FACTORS AND POLICIES AFFECTING DEMAND FOR LIGHT VEHICLE TRANSPORTATION IN THE LOWER MAINLAND OF BRITISH COLUMBIA

by

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B.Sc. (Agr.), University of Alberta, 1992

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF

THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE

in

THE FACULTY OF GRADUATE STUDIES

Department of Agricultural Economics

We accept this thesis as conforming
to the required standard

THE UNIVERSITY OF BRITISH COLUMBIA

May 1995

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Date June 28, 1995

DE-6 (2/88)

ABSTRACT

As transportation is a key component of economic success, it is crucial that the transportation systems in the Lower Mainland accommodate, and shape the projected increases in population. This paper has two main objectives. The first is to explore the factors and variables influencing demand for automobile transportation that are unique to the Lower Mainland of BC. General trends and statistics are explored for peak a.m. period automobile demand. The second part of this paper looks at the policies affecting demand for automobile transportation. Economic theory is introduced to two prominent traffic demand management (TDM) policies: road pricing and high occupancy vehicle (HOV) lanes. Conceptual models are proposed for both policies.

In 1993 the GVRD completed the *Transport 2021* study. Using data that was generated by the EMME2 model, empirical estimates of consumer surplus changes (resulting from various TDM policies being implemented) are considered under a range of elasticities. Empirical estimates of consumer surplus changes are also calculated for the conceptual models.

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ACKNOWLEDGMENTS

I would like to thank my Advisor, Dr. Case van Kooten, for his helpful comments and for arranging my funding. I would also like to thank my committee members Dr. Jim Vercammen, and especially Dr. Bill Waters, for their insightful comments. I am very grateful to Roger McNeill and Environment Canada for supporting this project.

Many thanks to Kathy and Retha for all their support in maneuvering through the university bureaucracy. Thanks to my Ag Ec friends and colleagues for their help and laughter.

I would like to dedicate this thesis to the Three Sisters and Shelley, whose love and support kept me going.

CHAPTER ONE: INTRODUCTION

1.1 Background

Travel and transportation are essential factors in human survival and success. Our relentless quest for food, shelter, work and recreation are all facilitated by mobility. It follows that a key component to our success is the availability of efficient and reliable transportation.

By the year 2021, the population in the lower mainland of British Columbia is projected to grow by 69%, from 1.72 million to 2.90 million people. As well as growing in size, the population is expected to undergo demographic changes. Population will shift by geographical location, employment distribution and age distributions (GVRD 1993). If current trends in transportation continue, and if no demand management measures are implemented, the number of automobile trips made between 6:00 and 9:00 a.m. will double by the year 2021 (Table 1.1). As transportation is a key component of economic success, it is crucial that the transportation systems in the Lower Mainland both accommodate and shape the projected changes in population.

Table 1.1: Morning Rush Hour Statistics for the City of Vancouver, Current and Projected

Transportation Criteria	1991 Base	2021 (Current Trends)
a.m. Peak Hr. Person Trips		
Total	**392,100**	**701,700**
Auto Passengers	74,100	135,500
Auto Drivers (vehicle trips)	215,400	405,900
Transit	49,300	80,300
Walk	53,300	80,000
Vehicle Kilometres Travelled (VKmT)	**2,670,000**	**5,040,000**

Source: (GVRD 1993d).

Private use of automobiles is primarily responsible for many harmful and costly externalities imposed on society. Rapidly increasing levels of air and noise pollution, congestion and urban sprawl cannot be adequately abated with technological solutions. Therefore, it is important to focus on factors affecting the demand for automobile use, and on policies that reduce the use of single occupancy vehicles (SOVs).

Some recent statistics on the harmful effects of automobile use in Canada are listed below (see MacRae 1994).

Environmental: In 1990, the transportation sector accounted for 32% of Canada's human generated emissions of carbon dioxide (CO_2), 63 % of the nitrogen oxide (NO_x) emissions and 43 % of volatile organic compounds (VOC). Exhaust emissions produced by vehicles contribute significantly to global warming, acid rain and urban pollution. Table 1.2 provides some statistics on pollution per-unit by mode of transport in United States.

Table 1.2:Pollution Emitted from Typical Work Commutes in the United States[a]

Mode	Hydrocarbons	Carbon Monoxide	Nitrogen Oxides
	(grams per 100 passenger-kilometres)		
Rapid Rail	0.2	1	30
Light Rail	0.2	2	43
Transit Bus	12	189	95
Van pool	22	150	24
Car pool	43	311	43
Auto[b]	130	934	128

[a] Based on national average vehicle occupancy rates.
[b] Based on one occupant per vehicle.
Source: Lowe (1990, p.14)

Land Use: Cars radically alter the urban landscape. In urban areas up to 42% of the land in a downtown core, and up to18% of the land in the greater metropolitan area many be occupied by motor vehicle infrastructure. More than one-third of the land in

developed countries is used for roads and parking lots. In the United States, some 0.6 hectares (1.5 acres) of land per capita are paved. Vast areas of land are paved over to be used for private automobile transportation. Table 1.3 uses operating speed and persons moved per meter-width of land per hour as approximate measures mode efficiency.

Table 1.3: Number of Persons per Hour that One Meter-Width of Land can Carry, Selected Travel Modes

Mode	Operating Speed[a] (kilometres per hour)	Persons[a] (per meter-width of land per hour)
Auto in mixed traffic	15-25	120-220
Auto on highway	60-70	750
Bicycle	10-14	1,500
Bus in mixed traffic	10-15	2,700
Pedestrian	4	3,600
Suburban railway	45	4,000
Bus in separate busway	35-45	5,200
Surface rapid rail	35	9,000

[a] Ranges adjusted to account for vehicle occupancy and road speed conditions in developing countries.
Source: Lowe (1989, p.22)

Congestion: Time delays and costs are experienced by all drivers as the number of trips made increases. However, congestion is an external cost that is not realized by individual drivers. It is the effect that adding one more vehicle to the road has on other drivers. Unless road capacity is enhanced, an increase in the number of cars and number of miles travelled per capita results in increased congestion. Congestion increases environmental damage and commuter time. It also raises vehicle operating costs and lowers worker productivity.

British Columbians do not have to look far to see the effects that unbridled automobile use can have on cities, a prime example being Los Angles. Transportation stakeholders have begun to investigate policies that reduce the demand for automobile use. Until recently this approach has been seen as unorthodox, roadways were viewed as public utilities, to be provided on demand. However, engineers have long known of the concept of latent demand. If capacity is expanded, demand will increase to fill the new capacity. As well, rising costs of road construction and shrinking budgets have made road building increasingly difficult. These factors in combination with a heightened sense of responsibility for the environment has lead to policies know as transport demand management (TDM) (Orski 1990).

As the demand for light vehicle transportation in the Lower Mainland is projected to increase significantly, policy makers are faced with the difficult task of striking a balance between reducing demand for automobiles and providing alternative public transportation. The next section provides a brief history of the development of TDM policies in the Lower Mainland.

1.2 Historical Overview

During the past 30 years, the population of greater Vancouver doubled and employment tripled. In response to this growth the *Liveable Region Strategy* was developed in the early 1970s. Its primary goal was to manage the tremendous pressure of urban growth. During the next 30 years, population and employment levels in the greater Vancouver area are expected to double again. These projections prompted the Greater Vancouver Regional District (GVRD) to adopt the *Creating our Future* action plan in 1990. *Creating our Future* was a renewal of the region's commitment to maintain and enhance liveability in greater Vancouver. The mission statements contained in *Creating Our Future* were concerned with drinking water quality, sewage, solid waste disposal, air

quality, green zones and liveable communities. Transportation fell into the liveable communities category.

The *Liveable Region Strategic Plan* was developed as a framework to implement policies from *Creating our Future*. It was composed of several in-depth, technical studies that were carried out for each mission statement. In 1993, the GVRD in co-operation with the BC Ministry of Transportation and Highways (MoTH) and BC Transit carried out *Transport 2021*. *Transport 2021* was a technical analysis of how to carry out *Creating our Future*. *Transport 2021* recommends a long range transportation plan for greater Vancouver, with associated demand management policies and priorities for transportation investment.

1.3 Problem Statement

The factors affecting demand for automobile transportation are the same for each region or city. The costs of transportation, the costs of substitute forms of transportation, land use policies, demographic factors and income all affect the demand for transportation. However, the specifics of these factors are unique to a specific city or region. The first part of this thesis will identify the factors affecting demand for single occupancy vehicle (SOV) use during peak a.m. hours in the Lower Mainland. A non-theoretical approach will be used, major trends and strengths of these variables will be explored.

As automobile use creates congestion and pollution externalities, an understanding of externality theory and the economic instruments used to correct externalities provides a useful framework for understanding the rationale behind traffic demand management (TDM) policies. Because many TDM polices are derived from externality theory, they are modelled within a social cost-social benefit framework. Developing a private cost framework can provide insight into the costs and benefits to consumers. A conceptual

framework for four economic instruments being considered for the Lower Mainland is developed. Economic concepts such as elasticities are often neglected in planning reports, yet assumptions regarding elasticities can have major effects on policy evaluation.

