H. Lee, and E.F. Haites (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 129-144.

Ayres, R.U. and Walter, J. (1991). "The Greenhouse Effect: Damages, Costs and Abatement." Environmental and Resource Economics 1: 237-70.

Barnola, J.M. et al. (1987). "Vostok Ice Core Provides 160,000-year Record of Atmospheric CO_2." Journal of Geophysical Research 92, 14722-80.

Bateman, I. and K. Willis (eds.), (1995). "Valuing Environmental Preferences: Theory and Practice of the Contingent Valuation Method." Oxford University Press, Oxford, United Kingdom.

Batjes, J.J. and C.G.M. Goldewijk (1994). "The IMAGE 2 Hundred Year (1890-1990) Database of the Global Environment (HYDE)." 410100082, RIVM, Bilthoven.

Bein, P. (1997). "Monetization of Environmental Impacts of Roads." Ministry of Transportation and Highways. British Columbia, Canada.

Bein, P. and Rintoul D. (1996a). "Precautionary shadow price of greenhouse gases under Business-as-usual scenario." Economic Analysis Project Working Paper. Ministry of Transportation and Highways. British Columbia, Canada.

Bein, P. and Rintoul D. (1996b). "Shadow pricing stratospheric ozone depletion." Economic Analysis Project Working Paper. Ministry of Transportation and Highways. British Columbia, Canada.

Briguglio, L., (1995). "Small Island States and their Economic Vulnerabilities." World Development 23, 1615-32.

Brookshire D., Eubanks L. and Randall A. (1983) "Estimating Option Prices and Existence Values for Wildlife Resources." Land Economics 59.

Broome, J. (1992). "Counting the Cost of Global Warming." White Horse Press, Cambridge.

Brown, P.G. (1997). "Stewardship of Climate – An Editorial Comment." In Climatic Change, Vol. 37, 329-34.

Cameron T. and James M. (1987). "Efficient Estimation Methods of Close-ended Contingent Valuation Methods." Review of Economics and Statistics 64-2.

Casman, E.A., M.G. Morgan, and H. Dowlatabadi, (1999). "Mixed levels of uncertainty in complex policy models." Risk Analysis, 19(1), 33-42.

Clark, G.E., S.C. Moser, S.J. Ratick, K. Dow, W.B.. Meyer, S.Emani, W. Jin, J.X. Kasperson, R.E., Kasperson, and H.E. Schwarz (1998). "Assessing the Vulnerability of Coastal Communities to Extreme Storms: the Case of Revere MA, USA.." Mitigation and Adaptation Strategies for Global Change 3, 59-82.

Cline, W.R. (1992a). "The economics of global warming." Institute for International Economics, Washington DC, US.

Cline, W.R. (1992b). "Optimal Carbon Emissions over Time: Experiments with the Nordhaus DICE Model." Working paper.

Cline, W.R. (1993). "Modeling Economically Efficient Abatement of Greenhouse Gases." Working paper.

Cline, W.R. (1995). "Personal communication." Institute for International Economics. Washington DC. USA.

Cline, W.R. (1995a). "Pricing carbon dioxide pollution" Economic Analysis Project Working Paper, prepared for Planning Services Brach, Ministry of Transportation and Highway.

Conway, T.J., Tans, P., Waterman, L.S., Thoning, K.W., Masarie, K.A., and Gammon, R.H. (1988). "Atmospheric Carbon Dioxide Measurements in the Remore Global Troposphere, 1981-1984." Tellus 40, 81-115.

Costanza R., Farber S. and Maxwell, J. (1989). "Valuation and Management of Wetlands Ecosystems." Ecological Economics 1.

Cramer, W.P. and Leemans, R. (1991). "The IIASA Database for Mean Monthly Values of Temperature." RR-91-18, International Institute for Applied Systems Analysis, Laxenburg.

Cummings, R., D. Brookshire, and W. Schultze, (1986). "Valuing Environmental Goods: An Assessment of the Contingent Valuation Method." Rowman & Littlefield, Lanham, MD, USA.

Darwin, R., M. Marinos, J. Lewwandrowski, and A. Raneses, (1995). "World Agriculture and Climate Change – Economic Adaptations." Department of Energy, Economic Research Service Report 703, US Department of Agriculture, Washington, DC. USA.

Davis, R., (1963). "Recreational planning as an economic problem." Natural Resources Journal, 3, 239-249.

de Groot, R.S. (1992). "Functions of Nature: Evaluation of Nature in Environmental Planning, Management and Decision Making." Groningen, Wolters Noordhoff BV, Netherlands.

Dickinson, R.E. (1986). "The Climate System and Modeling of Future Climate", in B. Bolin, B.R. Doos, J. Jager, and R.A. Warrick (eds), *The Greenhouse Effect, Climate Change, and Ecosystems*, New York: John-Wiley, 207-70.

Downing, T.E., Greener, R.A. and Eyre, N. (1995). "The Economic Impacts of Climate Changes: Assessment of Fossil Fuel Cycles for the ExternE Project." Environment Change Unit. Oxford.

Downing, T.E., Eyre, N., Greener, R.A. and Blackwell, D. (1996). "Projected Costs of Climate Change for Two Reference Scenarios and Fossil Fuel Cycles." Environment Change Unit. Oxford.

Downing, T.E., T. Butterfield, S. Cohen, S. Huq, R. Moss, A. Rahman, Y. Sokona, and L. Stephen, (2001) "Climate Change Vulnerability: Toward a Framework for Understanding Adaptability to Climate Change Impacts." United Nations Environment Programme, Nairobi, Kenya, and Environmental Change Institute, Oxford University, Oxford, United Kingdom.

Duffield J. (1988). "The Net Economic Value of Elk Hunting in Montana." Report by the Montana Department of Fish, Wildlife and Parks, Helena, Montana.

Easterling, W.E., C. Polsky, D. Goodin, M. Mayfield, W.A. Muraco, and B. Yarnal (1998). "Changing Places, Changing Emissions: the Cross-scale Reliability of Greenhouse Gas Emissions Inventories in the US." Local Environment 3(3), 247-62.

ECMT (European Conference of Ministers of Transport), "Efficient Transport for Europe, Policies for Internalization of External Costs", OECD publication Service, Paris, 1998.

Environment Canada, (2001), "Canada's Third National Report on Climate Change." Ottawa, Ontario.

Environment Canada, (2003), "Canada's Greenhouse Gas Inventory 1990-2001." Ottawa, Ontario.

Eyre, N., Downing, T.E., Hoekstra, R. and Rennings, K. (1997). "Global Warming Damages." ExternE, Brussels.

Eyre, N., Downing, T.E., Hoekstra, R. Rennings, K. and Tol, R.S.J. (1998). "Global Warming Damages." Contract JOS3-CT95-0002, ExternE Program of European Commission.

Fankhauser, S., (1995). "Valuing Climate Change – The Economics of the Greenhouse." London: EarthScan.

Fankhauser, S., Tol, R.S.J. and Pearce, D.W. (1997). "The Aggregation of Climate Change Damages: A Welfare Theoretical Approach." Environmental and Resource Economics, 10, 249-66.

Farber, S. (1995). "The economic welfare loss of projected Louisiana wetlands disintegration." Graduate School of Public and International Affairs, University of Pittsburgh.

Goulder, L. and S.H. Schneider, (1999). "Induced technological change and the attractiveness of CO2 abatement policies." Resource and Energy Economics, 21, 211-253.

Hammitt, J.K., Lempert, R.J. and Schlesinger, M.E. (1992). "A Sequential-Decision Strategy for Abating Climate Change." Nature 357, 315-8.

Hammitt, J.K., A.K. Jain, J.L. Adams, and D.J. Wuebbles (1996). "A Welfare-Based Index for Assessing Environmental Effects of Greenhouse-gas Emissions." Nature 381, 301-3.

Hanley, N.J. and C. Spash, (1993). "Cost-Benefit Analysis and the Environment." Edward Elgar, Aldershot, The Netherlands.

Hanley, N.J., J.F. Shogren, and B. White, (1997). "Environmental Economics in Theory and Practice." Oxford University Press, Oxford, United Kingdom.

Hansen, J., and Lebedeff S. (1987), "Global Trends of Measured Surface Air Temperature." Journal of Geophysical Research, 92, 13345-72.

Hansen, J., and Lebedeff S. (1988), "Global Surface Air Temperature: Update through 1987." Geophysical Research Letters, 15, 323-6.

Hoen H.F. and G. Winther (1993) "Multiple Use Forestry and Preservation of Coniferous Forests in Norway: A Study of Attitudes and Willingness to Pay." Scandinavian Journal of Forestry 8.

Huq, S., Z. Karim, M. Asaduzaman, and F. Mahtab (eds.) (1999). "Vulnerability and Adaptation to Climate Change in Bangladesh." J. Kluwer Academic Publishers, Dordrecht, the Netherlands.

IPCC, (1996). "Climate Change 1995: Economic and Social Dimensions of Climate Change." Cambridge, UK: Cambridge University Press.

IPCC, (2000). "Emission Scenario." Cambridge, UK: Cambridge University Press.

IPCC, (2001a), "Climate Change 2001: The Scientific Basis." Cambridge, UK: Cambridge University Press.

IPCC, (2001b), "Climate Change 2001: Impacts, Adaptation and Vulnerability." Cambridge, UK: Cambridge University Press.

IPCC, (2001c), "Climate Change 2001: Mitigation." Cambridge, UK: Cambridge University Press.

IPCC, (2001d), "Climate Change 2001: Synthesis Report." Cambridge, UK: Cambridge University Press.

Kaly, U., L. Briguglio, H. McLeod, S. Schmall, C. Pratt, and R. Pal, (1999). "Environmental Vulnerability Index to Summarize National Environmental Vulnerability Profiles." SOPAC Technical Report 275, South Pacific Applied Geoscience Commission, Suva, Fiji.

Kandlikar M. (1995). "The Relative Role of Trace Gas Emissions in Greenhouse Abatement Policies." Energy Policy 23-10, 879-83.

Kandlikar M. (1996). "Indices for Comparing Greenhouse Gas Emissions: Integrating Science and Economics." Energy Economics 18, 265-81.

Kattenberg, A., F. Giorgi, H. Grassl, G.A. Meehl, J.F.B. Mitchell, R.J. Stouffer, T. Tokioka, A.J. Weaver, and T.M.L. Wigley (1996). "Climate Models – Projections of Future Climate", in J.T. Houghton, L.G. Meiro Filho, B.A. Callander, N. Harris, A. Kattenberg, and K. Maskell, (eds.) Climate Change 1995: The Science of Climate Change – Contribution of Working Group I to the Second Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge. Cambridge University Press.

Kattenberg, A., Giorgi, F., Grassl, H., Meehl, G.A., Mitchell, J.F.B., Stouffer, R.J., Tokioka, T., Weaver, A.J. and Wigley, T.M.L. (1996). "Climate Models – Projections of Future Climate." In Climate Change 1995: The Science of Climate Change – Contribution of Working Group I to the Second Assessment Report of the Intergovernmental Panel on Climate Change (eds, Houghton, J., Filho, L.G.M., Callander, B.A., Harris, N., Kattenberg, A. and Maskell, K.) Cambridge University Press, Cambridge, pp. 285-357.

Keeling, C. D., Bacastow, R. B., Bainbridge, A.E., Ekdahl, Jr., C.A., Guenther, P.R., Waterman, L.S., and Chin, J.F.S. (1976). “Atmospheric Carbon Dioxide Variations at Mauna Loa Observatory, Hawaii.” Tellus 28, 538-51.

Komhyr, W.D., Gammon, R.H., Harris, T.B., Waterman, L.S., Conway, T.J., Taylor, W.R., and Thoning, K.W. (1985). “Global Atmospheric CO_2 Distribution and Variations from 1968 to 1982 NOAA/CMCC CO_2 Flask Sample Data.” Journal of Geophysical Research 90, 5567-96.

Koopmans, T.C. (1967). “Objectives, Constraints, and Outcomes in Optimal Growth Models.” Econometrica 35, 1-15.

Lancaster, K., (1966). “A new approach to consumer theory.” Journal of Political Economy, 74, 132-157.

Leggett, J., W.J. Pepper, and R.J. Swart (1992). “Emissions Scenarios for the IPCC: An Update.” In J.T. Houghton, B.A. Callander and S.K. Varney, (eds.) *Climate Change 1992 – The Supplementary Report to the IPCC Scientific Assessment.* Cambridge. Cambridge University Press.