Transport 2021 has estimated various base case scenarios for numbers of trip made in the a.m. peak hours and the average cost of these trips. Applying this data to the conceptual models developed, welfare changes as a result of various TDM policies can be estimated.

1.4 Thesis Overview

Chapter two focuses on factors affecting the demand for light vehicle transportation in the Lower Mainland. A non-theoretical approach is taken; general trends and statistics specific to the Lower Mainland are highlighted. Chapter three looks at the externalities associated with automobile use, and the theory behind how economic instruments are used to correct for market failure. Chapter three then examines four economic instruments (TDM polices) being considered in the Lower Mainland. Conceptual models are developed for road pricing and high occupancy vehicle (HOV) lanes and incentive scenarios are dicusssed for parking charges and gas taxes.

Chapter four provides empirical estimates of welfare changes resulting from the TDM policies being implemented. Firstly, welfare results are estimated under different assumptions regarding demand elasticity. Secondly, welfare changes resulting from implementing road pricing and HOV lanes are estimated using the conceptual models developed in chapter three. Sensitivity analysis is performed under various elasticities and price changes. Chapter five provides conclusions from the empirical estimates obtained in chapter four. It also proposes further conclusion from the literature and further research is recommended.

CHAPTER TWO: FACTORS INFLUENCING DEMAND FOR AUTOMOBILE TRANSPORTATION IN THE LOWER MAINLAND

2.1 Demand for Transportation: What is it?

Before introducing the factors influencing demand for automobile transportation in the Lower Mainland, it is important to define exactly what is meant by transportation demand and highlight some of the unique characteristics of transportation demand.

The demand for transportation stems from the interaction among social and economic activities that are dispersed throughout space (Kanafani 1983). There are many socio-economic variables involved in creating transportation patterns. Thus, systematic and formal methods of analysis are required in order to understand the relationships among these variables. The first step in determining the relationship between socio-economic activities and transportation needs is to develop a meaningful measure of those needs. Transportation needs manifest themselves in the form of traffic volume. However, a single measurement of traffic volume is not sufficient to express the need for transportation for two reasons. First, the flow of traffic in a congested area does not truly measure demand as it does not account for the flow of traffic into the area if additional capacity is provided (Kanafani 1983). Second, traffic volume is a function of the supply of transportation services.

To illustrate the first part more clearly consider the following scenario: Town A is located in a rural community and grows food. Town B is an industrial area where no food is produced. The two towns are separated by rugged mountains. Town B is the obvious market for the goods produced in town A, but initially there is only a crude path connecting the towns that can only be negotiated by mule. As it takes many hours for a merchant from town A to reach the markets in Town B, the price of food is much higher in town B than in Town A. Now consider a primitive road that cuts travel time in half.

It now pays for the merchant to lower the selling price at B and sell the food products to more people in the industrial town. The same scenario can be extended for a paved road; lower travel costs result in more merchants from town A travelling to Town B. If a traffic counter had been placed along the rugged path there would have been very little traffic, and the conclusions would have been that there is very little demand for transportation. However, as traffic counts increase with improved road condition, an observer would assume that there is a high demand for transportation. This suggests that the demand for transportation between A and B depends on the type of transport system, and that demand can be increased by improving that system. This is an incorrect conclusion. What is required to measure the true demand for transportation is the economic definition of demand.

In economics, demand is expressed as a schedule or demand function; the different amount people are willing to pay for different quantities of a good or service. Transporting people consumes time and energy and thus creates a cost. Traffic levels that occur at different levels of cost represent the demand for transportation. In summary, the demand for transportation results from the spatial distribution of socio-economic variables, while the volume of traffic is the interaction between the demand and the supply of services being provided. Demand for transportation and traffic volume should not be used synonymously.

2.2 Demand Versus Behavioural Factors

Synthesising the vast theory and literature on traffic forecasting, with transportation economics is a conceptually challenging task. The nature of demand analysis has changed substantially over the years. Initially transportation studies were aggregate, engineering models--giant traffic counts that were used in large scale, land use

plans. They extrapolated "traffic demand" from observed data on route choice, mode choice and trip generation. These are all observable behaviours that manifest as the demand for transportation. What these models did not take into consideration are the underlying factors affecting these observed choices; the true factors influencing demand.

Modern transportation demand models are solidly based on microeconomics theory, and use behaviourally-based, disaggregate models (Small 1992). The standard demand equation specifies the quantity demanded as a function of the price of that particular travel, the price of available substitutes, income and a range of other socio-economic variables. In turn these variables affect the different observed behaviour patterns (route choice, mode choice and trip generation), which in turn affect demand levels for transportation. It is important to distinguish between these underlying economic factors and the observed aspects of demand.

2.3 Price

The main factor determining demand for all goods and services is the price. There are two main costs individuals perceive when making decisions about driving. The first is out of pocket expenses that necessitate driving, such as gas, oil, maintenance, insurance and depreciation (Quand 1970). These prices can vary from day to day, but they are usually considered fixed in the short run, and they are definitely fixed along the course of one trip. The second, more important and controversial category is time costs. There are many divergent theories on the value of time and how people perceive differences in time savings. Some generalisations or themes can be recognised from the literature.

Value of Time Travel Savings

Economists have long recognised that the time spent consuming a commodity may be an important determinant of the demand for that commodity. Numerous studies have attempted to develop methodologies that incorporate the value of time into a behavioural model. Much of the work done in this field has been done by transportation and recreation economists. The value of time travel savings can be defined as "the amount of money an individual must be willing to lay out in order to receive a given amount of a composite characteristic named 'time', but of which time savings is only one element" (Hensher 1976). In conceptual terms, the value of travel time saved can be measured along a driver's indifference curves between transportation choices. These choices could be anything from route choice to mode choice. It is the rate the motorist is willing to trade more money for less time travel. For example, route one is a tolled road that allows a time savings while route two is an untolled, congested road that allows for a monetary savings.

There are diverse estimates of the value of time savings. They are almost always expresses as a percentage of an individuals wage rate. Estimates range from 40% of wage rate in the UK to 60% in the US (Waters 1994). *Transport 2021* value personal time as 50% of the wage rate for Lower Mainland residents, or about $18.00 per hour. There is little dispute with the concept that time is a scarce resource that consumers base transportation mode choices on. However there is controversy on how time saved or lost translates directly into changes in production.

There are many factors that influence how consumers value time, and subsequently the value of time travel savings. As the value of time is one of the main components of cost (price), which in turn is one of the most important factors to affect demand for vehicle transport, the value of time is important. The reduction in a motorist's travel time is often the major benefit of proposed transportation policies, so it is important to convert hours of time saved to dollars. In real life we can not observe all the decisions drivers make, so the money versus time saved trade off must be inferred from the relationship that emerges when route choices of motorist are estimated. Data for estimating these choices include: alternate trip costs and time saved.

VTTS and Income

Thomas and Thompson (1970) discovered that the value of time saved for commuting motorists is a function of the motorist's income level and the amount of time saved; the value of time is higher for motorists with higher incomes. The value of time saved (VTTS) for commuting motorists is equivalent to their willingness to pay to reduce commuter time. However they also found that this relationship is not as straightforward as it appears. Waters (1994) agrees that the value of time travel savings will differ with income levels and it is likely to be a positive relationship. "Since time is fixed at 24 hours per day, higher wages imply an increased opportunity cost of time." What is less obvious is the role that cultural and personal differences will play in affecting how consumers value time. Waters (1994) also conducted a survey of literature that links the value of time travel savings and income. The results range from Quarmby (1967) finding the

VTTS to be a constant proportion of income, to Heggie (1976) who did not find a link between incomes and values of time.

This relationship between income and the VTTS could have important ramifications in affecting the demand for automobile transportation in the Lower Mainland. Certain regions within the Lower Mainland have experienced large changes in income levels during the past 10 years. Commuters in the regions with higher incomes are going to be more likely to have higher values of time travel savings. As a result, promoting alternative forms of transportation in these regions (Table 2.1) may be more difficult.

Table 2.1: Per-cent Change from 1984-1991 in Income per Taxfiler-Current Dollars [a]

Localities	% Change	Localities	% Change
Burnaby	0.11	Port Coquitlam	4.41
Coquitlam	2.32	Port Moody	8.30
Delta	4.58	Richmond	-0.29
Langley*	22.73	Surrey	4.55
New Westminster	1.98	Vancouver	0.78
White Rock	13.46	West Vancouver	16.74
North Vancouver**	5.10	Greater Vancouver	9.59

a These figures have been adjusted for inflation (1986 dollars)
* Denotes both the city and Township Langley
** Denotes both the city and the district of North Vancouver
Source: GVRD 1993d

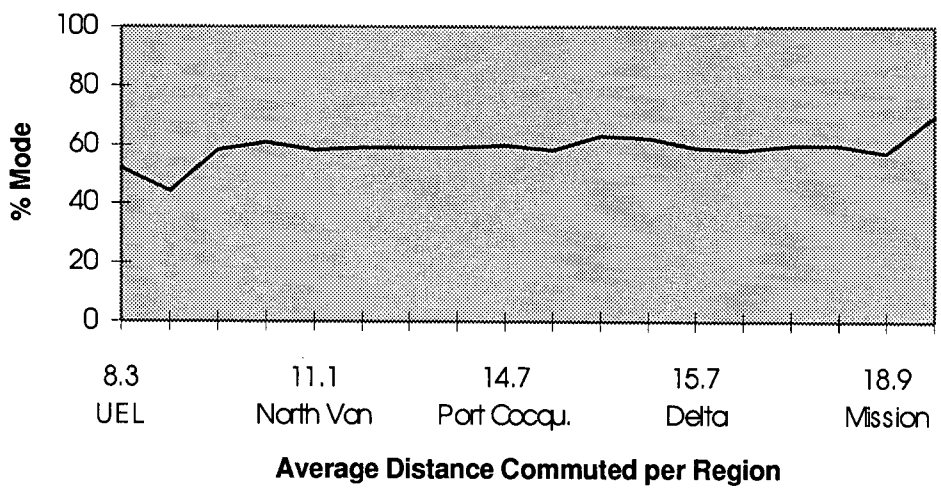
VTTS and Journey Length (Amount of Time Saved)

Hensher (1976) estimated that "as the amount of travel time increases, an individual is willing to pay more, for any trip length, to save a unit of time. As the trip length increased, however, the increment is proportionally less for that same unit of time." This finding corresponds to Thomas and Thompson (1970) speculation that the

relationship between time savings and journey length is not linear, but rather S-shaped. For very small amounts of time saved on longer journeys, motorists are insensitive to reductions in trip time, while economic theory suggests an eventual diminishing marginal utility of time saved as the amount of time saved continued to increase.

Using data for various regions in the Lower Mainland, distance commuted (in km) was plotted as a percentage of mode share for automobiles (Figure 2.1). As automobiles are perceived to provide the greatest time travel savings, the purpose is to determine the role distance (implied time) commuted is having on automobile mode share.

Figure 2.1: Mode % as a Function of Distance Commuted (km)



Source: (GVRD 1992a)

Figure 2.1 shows the average commuter distances within each region. In the University Endowment Land's (UEL), and other areas with a higher supply of public transport, the mode share of automobile usage is lower due to a relative abundance of public transportation. Until the journey distances are quite high, at almost 19 kilometres, mode share does not change much. It remains relatively consistent at 60%. This is

interesting as it shows that actual distance may not be that important determining mode share for automobiles.

VTTS and Uncertainty

Another factor that can influence how consumers value time is the notion of uncertainty. Menashe and Guttman (1986) showed that this is a significant variable in a consumer's decisions about mode choice. This could have many implications for evaluating substitutes for vehicle demand. For example, transit might become a much more viable substitute if the uncertainty of using transit was reduced.

2.4 Substitutes

Attempts to get North Americans to choose alternative modes of transportation have largely been unsuccessful. It has been difficult for all levels of government to adequately deal with excess private automobile use. One reason is political. There is little political will to spend large sums of taxpayer money to construct more rapid or light rail systems, while taxing private automobile use to take account of its externality effects. In the past, government emphasis was on supply expansion, building more and larger freeways. It is now recognised that larger roads, in conjunction with inappropriate land use, exacerbates the problems of urban sprawl, traffic congestion, pollution and time costs.

One of the challenges facing decision makers is that of encouraging individuals to adopt other forms of transportation, whether it is public transportation or alternatives

such as bicycles. Evidence from European countries such as the Netherlands indicates that a "carrot-and-stick" approach is needed. Penalties on private use of motor vehicles (e.g., gasoline taxes, high parking rates) can not be imposed without, at the same time, providing alternative modes of transportation that are competitive with private vehicles. European experience indicates that, since time is a major factor in commuting and is highly valued, penalties must be very high indeed before a commuter chooses to take public transit that increases commuting time. For example, Sweden has a gasoline sales tax of 133 percent and an automobile sales tax of 41 percent, compared to gasoline and automobile sales taxes of 41 and 5 percent, respectively, in the US (Lowe 1990). Yet, the average number of kilometres driven per person is higher in Sweden than the US (8,000 versus 7,700). A tax without adequate substitutes can be ineffective.

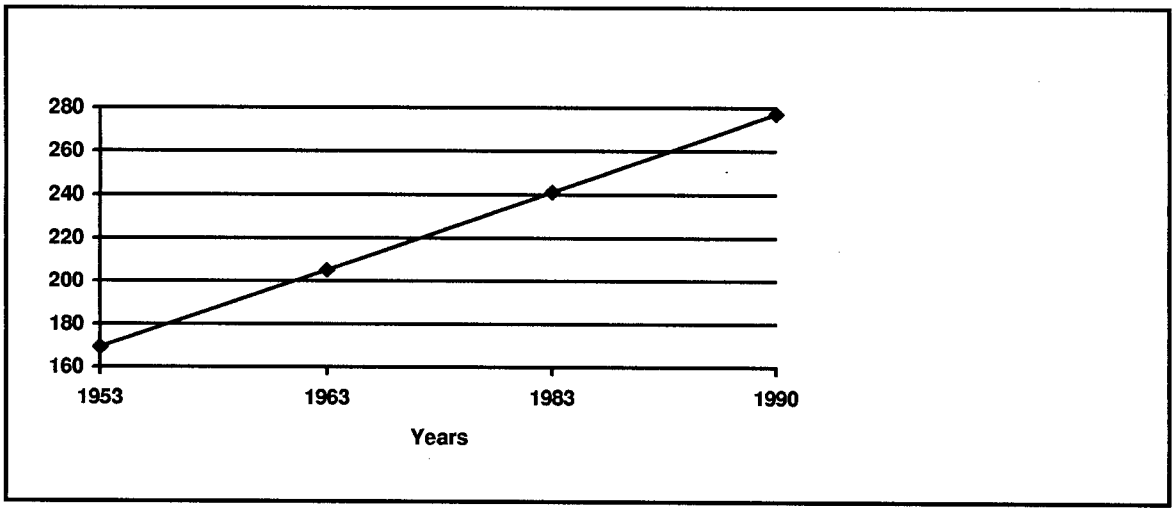
Therefore, it is necessary to employ the stick of high penalties with the carrot of a good public transportation system. For example, in 1988 the Dutch government announced a policy designed to reduce the number of automobiles from the current 5 million to just 3.5 million in 20 years, compared to the forecast number of 8 million. The policy will increase the costs of buying and operating an automobile by about 50 percent, but $5.7 billion per year will be spent on improving public transportation.

Similar comments can be made about the use of bicycles. In many low-income countries where there is greater reliance on bicycles because motor vehicles are too expensive for many citizens, high rates of traffic fatalities are the result of collisions between bicycles and motor vehicles (Lowe 1989). Data from cities in developed countries indicate that, unless bicycles can be physically separated from motor vehicles,

only a small proportion of daily vehicle trips will be made by this environmentally-preferred mode of transport. For example, 50 percent of daily passenger trips in the city of Groningen in the Netherlands are made by bicycles, compared to 20 percent for Copenhagen, Denmark. The main reason has to do with the adoption of a pro-bicycle policy designed to separate bicycles from motor vehicular traffic in the former city. The approach in most North American cities has simply been to identify some streets as bicycle routes, sometimes including bicycle lanes, but this has been done as a political expedient with little if any attempt to separate bicycles from other traffic. Hence, "bike route" policies have failed to encourage greater reliance on bicycles and a shift away from automobiles.

Another European example of how developing substitutes can affect the demand for transportation is Zurich. The city of Zurich has had great success altering behaviour by strengthening substitutes. Zurich has introduced and rigorously enforced exclusive lanes for buses, with a complementary, transferable fare structure, zero waiting time at traffic signals and service that is comfortable and convenient for users (Fitzroy and Smith 1993). Zurich's dramatic increase in the use of substitutes is illustrated in Figure 2.2. Since 1985 the absolute number of trips have risen dramatically to about 280 million in 1990. This represents a 33 percent growth in six years. This growth is accompanied with a stabilisation in car numbers on main roads since 1981.

Figure 2.2: Passenger Trips Made by Public Transit in Zurich (in millions)



Source: FitzRoy and Smith (1993 p.21)

When quantifying the relationships between substitute forms of transportation, cross price elasticities are used. Elasticity refers to the sensitivity of a dependent variable (number of trips) to a change in one of the independent variables, *ceteris paribus*. Demand elasticities are approximate measures of aggregate response in a market; they are empirically estimable, easy to understand and important for policy assessment. Low elaticities imply difficulty in influencing amount demanded, and an ability to influence revenue. High elasticities have the opposite relationship. Cross-price elasticities are important as they measure the strength and direction of the relationship between two markets.

The own-price elasticity of demand for mode i is defined as;

$$\varepsilon_{ii} = \frac{\partial q_i}{\partial p_i} \quad \frac{p_i}{q_i}$$

If mode i is bus use, then own price elasticity indicates the change in number of trips made by bus as the costs of making each trip change. The cross-price elasticity of demand for mode i with respect to the price of mode j is:

$$\varepsilon_{ij} = \frac{\partial q_i}{\partial p_j} \frac{p_i}{q_j}$$

Cross-price elasticity indicates changes in number of trips made by bus as the costs of using mode *j* (i.e., an automobile) change. Two goods are considered substitutes if the cross price elasticity is positive. If the costs of driving an automobile go up what will be the effects on number of trips taken by public transit? Presently, there is little empirical evidence to indicate if there is any strong substitution between public and automobile transportation during peak hours. The few studies that have looked at cross price elasticities involving automobiles report very inelastic figures. Table 2.1 provides estimates for various cross price elasticities.