Levinson, David M., David Gillen, and Adib Kanafani (1998). “The Social Cost of Intercity Transportation: a Review and Comparison of Air and Highway.” Transport Reviews 18 (3), 215-240.

Maddison, D.J. (1995). “A Cost-Benefit Analysis of Slowing Climate Change.” Energy Policy 23(4/5), 337-46.

Manne, A.S. and R. Richels, (1992). “Buying Greenhouse Insurance: The Economic Costs of CO_2 Emissions Limits.” MIT Press, Cambridge, MA, USA.

Manne, A.S., Mendelsohun, R. and Richels, R.G. (1995). “MERGE – A Model for Evaluating Regional and Global Effects of GHG Reduction Policies.” Energy Policy 23(1), 17-34.

Mayeres, Inge, Sara Ochelen and Stef Proost (1996). “The Marginal External Costs of Urban Transport.” Transportation Research (Part D) 2, 111-130.

Miller, J.R. (1984). “The Value of Fish and Wildlife-associated Recreation Days in the Mississippi Bottomland Hardwoods Area.” University of Utah, prepared for the US Fish and Wildlife Service, Washington DC, USA.

Myers, N. (1988). “Tropical Forest: Much More Than Stocks of Wood.” Journal of Tropical Ecology 4.

Mearns L.O., T. Mavromatis, E. Tsvetsinskaya, C. Hays, and W. Easterling, (1999). "Comparative Responses of EPIC and CERES Crop Models to High and Low Spatial Resolution Climate Change Scenarios." Journal of Geophysical Research – Atmospheres, 104(D6), 6623-46.

Mendelsohn, R.O., and Neumann, J.E. (eds) (1999). "The Impact of Climate Change on the United States Economy." Cambridge University Press, Cambridge.

Mendelsohn, R., A. Andronova, W. Morrison, and M. Schlesinger, (2000). "Country-specific market impacts of climate change." Climatic Change, 45, 553-569.

Mitchell, R., and R. Carson, (1989). "Using surveys to value public goods: The contingent valuation method." Resources for the Future, Washington DC. US.

Moore, M.A., Boardman, A.E., Vining, A.R., Weimer, D.L., and Greenberg, D.H., (2004), "'Just Give Me a Number!' Practical Values for the Social Discount Rate." Working paper. Sauder School of Business, The University of British Columbia.

Morgan, M.G., (1998). "Uncertainty analysis in risk assessment." Human and Ecological Risk Assessment, 4(1), 25-39.

Nordhaus, W.D. (1991). "To Slow or Not to Slow: The Economics of the Greenhouse Effect." Economic Journal 101, 920-37.

Nordhaus, W.D., (1994a) "Expert opinion on climatic change." American Scientist, 82, 45-52.

Nordhaus, W.D. (1994b) "Managing the Global Commons: The Economics of Climate Change." The MIT Press, Cambridge.

Nordhaus, W.D. (1994). "Managing the Global Commons: The Economics of Climate Change." Cambridge, MA. The MIT Press.

Nordhaus, W.D. and Yang, Z. (1996). "RICE: A Regional Dynamic General Equilibrium Model of Optimal Climate-change Policy." American Economic Review 86(4): 741-65.

Noss, R.F. (1990). "Indicators for monitoring biodiversity: A hierarchical approach." Conservation Biology 4.

Neftel, A., Moor, E., Oeschger, H., and Stauffer, B. (1985). "Evidence from Polar Ice Cores for the Increase in Atmospheric CO_2 in the Past Two Centuries." Nature 315, 45-47.

OECD, Environmental Policy: How to Apply Economic Instruments, 1991

OECD (Organization for Economic Co-operation and Development), "The Environmental Effects of Freight ", OECD, Paris, 1997a. Available at: http://www1.oecd.org/ech/pub/TRANSP4.PDF

Parikh, J.K. and K.S. Parikh, (1998). "Accounting and Valuation of Environment: Vol. II, Case Studies from the ESCAP Region." Economic and Social Commission for Asia and the Pacific Region, United Nations, New York, NY, USA.

Parry, M. and T. Carter, (1998). "Climate Impact and Adaptation Assessment." Earthscan Publications, London, UK.

Pearce, D.W., (1993). "Economic values and the natural world." Earthscan. London.

Pearce, D.W., Cline, W.R., Achanta, A.N., Fankhauser, S., Pachauri, R.K., Tol, R.S.J. and Vellinga, P. (1996). "The Social Costs of Climate Change: Greenhouse Damage and the Benefits of Control." In *Climate Change 1995: Economic and Social Dimensions – Contribution of Working Group III to the Second Assessment Report of the Intergovernmental Panel of Climate Change* (Eds, Bruce, J.P., Lee, H. and Haites, E.F.) Cambridge University Press, Cambridge. 179-224.

Peck, S.C. and Teisberg, T.J. (1991). "CETA: A Model for Carbon Emissions Trajectory Assessment." The Energy Journal 13(1), 55-77.

Peck, S.C. and Teisberg, T.J. (1994). "Optimal Carbon Emissions Trajectories When Damages Depend of the Rate or Level of Global Warming." Climatic Change 28, 289-314.

Ramanathan, V., Cicerone, R.J. Singh, H.B., and Kiehl, J.T. (1985). "Trace Gas Trends and Their Potential Role in Climate Change." Journal of Geophysical Research 90, 5547-66.

Ramsey, F. (1928) "A Mathematical Theory of Saving." Economic Journal 38, 543-9.

Raphaeal C. and Jaworski E. (1977) "Economic Value of Fish, Wildlife, and Recreation in Michigan's Coastal Wetlands." Coastal Zone Management Journal 5-3.

Root, T.L. and Schineider, S.H. (1995). "Ecology and Climate: Research Strategies and Implications." Science 269, 331-41.

Rosen, S., (1974) "Hedonistic prices and implicit markets: product differentiation in pure competition." Journal of Political Economy, 82, 34-55.

Schimel, D., Alves, D., Enting, I., Heimann, M., Joos, F., Raynaud, M., Derwent, R., Ehhalt, D., Fraser, P., Sanhueza, E., Zhou, X., Jonas, P., Charlson, R., Rodhe, H., Sadasivan, S., Shine, K., Fouquart, Y., Ramaswamy, V., Solomon, S., Srinivasan, J., Albritton, D., Isaksen, I., Lal, M. and Wuebbles, D.J. (1996). "Radiative Forcing of Climate Change." In Climate Change 1995: The Science of Climate Change – Contribution of Working Group I to the Second Assessment Report of the Intergovernmental Panel on Climate Change (eds, Houghton, J., Filho, L.G.M., Callander, B.A., Harris, N., Kattenberg, A. and Maskell, K.) Cambridge University Press, Cambridge, pp. 65-131.

Schoemaker, T., and Bouman, P., "Facts and Figures on Environmental Effects of Freight Transport in the Netherlands", 1991, cited in OECD 1997a.

Shine, K.P., R.G. Derwent, D.J. Wuebbles, and J.J. Morcrette (1990). "Radiative Forcing of Climate." In J.T. Houghton, G.J. Jenkins, and J.J. Ephraums, (eds) *Climate Change – The IPCC Scientific Assessment*. Cambridge. Cambridge University Press.

Schneider, S.H., B.L. Turner, and H. Morehouse Garriga, (1998). "Imaginable surprise in global change science." Journal of Risk Research, 1(2), 165-185.

Schneider, S.H., K. Kuntz-Duriseti, and C. Azar, (2000). "Costing non-linearities, surprises, and irreversible events." Pacific and Asian Journal of Energy, 10(1), 81-106.

Shine, K.P., Derwent, R.G., Wuebbles, D.J. and Morcrette, J.J. (1990) "Radiative Forcing of Climate." In Climate Change – The IPCC Scientific Assessment (eds, Houghton, J., Jenkins, G.J. and Ephraums, J.J.) Cambridge University Press, Cambridge, pp. 41-68.

Smith, V.K., (2000). "JEEM and non-market valuation." Journal of Environmental Economics and Management, 39, 351-374.

Titus, JG., R.A. Park, S.P. Leatherman, J.R. Weggel, M.S. Greene, P.W. Mausel, S. Brwon, C. Gaunt, M. Trehan, and G. Yohe, (1991). "Greenhouse effect and sea level rise: The cost of holding back the sea." Coastal Zone Management 19, 172-204.

Tol, R.S.J., (1995). "The Damage Costs of Climate Change Toward More Comprehensive Calculations." Environmental and Resource Economics 5, 353-74.

Tol, R.S.J., (1996). "The Damage Costs of Climate Change Toward a Dynamic Representation." Ecological Economics 19, 67-90.

Tol, R.S.J., (1997). "On the Optimal Control of Carbon Dioxide Emissions – An Application of FUND." Environmental Modeling and Assessment 2, 151-63.

Tol, R.S.J., (1999). "The Marginal Costs of Greenhouse Gas Emissions." The Energy Journal 20, 61-81.

Tol, R.S.J., (2002a). "Estimates of the Damage Costs of Climate Change, Part I: Benchmark Estimates." Environmental and Resource Economics 21, 47-73.

Tol, R.S.J., (2002b). "Estimates of the Damage Costs of Climate Change, Part II: Dynamic Estimates." Environmental and Resource Economics 21, 135-160.

Tol, R.S.J., and Downing, T.E. (2000). "The Marginal Costs of Climate Changing Emissions." Institute for Environmental Studies, Vrije Universiteit, Amsterdam.

Transportation Table, National Climate Change Process, "Foundation Paper on Climate Change – Transportation Sector", December, 1998.

Transportation Table, National Climate Change Process, "Transportation and Climate Change: Options for Action", November, 1999.

TTNCCP (Transportation Table National Climate Change Process), "Foundation Paper on Climate Change", Transportation Sector, Ottawa, ON, 1988. Available at: http://www.wlu.ca/~wwwsbe/faculty/dgillen/UBC_social_cost/Studies/trans.pdf.pdf

Viner, D. and Hulme, M. (1994). "The Climate Impacts LINK Project – Providing Climate Change Scenarios for Impacts Assessment in the UK." University of East Anglia.

Walsh R., Greenley D., Young R., Mckean J. and Prato A. (1978). "Option Values, Preservation Values and Recreational Benefits of Improved Water Quality: A Case Study of the South Platte River Basin." Colorado EPA Report 600/5-78-001, Environmental Protection Agency, Washington DC, USA.

Walsh R., Loomis J. and Gillman R. (1984). "Valuing Option, Existence and Bequest Values for Wilderness." Land Economics 60-1.

Watsons, R.T., Zinyowera, M.C., and Moss, R.H. (eds) (1996). "Climate Change 1995: Impacts, Adaptation, and Mitigation of Climate Change – Scientific-Technical Analysis – Contribution of Working Group II to the Second Assessment Report of the Intergovernmental Panel on Climate Change." Cambridge University Press, Cambridge.

Weitzman, M.L., (1998). “Why the far distant future should be discounted at its lowest possible rate.” Journal of Environmental Economics and Management, 36, 201-208.

Wigley, T.M.L., Hulme, M. and Raper, S.C. B. (1993). “MAGICC: Model for the Assessment of Greenhouse Induced Climate Change.” University Consortium for Atmospheric Research, Boulder.