Table 2.2: Cross Price Elasticities Trended to 1991

	Year	Tube	Bus	Car
From Increased	1991 (i)	*-0.281*	+0.098	+0.006
Tube Fares	1991 (ii)	*-0.300*	+0.110	+0.008
From Increased	1991 (i)	+0.054	*-0.268*	+0.013
Bus Prices	1991 (ii)	+0.070	*-0.300*	+0.015
From Increased	1991 (i)			*-0.271*
Gas Prices	1991 (ii)			*-0.18*

* *Own price elasticities on diagonal*
(I) Trended to 1991
(ii) These trended elasticities adjusted to reflect long term adjustments to change in the base year.
Source: Beesley (1983, p.187)

These inelastic estimates are important as they indicate that increases in out of pocket expenses may be an ineffectual policy tool if the goal is to encourage people away from cars to other forms of transportation. The largest costs people perceive are the loss of time, comfort, convenience and safety. Lowering fares will not increase transit ridership. Fitzroy and Smith (1993) point out that preoccupation with road pricing is "inappropriate because, even with road charges, private vehicles obstruct the progress of spatially efficient buses and trams" (Fitzroy and Smith 1993, p.213).

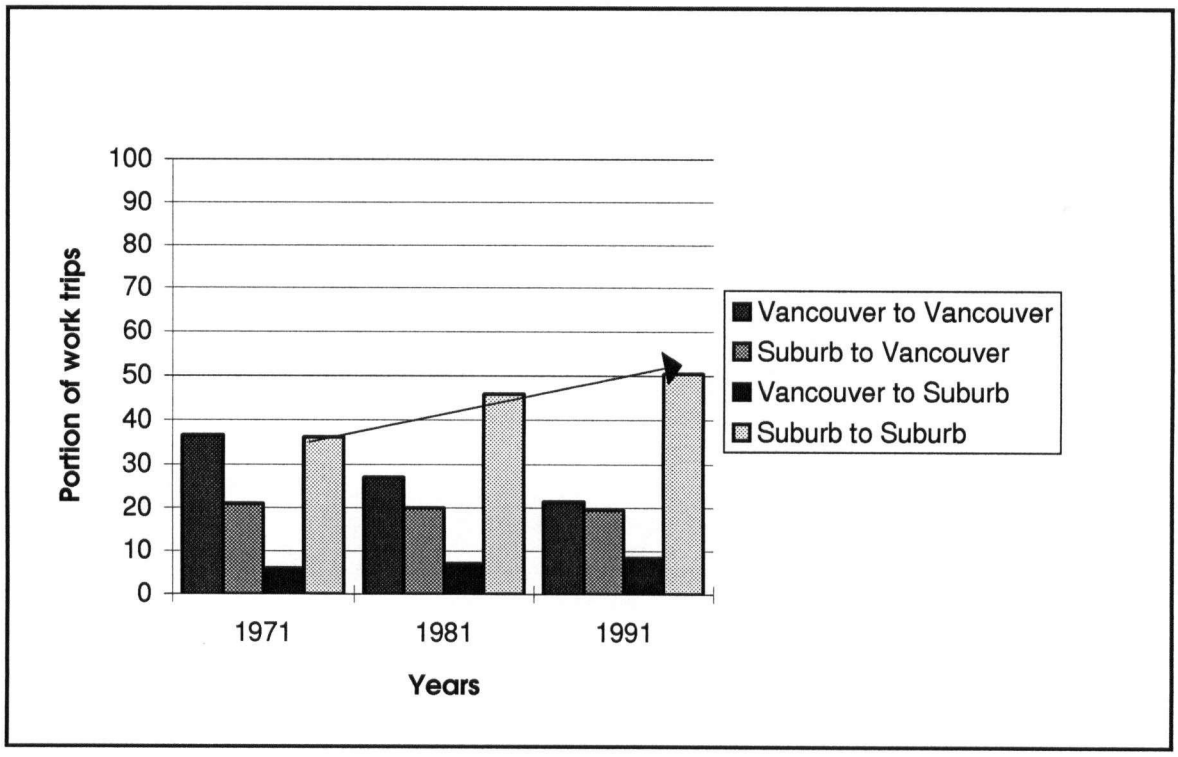
2.5 Demographics

There has been a growing awareness and concern over the relationships among population, jobs, housing and transportation. Lack of affordable housing within reasonable proximity to employment centres is lengthening commutes, while the sub-urbanisation of employment is creating strains on existing transportation capacity. Meanwhile, proposals to increase road capacity are denounced as they will only add to the problems of congestion and air pollution. Population and employment levels have risen dramatically in the past 20 years in the Lower Mainland and, according to projections, will continue to rise to 2021. However, it is not only employment and population levels that affect demand for transportation, but the spatial distribution of these demographic variables. Income levels and age are also important determinants of transportation demand.

Population and Employment

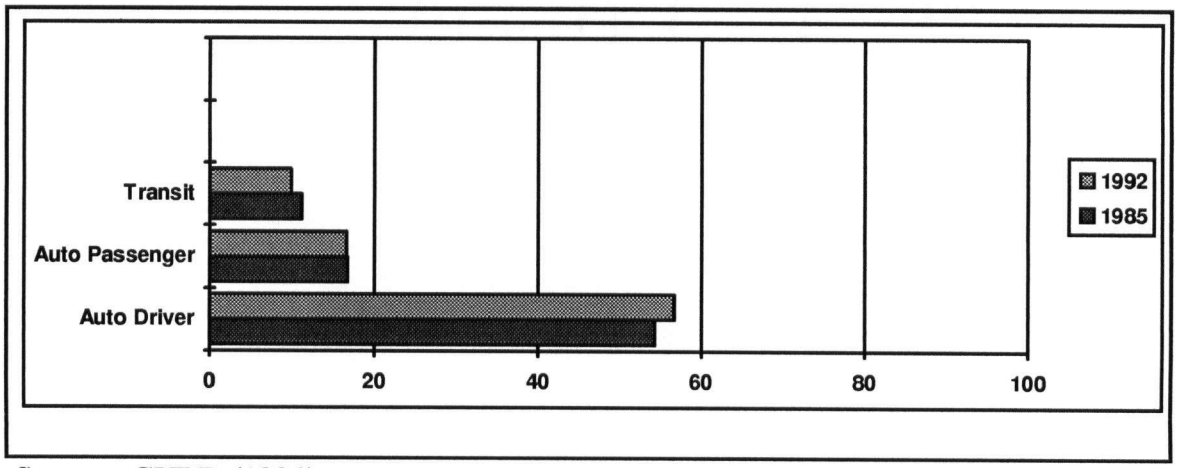
Between 1985 and 1992, the number of individual rush hour trips made within the Greater Vancouver District increased by 42 percent, to almost one million each morning. However, population growth and employment were insufficient to account for this growth alone. The key factor leading to the increased commuter demand was the sub-urbanisation of employment and population. There has been a long-term trend towards sub-urbanisation in the Lower Mainland and, as a result, new travel patterns have emerged. Twenty five years ago, almost 90 percent of commutes were made from the suburbs to downtown Vancouver. Travel patterns consisted of radial lines expanding out of a circle. Today only 50 percent of all commuter trips are made from suburbs to the downtown core; the remaining trips originate and end in a suburb. Figure 2.3 illustrates the increasing number of suburb to suburb commutes. Not only have the travel patterns changed, but more of these commutes (inter-suburb) were made by automobile as illustrated in Figure 2.4.

Figure 2.3: Changes in Commuting Patterns 1971-1991



Source: GVRD (1994)

Figure 2.4: Morning Peak Period Total Trips and Mode Share



Source: GVRD (1994)

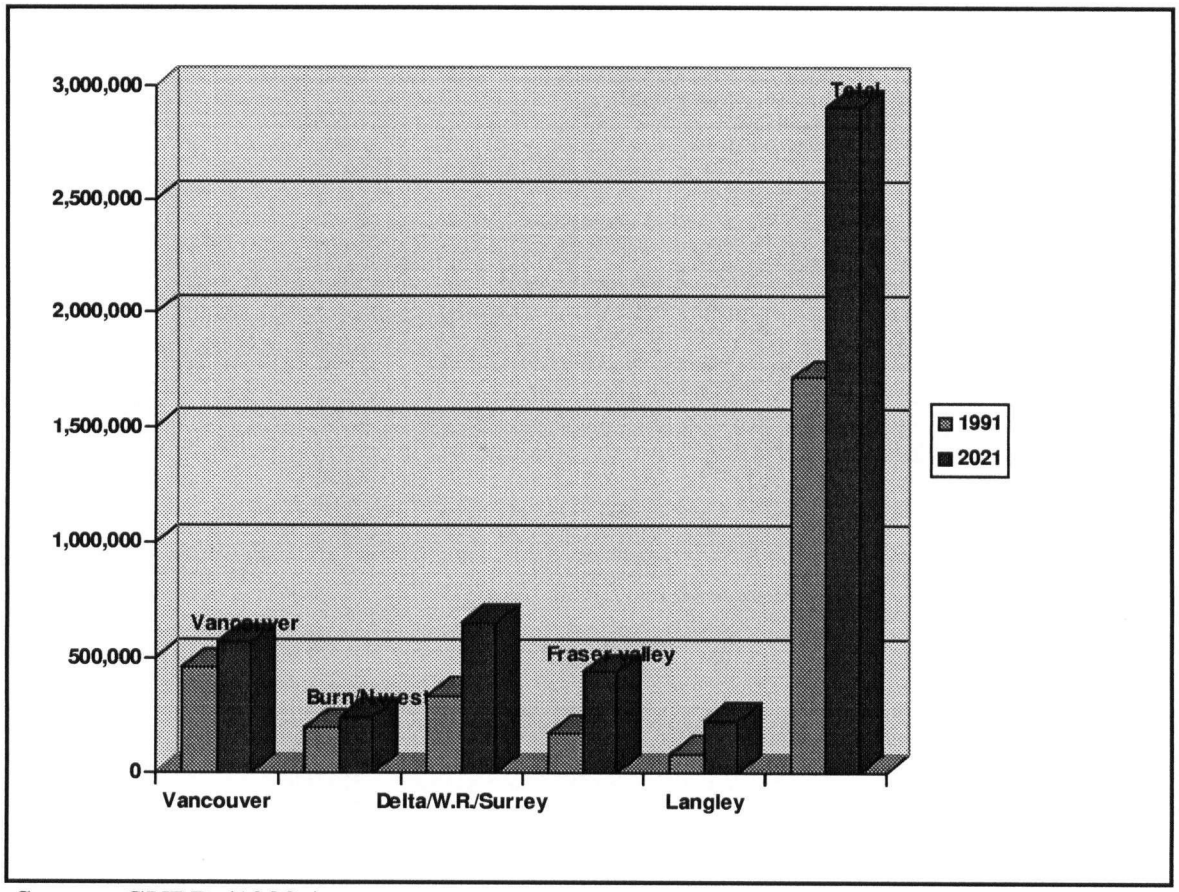
Population and employment distributions are especially important as they indicate "where" demand will be. For example, the *Transport 2021* study projects population distribution for the year 2021 under three different scenarios. The current trend scenario, provides a pattern of land use that could result in a metropolitan Lower Mainland if growth in housing demands follow historical trends. The second option is the Fraser North Option. It focuses growth on the north side of the river to ease development pressures on agricultural land, and other green spaces located on south side of the river. The third option is the compact metropolitan option, which would contain urban growth within the urbanised portion of the region: Vancouver, Burnaby, New Westminster, Northeast sector, North Delta and North Surrey. A detailed analysis of current and proposed zoning and land use policies would be essential if demand for automobiles is to be estimated.

What are the main driving forces behind this increasing demand? It is two things population and employment growth, both of which Vancouver is expected to have. Figure 2.5 illustrates regional, as well as total population projections within the GVRD. The same areas that show significant population growth are also the ones with the greatest employment growth. In 1991 number of persons employed was 814,700, while it is projected to be 1,518,000 by the year 2021 (GVRD 1992a).

There was more travel by automobile than public transit from 1985 to 1992. The number of a.m. peak period automobile trips increased by 48 percent, while trips by public transit increased by only 25 percent, which is only slightly ahead of population growth. The increase in automobile trips resulted from the majority of job growth being

dispersed throughout the region in suburban areas, and /or in areas that are difficult or inaccessible to public transit. Suburb to suburb commutes have increased overall, and particular suburbs are going to experience heavy demand increases (Figure 2.5).

Figure 2.5: POPULATION GROWTH BY SUB-REGION 1991-2021[a]



Source: GVRD (1992a)
a: assumes current growth rates

There was also a large increase in trips "other than" work trips. The largest increase was in numbers of trips taking children to school and dropping spouses off at work or transit stops (GVRD 1994). These changes in trip generation could have important policy implications.

Income

Demand for transportation is also a function of consumer income. The most common proxy variable is household disposable income. Income levels often determine which mode of transportation an individual will use. Higher income earners are more likely to travel by automobile, and lower income people are more likely to travel by public transit. It is not only the ability to own a car that induces wealthier people to use automobiles, it is also the high value of their time.

2.6 Land Use

There are some unusual relationships between the demand for transportation and land use that should be addressed. The first is an inherent endogeneity problem with regard to land use and transportation. Land use affects transportation and transpotation affects land use. This can have many implications for modelling techniques and policy decisions. Second, building and activities do not exist independently of the transportation systems that serves them. Whereas price and quantity of other goods and services are usually uniform throughout the city, transport varies greatly from one part of the GVRD to the next. This also can create modelling difficulties. Third, transportation is a derived demand. Even if transportation costs were zero, there would be little incentive to engage in transportation just for the sake of transportation. This creates a strong relationship between demand for transportation and demand for socio-economic activities, all of which involve the use of land.

There are many economic theories relating land use to transportation: from von Thunen and Ricardo, to the business location theory (see, e.g., van Kooten 1993). In summary, they postulate that transportation improvements will tend, simultaneously, to concentrate employment sites while decentralising worker housing. Conversely, worsening transportation services will favour decentralisation of jobs, but support higher density housing.

The economic viability of public transportation systems depends on a variety of factors that are related to land use. Urban densities and commuting choices are provided in Table 2.3. It is clear that the higher the urban density, the more likely a commuter will choose public transport (assuming public transport is an available option). However, it is unlikely that rapid rail transit will be a viable option in areas of low-density housing and urban sprawl.

Table 2.3: Urban Densities and Commuting Choices, Selected Cities, 1980

City	Land Use Intensity	Private Car	Public Transport	Walking and Cycling
	(pop.+jobs/ha)	(percent of workers using)		
Phoenix	13	93	3	3
Perth	15	84	12	4
Washington	21	81	14	5
Sydney	25	65	30	5
Toronto	59	63	31	6
Hamburg	66	44	41	15
Amsterdam	74	58	14	28
Stockholm	85	34	46	20
Munich	91	38	42	20
Vienna	111	40	45	15
Tokyo	171	16	59	25
Hong Kong	403	3	62	35

Source: Newman and Kenworthy (1989)

San Francisco and Vancouver are cities where house prices fall as one moves farther into the suburbs and commuting distances increase. Often the burden of economic penalties designed to reduce private automobile use falls upon those in the relatively lower income categories who cannot afford housing close to their jobs in the city. An increase in commuting costs gets capitalised in land values, so that land closer to the urban centre where jobs are located becomes more expensive. This increases commuting distances for many lower income earners because they are forced to locate even farther away from their place of employment in order to find affordable housing. It also puts greater pressure on conversion of agricultural land (Corbett 1990).

Land Zoning

While automobiles have had a profound affect on land use, land use policies themselves are a significant contributor to the demand for transportation services, particularly private-use vehicles. Land use policies are designed to preserve open space and/or agricultural land, to separate incompatible land uses, and often to exclude lower income people from certain areas (McDonald 1995). However, such policies have resulted in urban sprawl, which in turn has increased the demand for transportation services. Since urban sprawl makes public transport less efficient because people are not concentrated along public transportation corridors,[1] it has contributed to greater use of automobiles.

Land zoning and land use policies are major determinants of many of the exogenous variables just mentioned, such as population and employment. However, land zoning is also an economic instrument used to control demand. The endogeneity is a result of land use patterns affecting transportation as it dictates who and what economic activity will occur. Feedbacks from the economic activity then affect the demand for

[1] This assumes that roads would have been built in any case.

transportation. If solutions to the problem of urban congestion are to be solved, it is crucial that the interaction between land use and transportation be understood. Economic theory offers a strong paradigm for the basic relationships but sociological and historic insights also need to be examined (Brand 1991).

The pattern of land use reflects the locational requirement of many individual land users. It also reflects the requirements for the community as a whole. Both individual and community are factors in the composition, organisational structure and institutional processes of change in the community. The influence that the community, and the individual have in determining land use patterns are limited by conditions imposed by the actual process of land utilisation, and by formal and informal community controls. It is important to remember that underlying the functional relationship between traffic and land use is the movement of people and goods among various establishments.

CHAPTER THREE: ECONOMIC INSTRUMENTS AND CONCEPTUAL MODELS

3.1 Public Goods and Externalities

Congestion is the root of many economic inefficiencies associated with vehicle use. Congestion is an externality and therefore comes under the realm of welfare economics. This section discusses why and how congestion, and other traffic related externalities such as pollution, arise in the transport sector, and what economic theory suggests as solutions.

The definition of an ordinary private good is that it is both excludable and rival. A good is excludable if people can be excluded from consuming it, and it is rival if one person's consumption reduces the amount available to others (Varian 1992). Ordinary goods obtained in the market are usually private goods such as sugar and flour. A pure public good is both nonexcludable and nonrival. Classic examples of public goods are radio and military defence. No one can be excluded from listening to the radio or receiving the benefits of military protection, and one person's consumption of radio broadcasts or military protection does not affect another's consumption.