Annex 1.1 Transportation and Environment Projects in European and US

AREA	PROJECT PERIOD	RELEASED TIME	PROJECT/REPORT	• OBJECTIVES/MAIN RESULTS	LEAD RESEARCH INSTITUTION	PROJECT WEBSITE
Air Pollution	N/A	4/2004	Study on Air Pollutants in Cars	• Associations between tiny particles in the air inside automobiles and cardiovascular health • PM2.5 is associated with illness and premature death	EPA (US)	http://www.epa.gov/nheerl/copp/
Air Pollution	N/A	2004	Emissions Modeling in Transportation Planning: Institutional and Policy Processes	N/A	The New England University Transportation Center (US)	Contact Dr. Joseph F. Coughlin; Coughlin@mit.edu.
Air Pollution	0/2000-02/2004	N/A	ICLEAC Instability Control in Low Emission Aero-engine Combustors	N/A	Turbomeca (France)	https://www.iwr.uni-heidelberg.de/ICLEAC/
Air Pollution	01/2001-01/2004	N/A	FLYKLIM Aircraft induced change of high clouds and its impact on the regional climate in Sweden	N/A	Regional Climate research Group at Gothenburg University (Sweden)	http://www.gvc.gu.se/ngeo/rcg/flyklim/index2_flyklim.html
Air Pollution	01/2001-01/2004	N/A	INCA Inter-hemispheric differences in cirrus properties From anthropogenic emissions	N/A	OP DLR (Germany)	N/A
Air Pollution	02/2000-07/2003	N/A	CFD4C Computational Fluid Dynamics FOR Combustion	N/A	MTU (Germany)	https://www.iwr.uni-heidelberg.de/CFD4C/intro.html
Air Pollution	N/A	06/2003	" Economic Valuation of Health Effects due to Airborne Pollutants in ExternE"	• Main methodological principles for monetary valuation of health effects due to air pollution applied in the ExternE projects • Presenting and discussing the approach for estimating the value of a life year lost and valuing morbidity risks	University of Stuttgart (Germany)	http://www.fhi.se/pdf/bickel.pdf
Air Pollution	N/A	06/2003	"Health Costs of Transport Air Pollution in Urban Areas in Sweden"	• With Impact pathway approach, it is found that particles imposes the highest cost and is due to chronic mortality and morbidity. • Comparing average cost for all Swedish urban areas, it is found that the variation in cost is explained by population density and meteorology	VTI/ Swedish National Road and Transport Research Institute, (Sweden)	http://www.fhi.se/pdf/nerhagen.pdf
Air Pollution & Transport Safety and Risk	N/A	06/2003	"Workshop on Economic Valuation of Health Effects due to Transport"	• Air pollution, noise, physical activity, psychological and social effects, road safety and climate change	Jointly by Austria, France, Malta, The Netherlands, Sweden and Switzerland in cooperation with UNECE and WHO	http://www.fhi.se/pdf/program_transport.pdf
Air	N/A	06/2003	"Economic Evaluation in the	• Overview of the methodological approach	Economic Research and Policy	http://www.euro.who.int/document/

Pollution			Project 'Health Costs due to Road Traffic-Related Air Pollution'"	• Main results of this tri-national (France, Austria and Switzerland) project	Consultancy, (Switzerland)	trt/eval_title.pdf
Air Pollution	N/A	06/2003	"Transport Related Health Impacts: Psychological and Social Effects"	• Framework on health effects of transport with the Framing theory as "Human Needs"	Institute of Environmental Health, University of Vienna, (Austria)	http://www.fhi.se/pdf/trimmel.pdf
Air Pollution	3/2001-5/2003	N/A	Ammonia Emissions from Late Model Vehicles	• Measure exhaust emissions of ammonia from a range of late model year passenger cars and trucks • Other species were measured including N_2O	Coordinating Research Council (US)	http://www.crcao.com/annualreport/emission/e60.htm
Air Pollution	04/2000-03/2003	N/A	PARTEMIS Measurement and predictions of the emission of aerosols and gaseous precursors from gas turbine engines	• Rectify the important gap in the present knowledge base so that engine designers will be able to predict more accurately the total emissions performance of new or improved versions of existing engines and thereby control them • Application of special equipment, measuring techniques to generate the new database • Development of mathematical models of the physical and chemical processes so that effective prediction methods can be developed	QinetiQ (UK)	http://www.rmd.dft.gov.uk/project.asp?intProjectID=7969
Air Pollution	02/2000-02/2003	N/A	TRADEOFF Aircraft Emissions: Contribution of different climate components to changes in radiative forcing-tradeoff to reduce atmospheric impact	N/A	University of Oslo, Dept.of Geophys. (Norway)	N/A
Air Pollution	02/2001-01/2003	N/A	CYPRESS Future Engine Cycle Prediction and Emissions Study	• To make informed predictions of the probable changes in aero-gas turbine design in the near term and the longer term (17-20 years) and to predict the pollutant emissions from these engines	QinetiQ (UK)	http://www.aero-net.org/about/relproj/6-cypress.htm
Air Pollution, Air Pollution and Ground Vibration	1996-2003	02/2004	Safe Town Initiative Environmental Effects	• To monitor the effects on the environment of engineering measures, with particular reference to air quality, noise, traffic induced ground vibrations, and the public's perception of these changes • Examine the benefits and costs of measures in environmental terms	Department of the Environment, TRANS Greater Mission House (UK)	http://rip.trb.org/browse/dproject.asp?n=9567
Air Pollution	10/1999-10/2002	01/2004	EIATNE Identification and management of critical environmental impacts from air transportation over North Europe	• A potential exists to reduce the impact of greenhouse gasses by lowering the flight altitude in some regions. However not for the Arctic region • Minimize NO_X emissions at all levels is essential	FOI (Sweden)	http://www.eiatne.se/
Air Pollution	04/2000-03/2002	N/A	CRYOPLANE Liquid Hydrogen Fuelled Aircraft -	• Practical solutions (configurations) for all categories of commercial aircraft	DaimlerChrysler Aerospace Airbus	http://www.haw-hamburg.de/pers/Scholz/dglr/hh/tex

			System Analysis	• Architecture and quantitative analysis of new systems, including computer mode for fuel system simulation and weight estimate • Engine concepts with emphasis on minimizing NOx • Definition of airport infrastructure to fuel production and distribution • Analysis of Safety and Environmental Compatibility • Transition scenarios, global and regional.	GmbH, Hamburg (Germany)	t_2001_12_06_Cryoplane.pdf
Air Pollution	04/2000-03/2002	08/2003	NEPAIR Development of the technical basis for a new emissions parameter covering the whole aircraft operation	• To develop the technical basis, i.e. methodology, for a new emissions parameter covering all flight phases of aircraft operation. • An understanding of how current LTO cycle and in flight emissions are related • Methodology applicable to all aircraft flight phases, linking benefits to emissions produced (productivity) • Inclusion of important emissions not currently covered by regulation	QinetiQ, Farnborough (UK)	http://www.rmd.dft.gov.uk/project.asp?intProjectID=11453
Air Pollution & Noise	02/1999-01/2002	N/A	TRA-EEFAE Efficient and environmentally friendly aero-engine	• Integrates the various research projects of the European engine industry investigated under the 4th Framework Program • To emphasize the targeted character of the research work • To encourage mutual exchange of information between related research areas and to improve the strategic co-ordination of the programs	SNECMA (France)	http://www.aero-net.org/about/relproj/10-tra-eefae.htm
Air pollution	1997-2002	02/2004	Goods Vehicle Emissions	• Data on emission factors for heavy goods vehicles and buses • Predict the impact of traffic management measures on vehicle emissions	Department of the Environment, TRANS Greater Mission House (UK)	http://rip.trb.org/browse/dproject.asp?n=9568
Air Pollution	03/1998-02/2001	N/A	AEROJET II Prototyping a Non-Intrusive Exhaust Gas Measurement System for Gas Turbines	• To prototype the most appropriate instruments/techniques identified in AEROJET for different European end-users. • An industrial research activity, which will provide a non-intrusive analysis capability with an accuracy comparable or better than the currently used intrusive methods	AUXITROL, Bourges (France)	http://www.aero-net.org/about/relproj/3-aerojet2.htm
Air Pollution	01/1997-02/2001	N/A	AEROPROFILE Profiling Spectrometry to Simultaneously Investigate the Spatial Distribution of Temperature and Chemical Species in Aircraft	• Spatially resolved determination of temperature and concentrations in the exhaust gas of aircraft engines in test-rigs and in-flight. • Comparison intrusive versus non-intrusive measurements versus correlations based on ICAO data	DLR (Germany)	http://www.aero-net.org/about/relproj/4-aeroprofile.htm

				• Non-intrusive results obtained with the AEROPROFILE instrumentation and measurement methodology is superior to predictions (correlations). • Already the first non-intrusive set-up and measurement methodology as realized in AEROPROFILE nearly fulfils the requirements imposed by ICAO (i.e. deviations < 2%) even under test-rig conditions.		
Air Pollution	12/1997-01/2000	N/A	ACCIACOC Active Control of Instabilities in Advanced Combustion Chambers	N/A	CNRS/IMFT (France)	http://www.aero-net.org/about/relproj/1-acciacoc.htm
Air Pollution & Greenhouse Gas	N/A	09/2000	"The Marginal Costs of Climate Changing Emissions"	• Model of FUND2.0 and region-specific gases presenting the marginal costs of the emissions of a selected number of radiatively-active gases, three uniformly-mixed gases(carbon dioxide, methane, nitrous oxide) and two region-specific gases (nitrogen From aircraft and sulphur)	Institute for Environmental Studies, Vrije University, (Netherlands)	http://130.37.129.100/english/o_o/instituten/IVM/pdf/climatecosts.pdf
Air Pollution	07/1997-06/2000	N/A	AERO2K Global aircraft emissions data project for climate impacts evaluation	• Establish a new global 4D inventory of fuel usage and emissions of pollutants (NOx, CO, HCs, CO2, particles) relevant to aircraft impacts on the upper atmosphere	QinetiQ (UK)	http://www.eurocontrol.France/_centre/Projects/projects/300.htm
Air Pollution	07/1997-06/2000	N/A	AEROCERT Aircraft Environmental Impacts and Certification Criteria	• To identify necessary revisions and/or extensions of the emission certification procedures. • To identify the effect of operational and maintenance procedures on the certified emission levels	NLR Amsterdam (Netherlands)	http://www.aero-net.org/about/relproj/2-aerocert.htm
Air Pollution	12/1998-06/2000	N/A	CANTIQUE Concerted action on non technical measures and their impact on air quality and emissions	• To provide a synthesis of relevant results From national and EU-level transport RTD projects • To service the inter-governmental committee • To produce guidelines at local, national and European level for the evaluation and selection of cost-efficient non-technical measures to reduce emissions of toxic pollutants and greenhouse gases From transport • To foster information exchange and consensus building in the Framework of the Transport RTD program • To indicate future research needs	TUV RHEINLAND SICHERHEIT UND UMWELTSCHUTZ GMBH (Germany)	http://europa.eu.int/comm/transport/extra/cantiqueia.html
Air Pollution	06/1998-05/2000	N/A	CHEMICON Chemistry and Microphysics of Contrail Formation	N/A	UNI-GH Essen (Germany)	http://www.aero-net.org/about/relproj/7-chemicon.htm
Air	05/1998-	N/A	AEROCHEM II	N/A	Univ. of Oslo (Norway)	http://www.aero-

Pollution & Greenhouse Gas	04/2000		Modeling of the impact on Ozone and other chemical compounds in the atmosphere From airplane emissions			net.org/about/relproj/2-aerochem2.htm
Air Pollution, Air Pollution and Ground Vibration	1995-2000	02/2004	Environmental Management Main Study	• Changes in terms of air quality, noise, ground vibration, and accidents, resulting from different types of traffic management schemes, including pedestrian, urban traffic control, and traffic calming will be studied.	Department of the Environment, TRANS Greater Mission House (UK)	http://rip.trb.org/browse/dproject.asp?n=9566
Air Pollution & Transport Technology	01/1997-06/1999	N/A	FANTASIE Assessment of New Technologies and Environmental Issues	• Telematic technologies • Fuel cell and hybrid propulsion systems • Improvements in the conventional all-purpose car, such as advanced turbo-diesel engines, direct injection petrol engines and reduced weight • Tilt rotor technologies for air transport • Airships for moving heavy and bulky loads • New systems for personal rapid transit • Road trains	INDUSTRIEANLAGEN BETRIEBSGESELLSCHAFT MBH (Germany)	http://www.cordis.lu/transport/src/fantasie.htm
Air Pollution	04/1996-04/1999	N/A	COMMUTE Common Methodology for Multimodal Transport Environmental Impact Assessment	• To define a methodology for strategic assessment of the environmental impacts of transport policy options, to support transport policy decision making at the European level. • To develop computer software that embodies the main aspects of the methodology and can present the results to users • To demonstrate the use of the main aspects of the methodology and the computer software.	TÜV RHEINLAND SICHERHEIT UND UMWELTSCHUTZ (Germany)	http://www.gopa.de/en/projects/ie/rdtm/envencon/p7.html
Air Pollution	01/1996-12/1998	N/A	LES 4 LPP Large Eddy Simulation modeling FOR Lean Pre-vaporized Premixed combustion	N/A	University of Crandfield (UK)	http://www.aero-net.org/about/relproj/13-les4lpp.htm
Air Pollution	01/1996-12/1998	N/A	LES/PDF - ECT Low Emission Systems simulation Procedures for Development of Fuel Efficient Combustor Technology	N/A	University of Zaragoza (Spain)	http://www.aero-net.org/about/relproj/14-lespdf-ect.htm
Air Pollution	04/1996-07/1998	N/A	MEET Methodologies for Estimating Air Pollution Emissions From Transport	• Catalogue of methods, emissions factors and functions, for use in estimating pollutant emissions and energy consumption From transport • Data are also provided on the pollutant emissions associated with energy production	INSTITUT NATIONAL DE RECHERCHE SUR LES TRANSPORTS ET LEUR SÉCURITÉ (France)	http://www.cordis.lu/transport/src/meet.htm