Highways and roadways are unique in that they possess both private and public good characteristics. Under all conditions highways are nonexludable. However, roads that are infrequently used are considered nonrival, because joint consumption of the road yields benefits to more than one consumer, without substantial detriment in the satisfaction of others (Hau 1993). Roads that are heavily utilised become rivalrous in nature when one person's use reduces the amount of space available to the next person. Under variable use, highways possess both private and public good characteristics.

Private goods are provided contingent on payment, and those who are unwilling to pay are excluded. Because highways are open access (nonexcludable) people are not barred from scarce services, resulting in overuse (Hau 1993). It is this inability to exclude people from using roads that results in market failure and/or a non-Pareto optimal solution.

The fundamental reason why externalities such as congestion and air pollution occur is because property rights are not clearly defined. The lack of clear property rights often causes individuals (firms) not to internalise all the costs associated with consumption (production) of a good. Externalities exist when one individual's activities affect another's welfare without payment or compensation being made (Button 1977). The notion of externalities is especially interesting in connection with welfare analysis. When externalities exist, benefits or costs perceived by private individuals, differ from the true social costs of their actions. This results in a non-optimal allocation of resources in society (Lin 1974). In the specific case of congestion or pollution, the externality results from the failure of additional motorists to take full account of the impediments imposed on other motorists. Drivers are usually concerned only with out of pocket expenses such as gas, and the time costs associated with making the trip. As a result, drivers underestimate the overall social costs of driving, which should include the impacts on non-drivers as well as other drivers (Button and Pearman 1985).

3.2 Regulatory and Economic Instruments

Canadian governments have traditionally used regulatory or command approaches to deal with environmental externalities. Legislation is used to control firms or industry behaviour. An example of a regulatory policy in the Lower Mainland is "Air Care"

certification. The provincial government has regulates the amount of automobile emissions through mandatory certificates that are required in order to obtain insurance.

Economic instruments are different in that they use market forces to integrate economic and social/environmental decision making. These instruments use price and other market signals that enable decision makers to realise the implications of their actions. Financial incentives and/or market mechanisms are designed to make environmentally harmful practices more expensive, thus creating an incentive to reduce the offending behaviour.

The most important aspect of economic instruments is that they are efficient. They are flexible and allow for the reality that the cost of controlling pollution and congestion may not be the same for everyone. According to the OECD (1991, p.13), "markets are much better than individuals at processing a multiplicity of information and result in a better allocation of resources and establishment of trade-offs between different goods and services". A second advantage is that economic instruments provide a continuous incentive, thereby encouraging new technologies and processes. Instruments are often less of an administrative burden and they can allow for faster achievement of objectives.

Theoretical Considerations for the Remedy of Market Failure

When externalities are present "the socially optimum level of economic activity does not coincide with the private optimum" (Pearce and Turner 1990, p.70). Pigou, in his classic work the *Economics of Welfare* (1932), proposed a system of taxes and bounties that would equate marginal social and private products, thereby bringing the markets back to the optimal levels of output. Essentially Pigou's theory suggests that, if it were possible to place a monetary value on the social costs of congestion and the

environmental costs of pollution, then a 'charge' could be levied equal to these 'costs'. This is also known as the first best or optimal tax solution. It creates a disincentive for harmful behaviour and optimal levels of pollution occur (Government of Canada 1992).

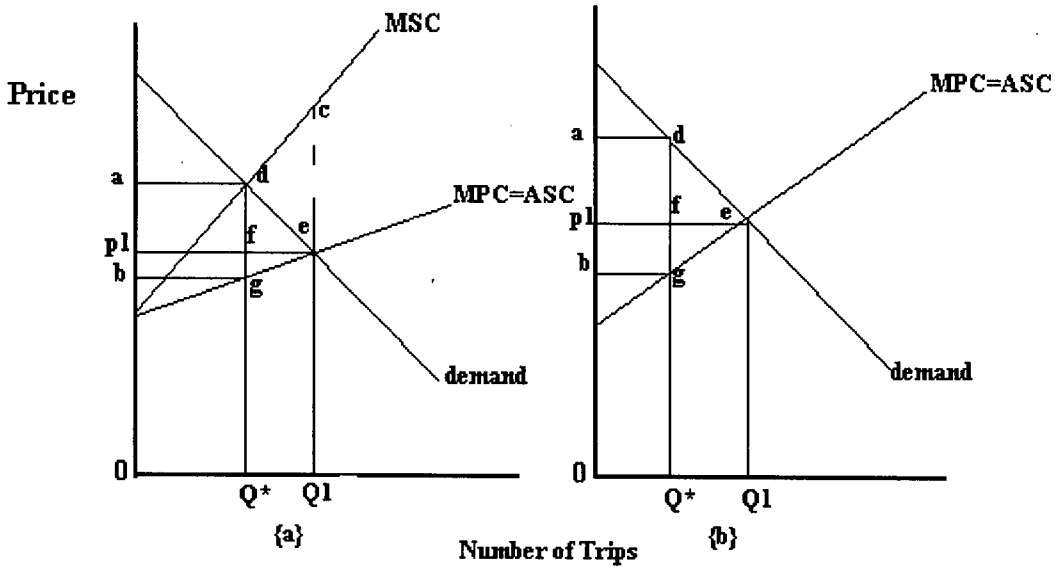
There are two broad categories of external effects from transportation. The first are the external costs users impose on non-users, such as air pollution, noise and danger. Second are the external costs users impose on other users, mainly congestion. In the case of congestion, each driver will decide whether it is worthwhile making a journey by contrasting the perceived benefits (as reflected in the demand schedule) with the private costs of the journey. How individual commuters perceive the private costs associated with commuting are expressed as average social cost curves or marginal private cost curves. Pigouvian solutions often use marginal social costs (MSC) curves to illustrate the reduction in external costs, and the ensuing welfare changes. Figures 3.1(a) and 3.1 (b) illustrate how average social cost (ASC) curves can also be used to obtain the welfare changes from "optimal tax" solutions.

Figure 3.1 (a) is the classic remedy for a market externality using MSC and MPC. The MPC represents the private costs of (in this case automobile use) which begins to rise as congestion levels increase. Journeys will be made as long as demand (marginal benefit) exceeds marginal private costs (MPC), until Q1 in panal (a). After Q1, the benefits are less than the cost to the driver at the margin, and no more journeys are made. However, this is not the optimal level of traffic as the private marginal cost does not take into consideration the costs to society, which are represented by the MSC curve. Users fail to consider that their own decisions to use the road increases costs to other drivers; thus the

marginal social cost (MSC) exceeds the marginal private costs (MPC). The results are consumption at Q1, and not Q*, which is the optimum optimal level of consumption. Beyond the point Q*, commuters enjoy a benefit of only (Q* d e Q1), but at the overall cost of (Q* d c Q1). The difference is the dead-weight loss of area (c d e). The optimal tax (road pricing) equates MSC with demand; the tax payment needed to ensure that motorists are made aware of the full social costs of their actions.

An alternative, and equally valid, analysis is to look at the changes in overall total cost. This method does not require the use of the MSC curve. Figure 3.1(b) shows old commuting total costs to be area (P1 e Q1 0); with the optimal tax in place, the new total costs are area (b g Q* 0). The gain to society can be measured as the change in total costs (P1 f g b) less the demand--area (d e f). This area is equal to the area (c d e) from panel (a). As ASC curves are what drivers actually perceive, the models developed in later sections will use ASC curves and this second approach to the analysis. Table 3.1 provides some examples of "social costs" associated with driving.

Figure 3.1(a) and 3.1(b): Congestion Externality



Source: Waters 1993a

Table 3.1: Private versus Social Costs of Automobiles

The Personal Cost of Transportation	The External costs to Society
• Automobile Registration	• Air Pollution (CO_2, Smog)
• Depreciation and Finance	• Costs of congestion (delays, loss of productivity, stress)
• Repairs	• Noise pollution
• Insurance	• Wear and tear on roadways, transportation and transit facilities
• Gasoline	• Cost of emergency services related to transportation accidents
• Transit fares	• Social health costs of accidents
	• Traffic enforcement
	• The cost of free parking (passed on to retail and consumers)

Source: City of Calgary 1992

3.3 TDM Policies in the Lower Mainland: Conceptual Models

The vast majority of economic instruments being studied and implemented in the transportation sector are demand side policies. Traffic Demand Management (TDM) is a group of economic instruments and incentives designed to change the behaviour of automobile users. The goal is to reduce the number of single occupancy vehicles (SOVs). "TDM are actions aimed at influencing travel behaviour to reduce vehicle trip and vehicle kilometres of travel" (GVRD 1993b). There are three main methods for reducing the demand for single occupancy vehicles.

Modal shift reduces the number of trips in low occupancy vehicles to ones in high occupancy vehicles such as buses and vans. This can be achieved through taxes or charges that discourage low occupancy automobile use by making it more expensive compared to high occupancy vehicle trips. Second are *trip elimination* goals that consist of incentives to work at home or telecommute. Finally, *peak demand lowering* is a wide range of instruments that can be applied to shift trips to from peak to off peak periods. While most of the emphasis on traffic demand management in the Lower Mainland is on mode shift, there are certain criteria that must be met if all forms of TDM are to be successful:

- a choice of travel alternatives must be offered and commuters need to feel that the alternatives are true substitutes for automobiles;
- incentives to use those alternatives must be provided; and
- broad private sector support and participation in demand management programs needs to be secured (MacRae 1994, p.250).