Air Pollution & Transport Policy Design	N/A	02/2000	"Are We Moving in the Right Direction? Indicators on Transportation and Environment Integration in the EU"	• Studies on environmental consequences, transport demand and intensity, spatial planning and accessibility, transport supply, price signals, technology and utilisation efficiency, and management integration for EU 15 member countries	European Environment Agency (EEA), (Denmark)	http://reports.eea.eu.int/ENVISSUENo12/en/page036.html
Air Pollution	N/A	12/1999	"Economic Instruments for Reducing Emissions From Sea Transport"	• On emissions of sulphur dioxide and nitrogen oxides From shipping and their impact on human health and the environment • Cost-effectiveness of land versus sea based abatement measures • Measures and potential policy instruments to reduce emissions • Environmental differentiation of fairway and port dues	The Swedish NGO Secretariat on Acid Rain, European Federation for Transportation and Environment and the European Environmental Bureau (EEB)	http://www.acidrain.org/APC10.pdf
Air Pollution	N/A	1997	Effects of Mobile Source Emissions on Health and Property	• Literature review on the effects of mobile source emissions on health and property • Nearly 80 resources on the impacts on health, occupational health, and property impacts	Center for Transportation and the Environment (CTE) at N.C. State University (US)	http://www.fhwa.dot.gov/environment/accomp/nat_env.htm#air
Air Pollution	N/A	1997	Literature Review on Vehicle Emissions Models	• Cover both United States and international research on this topic, with a total of 40 abstracts, including journal articles and summary proceedings from 1987 to 1997 • Computer model evaluations and on-board emission diagnostic tests performed by researchers are also presented	Center for Transportation and the Environment (CTE), N.C. State University (US)	http://www.fhwa.dot.gov/environment/accomp/nat_env.htm#air
Air Pollution and Noise	N/A	1995	Environmental Pricing Policies for Transportation: A Distributional Analysis of the Twin Cities (1995)	• Distribution impacts of environmental pricing policies on groups in the Twin Cities • The impacts these policies had according to income, region, gender, and age	Humphrey Institute of Public Affairs, University of Minnesota (US)	http://www.cts.umn.edu/research/complete/environment.html#1994014
Air Pollution	N/A	1994	Automotive Exhaust Emissions During Cold-Starting	• Determine the effectiveness of simple retrofit technologies, such as electric engine block heaters and oxygenated gasoline, on the exhaust emissions of automobiles during cold-start and commuting during the winter months in Minnesota • To lower ambient CO concentrations	Mechanical Engineering Department, University of Minnesota (US)	http://www.cts.umn.edu/research/complete/environment.html#1994014
Air Pollution	N/A	1994	Evaluation of the MOBILE Vehicle Emission Model	• Modifications to the MOBILE model structure in attempts to account for technical and policy changes including Inspection and Maintenance (I& M) programs, reformulated gasoline and oxy-fuel programs, and other initiatives • Comparisons between the assumptions used in MOBILE5, MOBILE4.1, MOBILE 4, and emission rate projections	Sierra Research, Inc (US)	http://www.fhwa.dot.gov/environment/accomp/nat_env.htm#air

Air Pollution	N/A	N/A	SULFUR TOLERANT VEHICLE SYSTEMS	• Determine how light-duty, low emission vehicles systems can be designed to meet the existing TLEV, LEV, and ULEV emission standards • Explore tradeoffs between emission control technology and fuel sulfur level	University of Pittsburgh, Northwestern University, University of Pennsylvania (US)	http://www.crcao.com/annualreport/emission/e7a.htm
Air Pollution	N/A	N/A	REMOTE-SENSING MEASUREMENT OF REAL WORLD VEHICLE HIGH-EXHAUST EMITTERS	• Follow vehicle conditions and emissions using remote-sensing measurements of on-road vehicles at selected sites to identify trends over a multi-year period • Use the information to estimate high exhaust emitter populations	University of Denver (US)	http://www.crcao.com/annualreport/emission/e23.htm
Air Pollution	N/A	N/A	EFFECT OF AIR CONDITIONING ON REGULATED EMISSIONS FOR IN-USE VEHICLES	• Measure regulated emissions from in-use vehicles with and without the air conditioning in use	Clean Air Vehicle Technology Center (CAVTC), California Air Resources Board (CARB) and Texas Natural Resources Conservation Commission (US)	http://www.crcao.com/annualreport/emission/e37.htm
Air Pollution	N/A	N/A	HEAVY-DUTY VEHICLE CHASSIS DYNAMOMETER TESTING FOR EMISSIONS INVENTORY	• Characterize current in-use heavy-duty emissions in urban areas in a manner that can be used to assess the accuracy of the current particulate, NO_x and other emission factors used in mobile source inventory models	California Air Resources Board (CARB) and WVU (US)	http://www.crcao.com/annualreport/emission/e55.htm
Air Pollution	N/A	N/A	REMOTE SENSING MEASUREMENTS OF ON-ROAD HEAVY-DUTY DIESEL NO_X AND PM EMISSIONS	• Develop and apply remote sensing of HDD vehicle exhaust for NO and PM measurements in California's South Coast Air Basin	DU and DRI (US)	http://www.crcao.com/annualreport/emission/e56.htm
Air Pollution	N/A	N/A	TRAFFIC MODELING FOR THE ENVIRONMENT	• Examines directly the benefits of IVHS technology on the environment • A transportation model that effectively incorporates dynamic vehicle emissions data	Institute of Transportation Studies, UC Berkeley (US)	http://www.its.berkeley.edu/research/action.lasso?-database=wwwprojects.fp3&-layout=allfields&-response=researchdetail.html&-recordID=73&-search
Air Pollution	N/A	N/A	Roadway Tunnel Measurements of Carbon & Nitrogen-Containing Air Pollutants in Motor Vehicle Exhaust	• Measure the emissions of carbon and nitrogen-containing air pollutants from on-road vehicles during summer 1999 • Measuring ammonia emissions • Assess trends in emissions associated with changes in vehicle technologies and fuels	Institute of Transportation Studies, UC Berkeley (US)	http://www.its.berkeley.edu/research/action.lasso?-database=wwwprojects.fp3&-layout=allfields&-response=researchdetail.html&-recordID=94&-search
Air Pollution	N/A	N/A	Improving Airport Emissions Estimates and Controls	• Adjusted model to develop an emissions inventory for a major California airport • Study how airport activities can indirectly add to emissions and how to mitigate the effects of any non-conforming projects while minimizing effects on airport operations	Institute of Transportation Studies, UC Berkeley (US)	http://www.its.berkeley.edu/research/action.lasso?-database=wwwprojects.fp3&-layout=allfields&-response=researchdetail.html&-recordID=108&-search
Air Pollution	N/A	N/A	Airports and Air Quality: Emissions, Conformity, and	• Improve the state of the art in airport emissions	Institute of Transportation Studies, UC Berkeley (US)	http://www.its.berkeley.edu/research/action.lasso?-

			Mitigation	modeling, focusing on emissions estimation procedures and emissions factors used in the FAA/USAF EDMS model • Develop an emissions inventory for a major California airport, including aircraft, ground support, and aircraft sources		database=wwwprojects.fp3&-layout=allfields&-response=researchdetail.html&-recordID=32802&-search
Air Pollution and GHG	N/A	N/A	Lifecycle Emissions Model	• Take into account gaseous emissions from the entire energy cycle of a fuel and the entire lifecycle of vehicles, facilities, and materials • The 2002 version estimates energy use and emissions of regulated air pollutants and greenhouse gases, with input parameters for up to 20 countries for the years 1970 to 2050	U.S. Department of Energy, University of California Transportation Center, Pew Center on Global Climate Change (US)	http://www.its.ucdavis.edu/research-sec3.html
Air Pollution	N/A	N/A	Emissions of Nitrous Oxide and Methane from Conventional and Alternative Fuel Motor Vehicles	• Analyze a database of emissions estimates and developed emissions factors for N2O and CH4 from conventional vehicles • Estimate relative emissions of CH4 and N2O from alternative fuel passenger cars, light trucks, and heavy-duty vehicles	ITS, UC Davis and U.S. Department of Energy (US)	http://www.its.ucdavis.edu/research-sec3.html
Air Pollution	N/A	N/A	Evaluation of the Effect of On-Road Loads on Heavy-Duty Truck Emissions	• How real-world factors impact emissions of a heavy-duty truck • How this information can be simulated in models used to formulate policy	ITS, UC Davis, U.S. Environmental Protection Agency, California Air Resources Board, Freightliner LLC, Detroit Diesel Corporation (US)	http://www.its.ucdavis.edu/research-sec3.html
Air Pollution and Noise	N/A	1995	Environmental Pricing Policies for Transportation: A Distributional Analysis of the Twin Cities (1995)	• Distribution impacts of environmental pricing policies on groups in the Twin Cities • The impacts these policies had according to income, region, gender, and age	Humphrey Institute of Public Affairs, University of Minnesota (US)	http://www.cts.umn.edu/research/complete/environment.html#1994014
Air Pollution	N/A	1994	Automotive Exhaust Emissions During Cold-Starting	• Determine the effectiveness of simple retrofit technologies, such as electric engine block heaters and oxygenated gasoline, on the exhaust emissions of automobiles during cold-start and commuting during the winter months in Minnesota • To lower ambient CO concentrations	Mechanical Engineering Department, University of Minnesota (US)	http://www.cts.umn.edu/research/complete/environment.html#1994014
Air Pollution	N/A	N/A	Evaluation of the MOVES Mobile Emissions Factor Model	• Assessment of the current plans announced by EPA to develop the new MOVES emission factor model with specific application of the assessment toward the general model outline and greenhouse gas (GHG) portion of the model	ENVIRON (US)	http://www.crcao.com/annualreport/emission/e68.htm
Air Pollution	N/A	N/A	Measurement, Metrics and Health Effects of Emissions	• Characterize the emissions from aircraft and airports through measurements • Model the microphysical processes associated with particle formation	Boise State, FIU, MIT, Stanford, UCF, UMR, Aerodyne, Boeing, GE, PW, RR (US)	http://web.mit.edu/aeroastro/www/partner/projects/proj9.htm

				• Determine the health effects of emissions		
Congestion and Air Pollution	1994-1997	N/A	Congestion Mitigation and Air Quality Improvement Program Review	• Summary of a national review of the Congestion Mitigation and Air Quality Improvement (CMAQ) Program performed by the FHWA and the Federal Transit Administration (FTA)	FHWA, Office of Environment and Planning (US)	http://www.fhwa.dot.gov/environment/accomp/nat_env.htm#air
Congestion and Air Pollution	N/A	1995	Congestion Mitigation and Air Quality Improvement Program-Indirect Benefits	• Better understand and document the indirect benefits that could be attributed to the Congestion Mitigation and Air Quality Improvement (CMAQ) Program	Louis Berger and Assoc., Inc (US)	http://www.fhwa.dot.gov/environment/accomp/nat_env.htm#air
Cost of Accidents	N/A	06/2003	" Economic Valuation of Traffic Safety- The Development of Methods for Costing Accidents in Sweden"	• Cost estimation approaches • Data for estimating the current costs per casualty for each approach • Swedish National Road Administration's value of safety	Department of Technology and Society, Lund Institute of Technology and IHE, (Sweden)	http://www.fhi.se/pdf/persson.pdf
Cost of Accidents &Air Pollution & Congestion Costs	N/A	03/2000	"Accident, Environmental and Congestion Costs in Western Europe"	• On 17 European countries (EU member states, Switzerland and Norway) based on data in year 1995 for 4 transportation modes (road, rail, air, and inland water)	INFRANCEAS, Switzerland and IWW, Universitaet Karlsruhe, (Germany)	http://articles.findarticles.com/p/articles/mi_m0WXI/is_2000_April_29/ai_61867150
Costs of Accidents and The Value of Life	02/1997-02/2000	N/A	External Vehicle Speed Control	• EVSC has very large accident-reduction potential and the user trials provide clear indication of safer driver performance with EVSC. • Mandatory EVSC is far more effective than advisory or voluntary EVSC. • The Dynamic Variant provides the largest accident reduction. • Benefit-cost ratios for all variants of Mandatory EVSC are greater than 7, etc.	ITS, University of Leeds ,funded by UK DETR	http://www.dft.gov.uk/stellent/groups/dft_control/documents/contentservertemplate/dft_index.hcst?n=6638&l=2
The Cost of Accidents	02/1997-02/1999	N/A	ADRIA Advanced Crash Dummy Research for Injury Assessment in Frontal Test Conditions	• A methodology to identify head injury mechanisms and to evaluate the current head injury criterion (HIC) • Comparative test results for three advanced test dummy faces • An in-depth, retrospective accident analysis to investigate the types and mechanisms of lower leg injuries sustained by car occupants in frontal collisions	Netherlands Organization for Applied Scientific Research (Netherlands)	http://europa.eu.int/comm/transport/extra/adriaia.html
Costs and Financing	N/A	07/2001	"Surface Transport Costs and Charges: Great Britain 1998 Final report for the Department of the Environment"	• Reviews in the policy and research context on short run marginal cost analysis and fully allocated cost analysis • Estimates of social costs and revenues for 1998	Institute for Transport Studies, University of Leeds for Department of the Environment Transport and the Regions, (UK)	

				• Examining the differences between social costs and revenues with disaggregations relate to location of travel, road or rail infrastructure type, vehicle or train type and the time period of travel.		
Costs and Financing	N/A	01/2001	"Cost Evaluation and Financing Schemes for Urban Transport System"	• Practical guidelines on the evaluation of the real costs of urban mobility and on the most appropriate ways to finance it	European Commission	http://www.cordis.lu/transport/src/fiscus.htm
Ecological Costs	N/A	11/2002	Road Ecology: Science and Solutions	• Forms the basis of an integrative science of road systems ecology • Foundation for further research and the development of principles and practices for road construction and maintenance	ITS, UC Davis, Federal Highway Administration, and California Department of Transportation (US)	http://www.its.ucdavis.edu/research-sec3.html
Externality	N/A	2004	Tools for predicting usage and benefits of urban bicycle network improvements	• Develop guidelines to measure traditional benefits associated with bicycle mobility and develop tools for describing the benefits of cycling investments • Determine methods for estimating the demand for these facilities	HHH Institute, University of Minnesota (US)	http://www.cts.umn.edu/research/current/environment.html#2004026
External Costs	1999-2003	11/2003	UNITE Unification of accounts and marginal costs for Transportation Efficiency	• To support policy-makers in the setting of charges for transport infrastructure use • Efficiency, integration, cost coverage/equity issues, optimal infrastructure capacity investment rules, optimal setting of regulatory standards, etc.	ITS, University of Leeds (UK), DIW (Germany), NEI (Netherlands), CES/KUL (Belgium)	http://www.its.leeds.ac.uk/projects/unite/deliverables.html
External Costs	N/A	08/2003	"Meeting External Costs in the Aviation Industry"	• How and why to meet external cost; which external costs to consider; how to design the instruments for an internalisation policy; what incentive levels to use; and an outline assessment of whether the aviation industry covers its external costs, given the current policy regime • Fully based on a concise analysis of existing national sources and oral and written information From 12 key stakeholders in the United Kingdom	Commission for Integrated Transport (CfIT) (Netherlands)	http://www.ce.nl/eng/publicaties/03_7540_26.html
External Costs & Transport Safety and Risk	N/A	06/2003	"Cost-benefit Analyses of Walking- and Cycling Track Networks Taking Insecurity, Health Effects and External Costs of Road Traffic into Account"	• CBAs of walking- and cycling track networks in three Norwegian cities, taking into account the benefits of reduced insecurity and the health benefits	Institute of Transport Economics, (Norway)	http://www.fhi.se/pdf/saelensminde.pdf
External Costs	N/A	01/2003	"Environmental Marginal Cost Case Studies"	• It is not possible to derive one single value for the marginal costs of a certain vehicle type in urban areas. The cost categories have to be distinguished if we want to generalise values.	University of Stuttgart, (Germany)	http://www.knmi.nl/~velthove/TRADEOFF/

				• Two components have to be considered for generalisation of air pollution costs: the local situation and the geographical location within Germany. • Noise costs vary considerably between different times of the day, reflecting the higher disturbance effect of noise during night time and variations in background noise levels.		
External Costs	N/A	03/2002	" External Costs of Corridors: A Comparison between Air, Road and Rail"	• Accidents, noise, local air pollution costs, climate change risk costs and time costs studies and comparisons of three transportation modes on 5 corridors: Amsterdam-Milan, Munich-Athens, London-Paris, London-Manchester, and Rome-Madrid.	Air Transportation Action Group, Switzerland	
External Costs & Transport Pricing Design	01/1998-02/1999	N/A	" Concerted Action on Transport Pricing Research Integration CAPRI"	• Pricing principles for infrastructure use by all modes • Valuations of externalities • Road pricing, rail and other public transport and air transport pricing • Likely impacts of implementing efficient pricing • The role of pricing in transport policy development and facilitation of the exchange of results From European level research	ITS, University of Leeds (funded by European Commission)	http://europa.eu.int/comm/transport/extra/capriia.html
External Costs and Transport Policy Design	01/1996-05/1997	1997	"External Costs of Transport in ExternE"	• Impact Pathway Approach as a new methodology for quantifying energy-related environmental externalities of transport based on a bottom-up approach	IER (Germany) etc.	http://externe.jrc.es/trans.pdf http://externe.jrc.es/
GHG	N/A	N/A	Greenhouse Gas Emissions Trading and the Transport Sector	• Provide the potential for large emission reductions at low cost and may be more politically acceptable than tax and command-and-control approaches	Institute of Transportation Studies, UC Berkeley (US)	http://www.its.berkeley.edu/research/action.lasso?-database=wwwprojects.fp3&-layout=allfields&-response=researchdetail.html&-recordID=103&-search
Harbor Pollution	01/1998-01/2000	N/A	(H-SENSE) Harbours - Silting and Environmental Sedimentology	• Geochemical databases were established for the three test harbors • A new system for comparing contaminated sediments with different composition was proposed • Three modeling approaches were developed and compared for the spatial prediction of clay distribution, harbor bed conditions, zinc pollution and sediment thickness	Goeteborg University (Sweden)	http://europa.eu.int/comm/transport/extra/h-senseia.html

Highway Pollution	08/1997-08/1999	N/A	POLMIT Pollution of Groundwater and Soil by Road and Traffic Sources	• Determine and understand the absolute and relative importance of highway pollutants compared with other pollutant sources • Understand the dispersal mechanisms of these pollutants and the pathways by which they are released to soil and groundwater • Understand the physical and chemical impacts of highway pollutants on soil and groundwater • Both locally and nationally	TRL (UK), DWW (Netherlands), VTI (Sweden), etc.	http://www.dhi.dk/Consulting/WasteProducts/SolidWaste/POLMIT.htm
Noise	N/A	2002	Improvement of the FHWA Traffic Noise Model (FHWA TNM)	• Field measurements to support the model validation • Address problems and inconveniences users have identified subsequent to the release of the FHWA TNM, as well as incorporate improvements in the model's graphical user interface	Volpe National Transportation Systems Center (US)	http://www.fhwa.dot.gov/environment/accomp/nat_env.htm#air
Noise	11/1998-10/2001	N/A	TN X-NOISE Aircraft external noise thematic network	• The necessary co-ordination of EU-funded and national research efforts, • The need for an ambitious communication strategy towards airports and airport communities in order to promote a better understanding of progress and expectations, • The impact of the demonstrated level of technology on the definition of future rules and certification practices, • The capability of finding competitive answers to a well structured and very aggressive research effort already in place in the US with a similar noise reduction objective, regrouping all available national expertise.	NLR (Netherlands)	http://www.aero-net.org/about/relproj/9-tn-x-noise.htm
Noise	12/1998-01/2000	N/A	SOURDINE Study of optimization procedures for decreasing the impact of noise	• Five models for predicting noise exposure around airports were evaluated • Noise abatement procedures have been selected and assessed	ISR S.A. (France)	http://europa.eu.int/comm/transport/extra/sourdineia.html
Noise	01/1997-01/1999	N/A	METARAIL Methodologies and Actions for Rail Noise and Vibration Control	• Thirteen techniques were studied in the project, including the testing of four new ones. Hardware and/or software were developed for six techniques • Potential improvements to the ISO 3095 standard for railway exterior noise type testing • New methods for separating vehicle and track noise were demonstrated	SCHREINER Consulting (Austria)	http://www.cordis.lu/transport/src/metarail.htm
Noise	N/A	1996	Measurement of Highway-Related Noise	• Measurement of (1) existing noise; (2) vehicle noise emissions; (3) barrier insertion loss; (4)	Volpe National Transportation Systems Center (US)	http://www.fhwa.dot.gov/environment/accomp/nat_env.htm#air

				construction equipment noise; (5) noise reduction due to buildings; and (6) occupational noise exposure.		
Noise	N/A	N/A	Low Frequency Noise Study at Minneapolis-St. Paul Int'l Airport (MSP)	• Address the problem of low frequency noise • By measuring the sound, vibration and community impact (through subjective interviews) under various meteorological conditions, develop models that will then be used to perform analyses and by developing innovative mitigation techniques	Penn State, Purdue, UCF, Boeing, Wyle (US)	http://web.mit.edu/aeroastro/www/partner/projects/proj1.htm
Noise	N/A	N/A	Measurement, Metrics and Health Effects of Noise	• Develop a metric that can be used to evaluate the impact of airport and other noise sources on a community and to understand the relationship between noise annoyance, physiological responses, cognitive performance and sleep quality	FIU, Penn State, Purdue, UCF, Boeing, GE, PW, RR, Wyl (US)	http://web.mit.edu/aeroastro/www/partner/projects/proj2.htm
Noise, Air Pollution, and Green House Gas	N/A	N/A	Valuation and Tradeoffs of Policy Options	• Develop and use system-level performance and cost estimation tools to evaluate interactions between technology, operations, policy and environmental impact, based upon explicit valuations of the direct costs, opportunity costs and external costs of noise, local air quality and climate change	MIT, Stanford, Boeing, Delta, GE, LMI, PW, Rannoch, RR, Wyle (US)	http://web.mit.edu/aeroastro/www/partner/projects/proj3.htm
Noise	N/A	N/A	Continuous Descent Approach at Louisville Int'l Airport (SDF)	• Develop a near term noise abatement approach procedure that can be used for all aircraft in the UPS arrival bank by conducting a series of simulator experiments and flight demonstration tests at SDF	MIT, Boeing, Delta, RAA, UPS (US)	http://web.mit.edu/aeroastro/www/partner/projects/proj4.htm
Noise	N/A	N/A	Aircraft Operations and Air Traffic Control	• Evaluate the utility of existing noise abatement procedures to determine whether they are effective and whether more advanced procedure will provide significant benefits; • Determine the impact of weather on noise propagation and thus the impact on the ground; • Determine the impact of weather on both noise and air traffic control; • Develop and evaluate candidate procedures; • Determine the impact of these procedures on system capacity	FIU, MIT, Penn State, Purdue, Boeing, Delta, LMI, Metron, MWAA, PW, RAA, UPS, Wyle (US)	http://web.mit.edu/aeroastro/www/partner/projects/proj5.htm
Noise	N/A	N/A	Land Use Management and Airport Controls	• Better understand the effects of aviation noise and thereby provide the basis for improved response thresholds, especially on the mitigation of noise in residences and schools • Develop methods, metrics, and models to assess	FIU, MIT, Purdue, UCF, Delta, MWAA, RAA, Wyle (US)	http://web.mit.edu/aeroastro/www/partner/projects/proj6.htm