The conceptual framework used to describe two TDM policies being considered in the Lower Mainland is examined in the next section. Conceptual models are built for a road pricing scenario and two high occupancy vehicle (HOV) scenarios. Section 3.5 highlights some of the possible incentives that could arise if gas taxes or parking charges were implemented.

Conceptual Framework

Modelling demand and supply for transportation markets is a conceptually challenging task. The theoretical considerations for demand and supply functions are discussed in the next section. Using various assumptions, a graphical analysis of a two market model for road pricing and HOV lanes is conducted; from these models various welfare changes can be hypothesised.

Supply and Producer Surplus

In microeconomic theory the supply function is the quantity a supplier is willing to offer in the market at a given price. In transportation economics, the supplier is often not well defined and thus can not be studied explicitly. Much of what determines attributes of transport supply is a result of use, rather than supplier behaviour (Kafani 1983). For the purposes of analysing the TDM policies, the notion of a "generalised cost curve" must be introduced to facilitate welfare analysis.

In production theory the average variable cost curve (AVC) represents how the cost of production rises as output increases. The analogy is similar in transport theory. The longer the journey, the higher the travel time and the higher the costs to an individual. Cost curves used in transportation economics are derived from engineering speed-flow curves. These speed-flow curves can be used to derive a travel, time-flow curve as travel time is the inverse of speed (Hau 1993). Using a constant value of time as a shadow price for the individual driver, travel time is then converted to a monetary basis that then yields the time-cost relationship, or the average cost curve. Operating costs can then be added to the time costs to form the generalised cost. Generalised costs are an accepted construct of transportation economics and are also referred to as marginal private cost curves (MPC) or average social cost curves (ASC).

Calculating producer surplus depends on the interpretation of the upward sloping supply curve. One interpretation assumes that rising costs are encountered only by those

additional "producers" entering the market. Agricultural land is a common example. Higher costs are encountered only by those additional "producers" who enter the market and must contend with less fertile land. Those producers with the first and most fertile land realise an economic rent or producer surplus. However, in some instances, rising costs affect all producers. This situation occurs when there is a difference between the marginal costs perceived by drivers, and the marginal costs borne by society as a whole (MSC). The perceived marginal private costs are the same for all and equal the average social costs. For example, at low levels of traffic the costs of driving are low, but as traffic levels increase the costs of driving go up for all drivers. In this example the difference between the price and the marginal cost of driving at low traffic levels (producer surplus) has no meaning. Only if the costs of additional drivers (i.e., congestion costs) are included on an incremental basis would producer surplus mean anything (Waters 1994).

MPC curves represent the private or individual cost to each user. They are composed of out of pocket expenses, all operational expenses and time cost (Nash 1976; Button 1982). MPC curves are upward sloping and represent the costs faced by all drivers at a particular level of traffic (MPC=ASC). It should also be noted that both the MSC and the ASC can be used to measure welfare changes as there is a direct relationship between MSC and ASC, specifically, MSC= ASC(1+elasticity of ASC curve) (Walters 1961).

Demand and Consumer Surplus

Hau (1992) describes how supply can be made congruent with demand when a conventional demand curve is specified to depend on the travel cost, or price facing a traveller for a single trip. User-borne costs are at the same time a cost and a measure of willingness to pay (WTP). Demand is essentially the WTP of each driver to make one trip. It is a decision curve where trade-offs are made between commuting with an automobile and all other goods and services. Demand is a function of generalised costs, costs of substitute transportation and income. *As congestion externalities are not being considered in the modelling scenarios, only consumer surplus, the area above price and to the left of the demand curve will be calculated.*

For the purpose of this discussion, the abscissa measures the "average number of trips per day accomplished during the a.m peak hour period". The MPC increases monotonically with number of trips. The two market models that are constructed in section 3.5 are designed to measure the gains and losses in consumer surplus resulting from various policy scenarios that change the private costs of driving.

Assumptions

- Operating costs of vehicle transport are fixed. In lower traffic volumes, there are higher speeds so fuel consumption is higher. At lower speeds, due to congestion, fuel consumption is higher due to repeated acceleration and braking. It is assumed that these two factors cancel one another out leaving vehicle operating costs independent of the level of traffic flow (Hau 1993; Mohring 1976). However, time costs are not constant, they increase with the number of trips made, and their length
- Congestion and pollution exist because they are external costs that individual drivers do not consider in their decision making. External cost are higher than private costs.
- The "alternative" market in the two market scenarios is assumed to be composed of public transit and van-pools.

- Number of trips are a function of user costs.
- MPC and ASC will be used interchangeably. The ASC and MPC curves only consider the private costs percieved by users. As congestion increases, the MPC (or ASC) will shift up, tracing out new equilibria. In the following models, the MPC is simply an average "social" cost curve and there is no producer surplus associated with it. Therefore, only consumers' surplus is considered as a welfare measure.

3.4 Models for Analysing Road Pricing and HOV Lanes

A two market model is used to investigate changes in the primary market (automobiles) that affect conditions in the substitute market (public transit and van-pools). The alternative market is considered a substitute because, theoretically, as the costs of automobile transportation increase, people will begin to use transit and van-pools. The strength of this substitution can be measured by the cross price elasticities.

Road Pricing: This is the most written about and controversial of the TDM policies being considered. Congestion costs imposed on others, and noise and pollution imposed on non-drivers, are not reflected in the market price of driving. User pay instruments attempt to correct these external costs through "optimal taxes" that were discussed in Section 3.2. Pigou (1920) was the first to suggest that roads should be treated like other normal goods, by charging for their use. The optimal tax, distance *a-b* in Figure 3.1(a), is given by the divergence between the private and social costs of driving. This road charge should not be confused with other forms of vehicle taxation such as non-TDM gas taxes or registration fees. Regular gas taxes are revenue raising schemes for the government that were never intended to lessen traffic demand, or to directly improve public transportation.

There are three main user pay instruments being considered for the Lower Mainland. Road pricing, bridge tolls and central business district (CBD) licensing. Most

policy scenarios assume that road pricing would be implemented with the use of vehicle scanners. Electronic devices are mounted along main thoroughfares and, during peak hours, motorists are scanned and billed accordingly. The effects of this kind of road pricing are realised in two ways. First, it eliminates commuters at the margin, those who are not willing to pay the external costs of commuting during peak hours. Second, the full effect of less people on the road is realised because motorist do not have to stop and queue to make payment. Road pricing may be most effective at reducing the externality. After the initial capital cost of implementing the electronic scanners, all revenues generated would be used to improve public transit. Enforcement costs could be minimised with strict legislation regarding payment and licensing.

Bridge tolls, not using scanning devices, also operate on the "user pay" principal, only now motorists must stop and make payment. Like road pricing, bridge tolls would eliminate those drivers at the margin, thus reducing congestion costs. However, delays caused by queuing would mitigate the full effect of the toll. As well, operating and staffing toll booths have long-term cost implications that could translate into less money available for public transit improvements.

Central Business District (CBD) licensing requires that all vehicles entering the CBD during peak hours must have a pre-paid permit and/or a smart card, regardless if they are just passing through the CBD or are destined for CBD. CBD permits also reduce the number of trips made at the margin, although they only apply in one area. Unlike road pricing, CBD permits would only be feasible for the Burrard peninsula and, as illustrated in Figure 2.3, over 50% of all commutes in the Lower Mainland are made suburb to suburb. Therefore, only 50% of congestion costs are assumed to be addressed by CBD licensing.

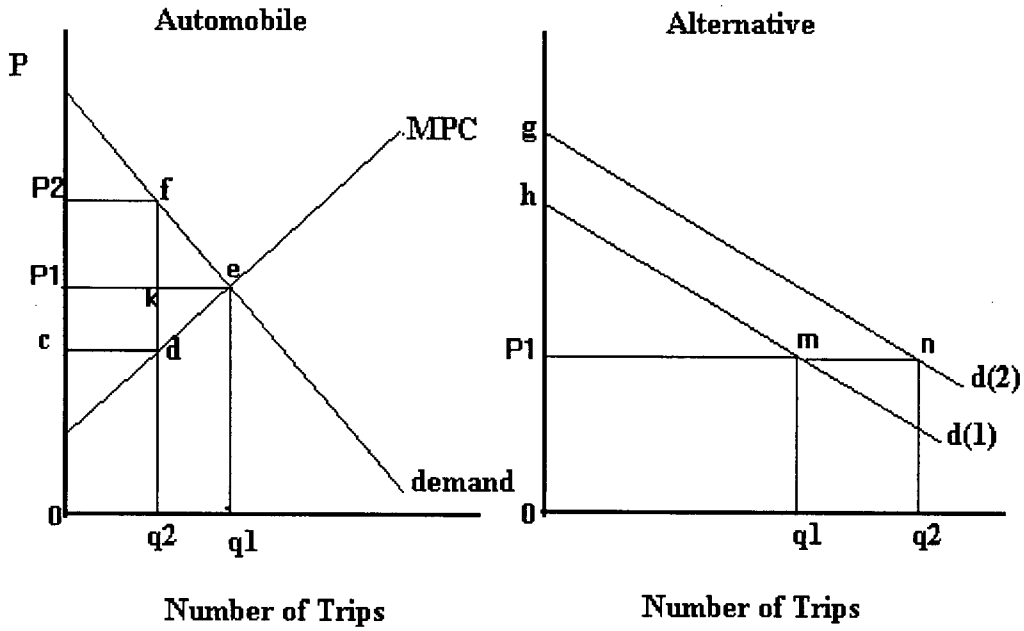
Figure 3.2 graphically represents a $2.00 bridge toll that may be implemented in the Lower Mainland. For this particular model price is assumed constant and equal to marginal cost in the alternative market. A $2.00 fee is charged, increasing the costs of

driving from P1 to P2, it is assumed in this diagram that a $2.00 charge is the "correct amount" that equated MPC with MSC. The actual tax is measured by the distance f-d. Automobile drivers experience a loss of consumers' surplus equal to area (P1 P2 f e). However, of this area, (P2 f k P1) is a transfer to the government, and thus only area (f e k) is the actual dead weight loss to automobile users. The total government revenue is given by area