				the relative impact of aviation noise on human health and to use this information to improve land use in and around airports		
Noise	N/A	N/A	Quiet Rotorcraft and Short Field Operations	• Develop a medium fidelity rotorcraft flight simulation/noise prediction system that can predict rotor noise in real-time • Develop a simple tip-vortex model that provides representative impulsive loading needed for prediction of blade-vortex-interaction (BVI) noise in decent flight conditions • Couple the real-time noise prediction tool with the Rotor Noise Model (RNM) to account for the effects of propagation, terrain and horizontally stratified atmospheres on noise predictions; • Develop optimal helicopter take-off, tilt-rotor take-off and approach operations for reduced noise;	MIT, Penn State, Purdue, LMI, Wyle (US)	http://web.mit.edu/aeroastro/www/partner/projects/proj7.htm
Noise	N/A	N/A	Supersonic Transport / Sonic Boom Mitigation	• The noise impacts of supersonic flight for the specific case of low boom aircraft designs	Penn State, Stanford, Boeing, Gulfstream, Wyle (US)	http://web.mit.edu/aeroastro/www/partner/projects/proj8.htm
Noise	N/A	N/A	Airport Noise Analysis with SIMMOD and INM	• Integrate the SIMMOD air traffic simulation model and the Integrated Noise Model • Connect the analysis package to a geographic information system	NEXTOR researchers and Maryland Aviation Administration (US)	http://www.its.berkeley.edu/research/action.lasso?-database=wwwprojects.fp3&-layout=allfields&-response=researchdetail.html&-recordID=32792&-search
Road Pollution	N/A	2001	Fine Particle Emissions from Minnesota Transportation	• Measure the size distribution of diesel aerosol on-highway and in the lab with emphasis on nanoparticles (< 50 nm) • Quantify and characterize nanoparticle concentration and size distribution at the Metropolitan Airport and along railways	Mechanical Engineering, University of Minnesota (US)	http://www.cts.umn.edu/research/current/environment.html#2004026
Road Pollution	N/A	1999	Environmental Hazard Assessment for Transportation-Related Chemicals	• Develop a decision tool to judge the potential risk associated with new or replacement chemicals used in roadway construction and maintenance, or as a result of direct vehicle use	Botany, University of Minnesota (US)	http://www.cts.umn.edu/research/current/environment.html#2004026
Road Pollution	N/A	1994	Evaluation of LIDAR System for Area Sensing of Vehicle Emissions(Phase 2)	• Scan a sector of the atmosphere near ground level and return data on particulate concentrations • Correlations between the LIDAR data and the other parameters	Process Inspection & Analysis Group, University of Minnesota (US)	http://www.cts.umn.edu/research/complete/environment.html#1994014
Road Pollution	N/A	1994	Remote Sensing of Particulate Emissions from Heavy Duty Vehicles (Phase 1)	• Develop a remote sensing system capable of measuring pollutant emissions from light- and heavy-duty vehicles under actual roadway conditions	Mechanical Engineering, University of Minnesota (US)	http://www.cts.umn.edu/research/complete/environment.html#1994014

				• An absorption cell calibration system as well as measurements of particulate emissions		
Water Pollution	N/A	6/2004	Molecular Tracking of Fecal Pollution in Surface Waters	N/A	EPA (US)	http://www.epa.gov/ORD/NRMRL/news/news062004.htm
Water Pollution	N/A	2/2003	Environmental Impacts of Bridge Cleaning Operations	• A potential low-cost/low-tech method for improving removal of heavy metals from wastewater by passing it through a sand filter	Kentucky Transport Center, UKY (US)	http://www.ktc.uky.edu/Reports/KTC_03_03_SPR_224_01_1F.pdf
Water Pollution	N/A	2002	Improving the Design of Roadside Ditches	Various methods to evaluate the effect of soil modifications and specialized vegetation in ditches to reduce transportation related non-point source pollution in Minnesota	Botany, University of Minnesota (US)	http://www.cts.umn.edu/research/current/environment.html#2004026

Note:

1. The table is sorted according to research areas.
2. "N/A": not available from websites. Individual contacts with the research institutions are necessary to reach the absent contents of the projects.

Annex 1.2 Governmental and Transportation Research Institutions in Europe

COUNTRY	INSTITUTION	WEBSITES
Austria	Institut fuer Verkehrswesen	http://www.boku.ac.at/verkehr/
	Technical University of Vienna Institute for Transportation System Planning	http://derpi.tuwien.ac.at/tuw/schools/srpa/urp/ins/E269.html
	Austrian Federal Forestry Company	http://www.bundesforste.at/index.php
Belgium	Institute of Nature Conservation	http://www.instnat.be/content/homepage_nl.asp
	Institute for Forestry and Game Management	http://www.ibw.vlaanderen.be/eng/text/index.html
	University of Namur, Transportation Research Group	http://www.fundp.ac.be/recherche/unites/fr/9207.html
	Site on environmental information in Flanders, page concerning habitat fragmentation (in Dutch)	http://www.mina.vlaanderen.be/fr.htm?http://www.mina.vlaanderen.be/beleid/mina2/
	University of Leuven	http://cwisdb.cc.kuleuven.ac.be/oc-bin/oc?lang=E
	Laboratory of Animal Ecology , University of Antwerp	http://bio-www.uia.ac.be/bio/deco/
Croatia	Ministry of Science and Technology Project: the Optimal Development of the Transport system of Croatia and the joining of it with the European systems.	http://www.mzos.hr/svibor/2/10/414/proj_e.htm
	University of Zagreb, Faculty of Transport and Traffic Engineering (in Croatian)	http://mafpz.fpz.hr/
Czech Republic	Agency for Nature conservation and Landscape Protection of the Czech Republic	http://www.aopk.cz/index.php?id_subjekty=en&PHPSESSID=1a2680370020917722e37e279ca90438
Denmark	College of Transport, Denmark [in Danish]	http://www.landtransportskolen.dk/
	Copenhagen Business School	http://web.cbs.dk/staff/markl/forum.shtml
	Technical University of Denmark	http://www.dtu.dk/index_e.htm
Finland	Finnish State Railways, VR (in Finnish)	http://www.vr.fi/heo/index.html
	Ministry of Transport and Communications Finland [in Finnish]	http://www.mintc.fi/
	Helsinki University of Technology, Transportation Engineering Laboratory	http://www.hut.fi/Units/Civil/Transportation/
	Tampere University of Technology, Transportation Engineering	http://www.uta.fi/english/index.html
France	French National Institute for Transport and Safety Research (INRETS)	http://web.inrets.fr/index.e.html
	French National Railway Company (SNCF) Research [in French]	http://www.sncf.com/
	Laboratoire Central des Ponts et Chaussées	http://www.lcpc.fr/index2.dml
	Ecole Nationale des Ponts et Chaussées [in French]	http://www.enpc.fr/
Germany	Bundesministerium für Verkehr, Federal Republic of Germany [in German]	http://www.bgsamt-see.de/frame.htm
	Technical University of Dresden, Institut für Bahntechnik [in German]	http://www.tu-dresden.de/
	Institut für Stadtbauwesen und Strassenbau [in German]	http://www.tu-dresden.de/biwiss/bauss.htm
	Universität Hannover, Institut für Verkehrswirtschaft, Strassenwesen und Städtebau [in German]	http://www.ivh.uni-hannover.de/
	Landesjagd verband Hessen e. V.[in German]	http://www.ljv-hessen.de/
	Institute for Geoecology of the University of Potsdam	http://www.uni-potsdam.de/u/Geooekologie/index.htm
Greece	Aristotle University of Thessaloniki, Transport Engineering Laboratory	http://www.auth.gr/
	National Technical University of Athens, Department of Transportation Planning and Engineering	http://frida.transport.civil.ntua.gr/transport/research/
	ARCTUROS, civil non-profit organization for the conservation of wildlife and natural environment Egnatia Odos	http://www.arcturos.gr/enhome.htm
Hungary	Technical University of Budapest Faculty of	http://www.bme.hu/en/organization/faculties/transp

	Transportation Engineering	ortation/index.html
Ireland	Trinity College, Dublin, Transportation	http://www.tcd.ie/
Italy	Centro Studi Arcadia (in Italian)	http://www.centrostudiarcadia.it/
	Italian Ministry of Transport and Navigation (in Italian)	http://www.infrastrutturetrasporti.it/
	Politecnico di Torino, Dipartimento di Idraulica, Trasporti e Infrastrutture Civili [in Italian]	http://www.polito.it/ricerca/dipartimenti/ditic/
	Universita di Genova, Facolta di Ingegneria Ambiental (in Italian)	http://www.diam.unige.it/
	LIPU/ Birdlife Italy (in Italian)	http://www.lipu.it/
Lithuania	Vilnius Technical University, Faculty of Transport Engineering	http://www.vu.lt/english/
Netherlands	Dutch Ministry of Transport, Public Works and Water Management	http://www.verkeerenwaterstaat.nl/?lc=uk
	Dutch Ministry of Environment, Directorate for Noise and Traffic	http://www.xs4all.nl/~rigolett/ENGELS/index.html
	Centrum Transportechnologie [in Dutch]	http://www.connekt.nl/
	The Netherlands Research School for Transport, Infrastructure and Logistics (TRAIL) , Transportation Planning & Traffic Engineering Section	http://cttrailf.ct.tudelft.nl/
Norway	Norwegian University of Science and Technology, Trondheim	http://www.ntnu.no/indexe.php
	Directorate for Public Works, Environmental Strategy Division	PO Box 8142 Dep, N-0033 Oslo
Poland	Warsaw University of Technology, Faculty of Transport	http://www.pw.edu.pl/english/transp.html
Portugal	INPECO - Portuguese Institute of Ecology (in English)	http://www.inpeco.pt/
Russia	Institute for Sustainable Communities	http://www.iscmoscow.ru/english/
Slovakia	University of Transport and Communications in Zilina, Slovak Republic	http://www.lar.ee.upatras.gr/ametmas/zilina.htm
Slovenia	National Building and Civil Engineering Institute (ZAG)	http://www.zag.si/latin2/index.html
Spain	Centro de Estudios y Experimentacion de Obras Publicas (CEDEX), Madrid (in Spanish)	http://www.cedex.es/
	Universidad Politecnica de Valencia, Ingenieria e Infraestructura de los Transportes (in Spanish)	http://www.upv.es/informa/estudiosc.html
	University of Alcalà, Departemento de Ecologia de la Universidad de Alcala (in Spanish)	http://www.uah.es/
	Collserola Parc	http://parccollserola.amb.es/catalan/home/marcos.htm
Sweden	Grimsö Wildlife Research Station	http://www-grimso.slu.se/
	Swedish National Road Administration [in Swedish]	http://www.vv.se/
	Swedish National Road and Transport Research Institute, VTI	http://www.transguide.org/
	Department of Civil Engineering, Road and Traffic Planning	http://www.chalmers.se/researchprofile/roadtraffic.html
	Railway Engineering Research	http://www.charmec.chalmers.se/
	Lulea University Traffic Engineering	http://www.luth.se/eng/
	Lund University Traffic Planning and Engineering	http://www.tft.lth.se/index.htm
	Royal Institute of Technology, Stockholm, Department of Highway Engineering	http://www.kth.se/eng/
Switzerland	Swiss Federal Department of Transport, Communications and Energy (DFTCE) [in French]	http://www.uvek.admin.ch/index.html?lang=en
	Swiss Federal Institute of Technology Institute of Transportation, Highway and Railway Engineering	http://www.ivt.baum.ethz.ch/indexE.html
	Swiss National Research Programs	http://www.snf.ch/default_en.asp
	Swiss National Research Programme NRP 41: Transport and environment: Interaction Switzerland - Europe 1996 - 2000	http://www.nfp41.ch/
	PiU Partner/-innen in Umweltfragen	http://www.piu-welt.ch/
	Zoological Institute	http://www.zoology.unibe.ch/index.php

United Kingdom	Highways Agency	http://www.highways.gov.uk/
	Aston University, Department of Civil Engineering, Transport Research Group	
	Cambridge University Transportation Research Group	http://www-mech.eng.cam.ac.uk/trg/people.html
	Middlesex University Road Traffic Research Centre	http://www.mdx.ac.uk/www/roadtraffic/welcome.htm
	Open University (U.K.) Energy and Environment Research Unit: Transport and the Environment	http://www.jxj.com/suppands/renenerg/companies/3102.html
	University of Birmingham International Study of Highway Development and Management	http://civ-hrg.bham.ac.uk/isohdm/Links.htm
	University of Cardiff, Spatial Analysis, Urban Planning and Transport Research Group	http://www.cf.ac.uk/
	University of Leeds, Institute for Transport Studies	http://www.its.leeds.ac.uk
	University of Newcastle Upon Tyne, Transport Engineering	http://www.ncl.ac.uk/civeng/civres.html
	University of Sheffield, Advanced Railway Research Centre	http://www.arrc.ac.uk/
	Loughborough University of Technology, Vehicle Safety Research Group	http://www.lboro.ac.uk/research/esri/vsrc/index-flash.htm
	Napier University, Transportation Engineering Research Unit	http://www.tri.napier.ac.uk/
	University of York, Institute of Railway Studies	http://www.york.ac.uk/inst/irs/
	Strategic Rail Authority	http://www.sra.gov.uk
	Transport Research Laboratory	http://www.trl.co.ok
	MVA for Traffic Modeling	http://www.mva-group.com
	SKM for Freight Modeling	http://www.skmconsulting.com

Source from http://www.iene.info/HFLinks.htm

Annex 2: Transportation and biodiversity

1. Biodiversity

The impacts of transportation are felt by the environment as a whole, including living organisms, also termed the biosphere. Air pollution, inefficient land use, waste disposal, water pollution, hydrological impacts and resource consumption all attribute to the discomfort, changes in productivity, illness and even death of species. The aggregate effect of these impacts can modify the biosphere through changes in population and species distribution

Species loss is the result of a variety of intertwined components of which transportation is only one. As with most environmental problems, poorly planned, unrestrained industrialization, population growth and the overuse of finite resources are the determinants of changes in population and distribution.

For example, there is debate about the impacts of biodiversity from road transportation. While "road kill" may be the most dramatic or visible aspect of highway-wildlife interactions, it represents only one small component of the damages that both flora and fauna are subjected to as a result of road construction and use. Roads may also contribute to less visible, but more harmful habitat loss, fragmentation and isolation, as well as general disruption of the normal behavior and movement patterns of affected species. Roads not only affect large mammals such as deer and moose, but also plant life, small mammals, amphibians, reptiles, birds, fish and microorganisms. Thus, roads can decrease biological diversity as a whole.

Biological diversity, called biodiversity, is widely recognized at three different levels (Noss, 1990)

- genetic diversity, or the variability within one species, such as eye or hair color in humans;
- species diversity, or the number of different plants, animals, fungi, bacteria, and protozoa, and
- ecosystem diversity, which refers to the various types of ecosystems and the ways they function.

Depending on their character, healthy ecosystems cycle the basic elements of all life: water, gases and nutrients, and provide ecosystem services that regulate the planet. Wetlands, for example, filter and clean water as well as ameliorate water flow, reducing flooding. Healthy forests act as a carbon sink helping to regulate the carbon content of the atmosphere.

Maintaining diverse and viable populations of wild plants and animals is of critical importance to the health of the global environment, and therefore to how human society can operate. The loss of genetically distinct populations within a species is, at the moment, at least as important a problem as the loss of entire species. Once a species is reduced to a remnant, its ability to benefit humanity ordinarily declines greatly, and its total extinction in the relatively near future becomes much more likely.

2. Ecosystem and Biodiversity Loss

Pearce et al. (1996) also discusses the impact of climate change on ecosystem and biodiversity. This is an area where changes due to climate change effects could be among the largest, yet past research has been the most limited. Uncertainties arise because of both the unknown character of ecosystem impacts, and because of the difficulty of assessing these impacts from a socioeconomic point of view and translating them into welfare costs. The reported figures are all rather speculative.

Economists identify three types of value: direct and indirect *use value* (e.g., plant inputs into medicine and the role of mangrove forests in coastal protection); *option value* (preserving a species to retain the possibility that it may be of economic use in the future); and *existence value* (e.g., the value of knowing that there still are blue whales). Table A2-1, based on Pearce (1993), summarizes the results of "contingent valuation" sample survey estimates of what the public would be willing to pay to preserve an endangered animal species. Average values range from $1 to $18 per person per year for preservation of an individual species, with a maximum of $40 to $64 obtained for humpback whales. The willingness to pay figure for the preservation of entire habitats is somewhat higher, with a range of $9 to $107 per person and year.

Table A2-1 Preference valuation for endangered species and prized habitats

Country	Species or Habitat	Value (1990US$/year/person)
Norway	Brown bear, wolf, and wolverine	15.0
	Conservation of rivers against hydroelectric development	59.0-107.0
United States	Bald eagle	12.4
	Emerald shiner	4.5
	Grizzly bear	18.5
	Bighorn sheep	8.6
	Whooping crane	1.2
	Blue whale	9.3
	Bottlenose dolphin	7.0
	California sea otter	8.1
	Northern elephant seal	8.1
	Humpback whale [a]	40-48 (without information) 49-64 (with information)
	Grand Canyon	27.0
	Colorado wilderness	9.3-21.2
Australia	Nadgee Nature Reserve	28.1

	Kakadu Conservation Zone [b]	40.0 (minor damages) 93.0 (major damages)
UK	Nature reserves [c]	40.0

1) Respondents divided into two groups, one of which was given video information.
2) Two scenarios of mining development damage were given to respondents.
3) Survey of informed individuals only.
   a) Note: People's WTP to preserve all listed species is not necessarily identical to the sum of individual WTP estimates, because of the so-called "embedding effect" (WTP estimates elicited in surveys depend on the "bundle of goods" presented to the interviewee; see Mitchell and Carson, 1989).

Source: Pearce (1993).

Monetary estimates of ecosystem damages through climate change are invariably ad hoc. Fankhauser (1995) cites the Pearce (1993) survey (see Table A2-1) to arrive at a willingness-to-pay estimate of US$30 per person per year to avoid species and habitat loss from climate change. Total costs amount to about US$40 billion annually for the world as a whole, with about one-third occurring in developing countries. Cline (1992) arrives at an estimate of about US$4 billion annually as a notional value of species loss from benchmark global warming for the US, but suggests that the figure could as easily be an order of magnitude higher ($40 billion). The estimate is based on an extrapolation of observed US public expenditures for the preservation of one particular species (the spotted owl).

3. Shadow Price Estimates of Biodiversity

Bein (1997) estimates the shadow price of biodiversity through multiplying the areas of natural reserves and the associated values. He suggests that about C$10,000 per hectare in annual economic benefits is available for an average habitat in Canada. The annual worth of current Canadian reserves would be at least C$700 billion.

Bein (1997) also summarizes other researchers' estimates regarding to biodiversity, shown in Table A2-9. These estimates illustrate a portion of the economic value for selected species and ecosystems. Total monetary values of various habitats are substantial, but so are the total recreational, option, existence and bequest values of individual species and wilderness when added up over all households or individuals in the country. Ecological economic values include the value of recreational activities, but do not include the very substantial contribution of option, existence and bequest values.

Table A2-9 Examples of Monetary Estimates of Selected Species and Ecosystem Values

Study	Subject	Technique	1994 C4
Farber (1995)	Louisiana wetlands	Ecological economic analysis	$29,300 to $54,700 /ha per year
Myers (1988)	Tropical forest wildlife	Market value	$256 /ha per year

de Groot (1992)	Galapagos National Park: tourism, harvesting, science	Market value	$154 /ha per year
Costanza et al. (1989)	Present value of wetlands ecosystem	Energy and ecological economic analysis	$86,300 /ha
Raphaeal and Jaworski (1977)	Fishing, hunting, recreation and trapping	Market values, survey	$254 /ha per year
Hoen and Winther (1993)	Virgin coniferous forest preservation	Contingent valuation method	$37 /household per year for 10 years
Walsh et al. (1978)	Clean water providing among other things natural habitat for plants, fish and wildlife	Contingent valuation method	Recreation $72 /household; option value $28 /household; existence value $32 /non-user and $44 /user household; bequest value $22/non use household and $42 /user household
Duffield (1988)	Elk hunting	Travel cost method	$34-85 /activity day
Miller (1984)	Small game hunting	Travel cost method	$20 /activity day
Cameron and James (1987)	Sport salmon fishing	Contingent valuation method	$63 /activity day
Brookshire et al. (1983)	Grizzly bear and bighorn sheep	Contingent valuation method	Option value (5 year): $28 for grizzly bear, $29 for bighorn sheep; existence value (5 year): #31 grizzly bear, $9 bighorn sheep
Walsh et al. (1984)	Wilderness preservation	Contingent valuation method	$76 /ha for an additional 0.4 million ha

4. Regulatory framework: Rio Convention on Biological Diversity

Signed in 1992 in Rio de Janeiro by a large number of nations, the Convention on Biological Diversity entered into force in December 1993. The convention is aimed at protecting the world's natural assets by introducing the term "biodiversity." It is a complex concept not only relevant in scientific terms, but also taking into consideration social and economic dimensions. All life on Earth is part of an immense, interdependent system, and biodiversity is an expression of the necessary variety of ecosystems, species and genes.

The parties of the Convention have pledged to develop and integrate their national strategies and plans for ex situ and in situ biodiversity conservation and sustainable use, monitor them, establish incentive measures for biodiversity conservation, employ an environmental impact assessment system and assure equal access to genetic resources and technology.

The Convention commits parties to preparing national strategies for the conservation and sustainable use of biological diversity. The term has gained international political recognition and is now used by governments, the media and society at large.

5. References

Bein, P. (1997). "Monetization of Environmental Impacts of Roads." Ministry of Transportation and Highways. British Columbia, Canada.

Cline, W.R. (1992). "The economics of global warming." Institute for International Economics, Washington DC, US.

Fankhauser, S., (1995). "Valuing Climate Change – The Economics of the Greenhouse." London: EarthScan.

Mitchell, R., and R. Carson, (1989). "Using surveys to value public goods: The contingent valuation method." Resources for the Future, Washington DC. US.

Noss, R.F. (1990). "Indicators for monitoring biodiversity: A hierarchical approach." Conservation Biology.

Pearce, D.W., (1993). "Economic values and the natural world." Earthscan. London.

Pearce, D.W., Cline, W.R., Achanta, A.N., Fankhauser, S., Pachauri, R.K., Tol, R.S.J. and Vellinga, P. (1996). "The Social Costs of Climate Change: Greenhouse Damage and the Benefits of Control." In *Climate Change 1995: Economic and Social Dimensions – Contribution of Working Group III to the Second Assessment Report of the Intergovernmental Panel of Climate Change* (Eds, Bruce, J.P., Lee, H. and Haites, E.F.) Cambridge University Press, Cambridge. 179-224.

Annex 3 Currency Conversion

Currency Conversion into 2002 CAD$ based on PPP (OECD Data)

Country	Currency		1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
AUSTRALIA	Dollar	A$	0.478	0.534	0.582	0.617	0.648	0.691	0.745	0.810	0.865	0.907	0.929	0.941	0.953	0.961	0.975	0.998	1.015	1.019	1.026	1.070	1.105	1.136
AUSTRIA	Euro (1999)	€	0.455	0.477	0.495	0.518	0.534	0.550	0.561	0.569	0.584	0.603	0.627	0.649	0.668	0.686	0.703	0.710	0.721	0.733	0.736	0.748	0.771	0.786
13.7603	Schilling	S	6.264	6.570	6.816	7.128	7.345	7.567	7.721	7.827	8.037	8.298	8.623	8.937	9.196	9.443	9.668	9.772	9.925	10.080	-	-	-	-
BELGIUM***	Euro (1999)	€	0.414	0.444	0.470	0.496	0.519	0.534	0.542	0.555	0.580	0.596	0.614	0.635	0.661	0.674	0.682	0.693	0.714	0.725	0.743	0.754	0.753	0.760
40.3399	Franc	BF	16.68	17.91	18.97	19.99	20.92	21.54	21.88	22.38	23.41	24.05	24.78	25.63	26.65	27.19	27.51	27.96	28.80	29.25	-	-	-	-
CANADA	Dollar	CAN$	0.559	0.606	0.639	0.660	0.680	0.701	0.733	0.767	0.801	0.826	0.851	0.862	0.874	0.885	0.904	0.919	0.930	0.927	0.942	0.980	0.990	1.000
CZECH REPUBLIC	Koruna	Kc	..	..	..	..	..	..	..	..	..	3.555	4.849	5.450	6.593	7.474	8.229	8.896	9.703	10.740	11.145	11.420	11.837	12.357
DENMARK	Krone	Dkr	3.497	3.877	4.216	4.467	4.688	4.882	5.126	5.263	5.527	5.725	5.892	6.064	6.146	6.250	6.353	6.456	6.589	6.654	6.651	6.877	6.997	7.246
FINLAND	Euro (1999)	€	0.357	0.388	0.422	0.457	0.482	0.504	0.524	0.568	0.603	0.641	0.654	0.663	0.680	0.692	0.725	0.732	0.739	0.757	0.777	0.801	0.818	0.849
5.94573	Markka	mk	2.124	2.305	2.511	2.720	2.864	2.994	3.113	3.378	3.584	3.809	3.888	3.945	4.046	4.116	4.308	4.355	4.394	4.502	-	-	-	-
FRANCE	Euro (1999)	€	0.394	0.439	0.480	0.513	0.541	0.570	0.585	0.604	0.621	0.639	0.659	0.672	0.687	0.699	0.709	0.717	0.718	0.723	0.734	0.749	0.754	0.764
6.55957	Franc	F	2.587	2.878	3.148	3.366	3.550	3.737	3.839	3.960	4.075	4.191	4.321	4.408	4.508	4.582	4.654	4.705	4.707	4.745	-	-	-	-
GERMANY	Euro (1999)	€	0.507	0.530	0.549	0.560	0.572	0.592	0.602	0.611	0.624	0.644	0.668	0.702	0.727	0.745	0.759	0.762	0.775	0.784	0.794	0.803	0.818	0.826

1.95583	Deutsche Mark	DM	0.992	1.037	1.074	1.095	1.119	1.157	1.176	1.196	1.221	1.260	1.306	1.372	1.422	1.457	1.485	1.491	1.515	1.533	-	-	-	-
GREECE	Euro (2001)	€	0.045	0.058	0.070	0.085	0.101	0.120	0.138	0.162	0.185	0.223	0.267	0.307	0.351	0.390	0.428	0.462	0.492	0.518	0.538	0.560	0.582	0.586
340.75	Drachma	Dr	15.45	19.61	23.73	28.91	34.42	40.99	47.18	55.12	62.98	75.96	91.12	104.63	119.69	133.02	145.89	157.39	167.49	176.61	183.44	190.85	-	-
HUNGARY	Forint	Ft	..	..	..	..	..	..	..	..	..	..	20.19	24.53	29.74	35.53	44.56	53.66	64.18	72.32	79.02	87.73	92.35	99.27
ICELAND	Krona	Ikr	4.05	6.19	10.95	13.73	18.03	22.66	27.04	33.26	39.76	46.44	50.28	51.97	53.06	54.11	55.59	56.79	58.88	61.64	64.12	68.10	74.41	79.82
IRELAND	Euro (1999)	€	0.312	0.359	0.398	0.423	0.446	0.475	0.485	0.502	0.528	0.524	0.534	0.549	0.578	0.587	0.604	0.623	0.640	0.681	0.729	0.780	0.825	0.848
0.787564	Pound	IR£	0.246	0.282	0.314	0.333	0.351	0.374	0.382	0.395	0.416	0.413	0.421	0.433	0.455	0.463	0.476	0.491	0.504	0.536	-	-	-	-
ITALY	Euro (1999)	€	0.196	0.229	0.264	0.294	0.321	0.347	0.368	0.393	0.418	0.452	0.487	0.509	0.529	0.547	0.574	0.600	0.621	0.625	0.640	0.661	0.686	0.710
1936.27	Lira	Lit	379.2	443.4	511.8	570.2	621.2	671.5	712.1	761.3	808.8	874.7	942.3	985.4	1023.8	1059.0	1111.0	1162.1	1203.3	1209.9	-	-	-	-
JAPAN	Yen	¥	107.3	109.0	111.4	114.4	117.0	119.1	118.8	119.8	121.9	124.7	128.6	130.7	131.4	131.5	130.7	129.7	130.2	130.2	128.2	125.7	123.7	121.8
KOREA	Won	W	209.3	223.7	237.9	251.0	262.7	276.6	291.8	314.2	331.6	366.9	407.3	438.5	469.3	505.1	540.5	561.8	579.8	609.5	597.4	590.7	604.9	615.7
LUXEMBOURG* **	Euro (1999)	€	0.448	0.496	0.531	0.554	0.571	0.572	0.572	0.588	0.611	0.626	0.638	0.662	0.701	0.726	0.742	0.760	0.784	0.788	0.777	0.809	0.836	0.855
40.3399	Franc	LuxF	18.08	19.99	21.43	22.35	23.05	23.07	23.06	23.73	24.63	25.23	25.73	26.70	28.28	29.27	29.92	30.64	31.61	31.79	-	-	-	-
MEXICO*	Peso	Mex$	0.009	0.015	0.028	0.045	0.070	0.122	0.292	0.583	0.737	0.943	1.164	1.332	1.459	1.579	2.174	2.844	3.349	3.866	4.458	5.001	5.312	5.562
NETHERLANDS	Euro (1999)	€	0.518	0.545	0.558	0.566	0.576	0.578	0.573	0.579	0.584	0.597	0.615	0.629	0.641	0.656	0.668	0.679	0.695	0.709	0.732	0.756	0.770	0.794
2.20371	Guilder	f.	1.142	1.201	1.230	1.247	1.269	1.273	1.262	1.276	1.288	1.315	1.355	1.387	1.413	1.445	1.472	1.497	1.531	1.563	-	-	-	-
NEW ZEALAND	Dollar	NZ$	0.454	0.489	0.529	0.569	0.650	0.771	0.861	0.925	0.970	1.000	1.007	1.022	1.052	1.062	1.087	1.114	1.118	1.136	1.135	1.163	1.216	1.219
NORWAY	Krone	NKr	3.933	4.320	4.638	4.912	5.145	5.094	5.451	5.721	6.017	6.243	6.391	6.353	6.496	6.489	6.666	6.742	6.990	7.288	7.289	7.378	7.640	7.902
POLAND**	Zloty	zl	..	..	..	..	..	..	..	..	..	0.170	0.264	0.366	0.478	0.656	0.839	0.990	1.139	1.274	1.371	1.487	1.550	1.576

PORTUGAL	Euro (1999)	€	0.074	0.089	0.111	0.138	0.168	0.203	0.223	0.249	0.274	0.310	0.342	0.381	0.409	0.438	0.453	0.473	0.490	0.504	0.513	0.532	0.551	0.567
200.482	Escudo	Esc	14.77	17.79	22.24	27.71	33.74	40.71	44.76	49.82	54.95	62.13	68.49	76.35	81.96	87.89	90.80	94.74	98.15	101.03	-	-	-	-
SLOVAK REPUBLIC	Koruna	sk	..	..	..	..	..	..	..	..	..	..	..	6.83	7.87	8.93	9.80	10.16	10.95	11.53	12.37	13.11	13.64	13.92
SPAIN	Euro (1999)	€	0.185	0.209	0.235	0.260	0.283	0.314	0.332	0.352	0.376	0.403	0.432	0.461	0.482	0.500	0.524	0.542	0.562	0.572	0.580	0.607	0.628	0.641
166.386	Peseta	Ptas	30.72	34.81	39.08	43.30	47.03	52.23	55.27	58.62	62.54	67.07	71.83	76.67	80.12	83.20	87.21	90.23	93.57	95.22	-	-	-	-
SWEDEN	Krona	Sk	3.048	3.288	3.634	3.906	4.163	4.443	4.652	4.954	5.339	5.804	6.335	6.406	6.597	6.748	6.968	7.028	7.217	7.382	7.389	7.521	7.826	8.073
SWITZERLAND	Franc	SwF	0.952	1.014	1.045	1.081	1.107	1.143	1.172	1.207	1.242	1.294	1.374	1.412	1.449	1.472	1.487	1.523	1.493	1.492	1.539	1.566	1.602	1.600
TURKEY	Lira	Tl	32.1	41.1	52.1	77.1	118.1	160.9	214.6	364.0	637.4	1008.0	1603.4	2625.8	4403.9	9088.5	16995.2	30037.3	55051.8	96760.1	151710.6	221684.2	355445.4	517410.3
UNITED KINGDOM	Pound	£	0.232	0.249	0.264	0.275	0.291	0.301	0.316	0.337	0.361	0.388	0.415	0.431	0.443	0.450	0.461	0.474	0.480	0.494	0.509	0.518	0.523	0.527
UNITED STATES	Dollar	$	0.470	0.498	0.519	0.538	0.556	0.569	0.586	0.606	0.628	0.652	0.677	0.694	0.710	0.725	0.740	0.754	0.770	0.780	0.791	0.808	0.826	0.837

* Mexico had a currency reform in 1993 and the conversion numbers refer to the "Nuevo Peso" which is equivalent to 1000 old pesos.

** Poland had a currency reform in 1995 and the conversion numbers refer to the "new" zloty.

*** Luxembourg and Belgium formed a currency union.

ECU Conversion into Local Currencies

Country	Currency		1981	1982	1983	1984*	1985	1986	1987	1988	1989**	1990	1991	1992	1993
BELGIUM*	Franc	BF	41.264	44.707	45.445	45.439	44.403	43.435	42.708	43.132	43.115	42.423	42.206	41.562	40.499
DENMARK	Krone	Dkr	7.917	8.153	8.128	8.144	7.924	7.867	7.825	7.897	7.999	7.856	7.906	7.803	7.590
FRANCE	Franc	F	6.040	6.431	6.774	6.872	6.719	6.734	6.876	6.988	6.981	6.913	6.974	6.844	6.629
GERMANY	Deutsche Mark	DM	2.512	2.374	2.269	2.238	2.202	2.111	2.056	2.060	2.057	2.051	2.051	2.019	1.935
GREECE****	Drachma	Dr	..	..	..	..	..	..	..	..	..	201.228	225.277	246.436	268.363
IRELAND	Pound	IR£	0.690	0.689	0.715	0.725	0.707	0.723	0.770	0.770	0.772	0.768	0.768	0.760	0.793
ITALY	Lira	Lit	1263.337	1323.409	1349.925	1381.610	1427.897	1449.546	1482.611	1526.917	1501.312	1520.946	1533.366	1593.242	1842.161
NETHER LANDS	Guilder	f.	2.773	2.613	2.537	2.523	2.484	2.382	2.317	2.319	2.320	2.312	2.311	2.273	2.174
PORTUGAL ****	Escudo	Esc	..	..	..	..	..	..	..	..	..	180.969	178.576	174.524	188.235
SPAIN******	Peseta	Ptas	..	..	..	..	..	..	..	..	..	129.402	128.433	132.354	148.972
UNITED KINGDOM	Pound	£	0.553	0.560	0.586	0.591	0.583	0.663	0.700	0.659	0.669	0.715	0.701	0.737	0.781

Country	Currency		1994	1995	1996	1997	1998***
BELGIUM*	Franc	BF	39.681	38.534	39.289	40.524	40.622
DENMARK	Krone	Dkr	7.544	7.323	7.358	7.482	7.499
FRANCE	Franc	F	6.585	6.524	6.491	6.612	6.602

GERMANY	Deutsche Mark	DM	1.925	1.873	1.909	1.964	1.969
GREECE****	Drachma	Dr	287.735	302.812	305.451	309.317	330.725
IRELAND	Pound	IR£	0.793	0.815	0.793	0.747	0.786
ITALY	Lira	Lit	1912.409	2129.210	1957.923	1929.254	1942.983
NETHER LANDS	Guilder	f.	2.159	2.099	2.139	2.210	2.220
PORTUGAL ******	Escudo	Esc	196.873	197.514	195.728	198.592	201.553
SPAIN******	Peseta	Ptas	158.879	162.984	160.727	165.856	167.187
UNITED KINGDOM	Pound	£	0.775	0.828	0.813	0.692	0.676

* The ECU-basket changed its composition on Sep 16, 1984. The values for 1984 are calculated with the old composition.

** The ECU-basket changed its composition on Sep 21, 1989. The values for 1989 are calculated with the old composition.

*** The Euro introduced in January 1999 replaced the ECU at par (1:1).

**** The currencies of Greece, Portugal and Spain are included in the composition of the ECU-basket since Sep 21, 1989.

Source: International Financial Statistics Online (database by the International Monetary Fund, http://www.imf.org) and PACIFIC Exchange Rate Service (UBC, http://fx.sauder.ubc.ca/)