(P2 f d c). On the benefit side, there is a reduction in costs from area (p1 e q1 0) to area (c d q2 0), creating a net gain of area (P1 k d c) for remaining automobile users[2]. The price increase in the automobile market causes the demand for alternative transport to shift out to d(2). However, the area (g h m n) in the alternative market does not represent a welfare gain. Pricing people out of the market and into a "second-best" market cannot be considered as consumer surplus, only as a transfer (Mishan 1971). The net benefits are the real cost savings to the remaining motorists (P1 k d c), less the consumer surplus lost by those who were priced off the roads (f e k).

[2] The area (q1 e k q2) is offset by the loss of consumers' surplus.

Figure 3.2: Road Pricing



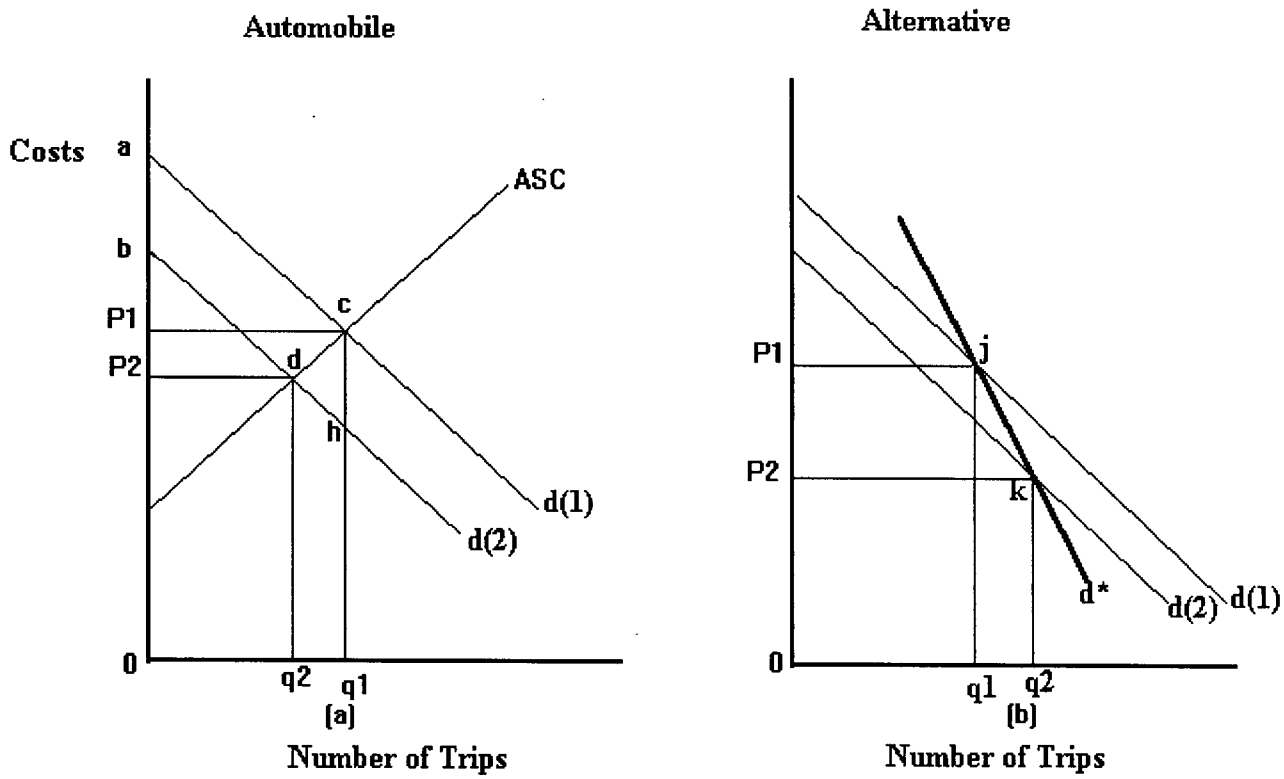
High Occupancy Vehicle (HOV) Lanes: HOV lanes are becoming an integral part of regional transportation planning. Their purpose is to increase ridesharing by offering a travel time advantage to multiple occupant vehicles. Smaller savings can also be offered in reducing out of pocket expenses such as reduced parking fees or tolls. HOV facilities are currently operating in seventeen U.S. metropolitan areas, such as Seattle (WA), Houston (TX), Pittsburgh (PA) and Orange County (CA). HOV lane projects can range from multi-million dollar transit way construction to simple freeway restriping projects (Giuliano, Levine and Teal 1990). When conceptually considering HOV lanes, it is important to distinguish between building roads or restriping roads.

Building a separate, additional lane for HOVs is essentially increasing capacity for HOV users. It creates an incentive to switch to transit or van pools, but it does not

necessarily create a disincentive for SOV use. Figure 3.3 illustrates a possible scenario for automobile and alternative mode users if an additional HOV lane is constructed. Creating an HOV lane reduces costs in the alternative market, as shown by the reduction in marginal costs from P1 to P2 (Figure 3.3 panel(b)). The price reduction results in an inward shift of the demand for automobiles from d(1) to d(2) in panel (a). This shift causes price, and unit costs, to fall in the automobile market which, in turn, shifts demand for the alternative transportation inward from d(1) to d(2) in panel (b). The *interpolated* demand curve, d* in panel (b), specifies the respective marginal cost and price that results in the alternative market, for various price changes in the automobile market (Just, Hueth, Schmitz 1982). Demand, d* connects the original equilibrium j and the final equilibrium k.

The welfare changes are calculated in both the automotive and alternative markets. The area (P1 j k P2) in panel (b) represents the gain in consumers' surplus for alternative users, as a result of adding MC reducing HOV lanes. There is also a gain in the automobile market resulting from less congestion on the road system. The total gain for automobile users is given by area (P1 c d P2) panel (a), which is the change is total costs, area (P1 c q1 q2 d P2) minus demand, area (d c q1 q2).

Figure 3.3: HOV Lanes With Investment



Alternatively, HOV lanes could be implemented in the Lower Mainland without investment, i.e., dedicating one lane of a two lane roadway for HOV use only. Further theoretical considerations must also be made as to whether the HOV policy is implemented sequentially in the markets, or if there is joint supply substitution. Figures 3.4a and 3.4b illustrate the impacts a HOV lane could have on both markets if no additional lanes are constructed, and if the policies were implemented sequentially.

Changes in consumer surplus are not so well defined for cases of multiple price changes. The change in consumer surplus depends on the order in which price changes (substitution effects) and demand shifts (income or intercept effects) are considered. The associated problem is called the path-dependency problem (Just, Hueth, Schmitz 1982,

pp. 73-75). For the purpose of this discussion, two adjustment paths will be considered. The first will be the welfare changes that result when marginal cost is *first* lowered in the alternative market and *then* automobile MPC is shifted inwards (see Figure 3.4a). The second will be the other way around, MPC is *first* shifted inwards in the automobile market and *then* the alternative market marginal cost curve decreases (see Figure 3.4b). Hence, two measures of welfare will be considered for one policy. These measures should be different, they will only be equal if the income effect is zero.

Figure 3.4a illustrates the welfare changes that would result if MC *first* falls in the alternative market (a large cost savings would be experienced by alternative users as their travel time would be significantly reduced). P1 falls to P2 in the alternative market, this leads to a welfare gain under Dt(1) of area (P1 a b P2) in panel (b). The price reduction in the alternative market shifts the demand curve in the automobile market from Da(1) to Da(2) in panel (a). Now the relevant demand curve in the automobile market is Da(2) with R as the corresponding price. The second stage is the MC in the automobile market shifting upwards from MC(1) to MC(2). The final equilibrium in the automobile market is at P3 Q3. The price increase (to P3) in the automobile market shifts demand out in the alternative market to Dt(2), but there is no additional welfare measure. The resulting welfare loss in the automobile market is area (P3 c d R). The automobile welfare change is measured under the "new" demand curve and the net change is equal to area (P1 a b P2) in panel (b) less area (P3 c d R) in panel (a).

Figure 3.4a: HOV lanes Without Investment

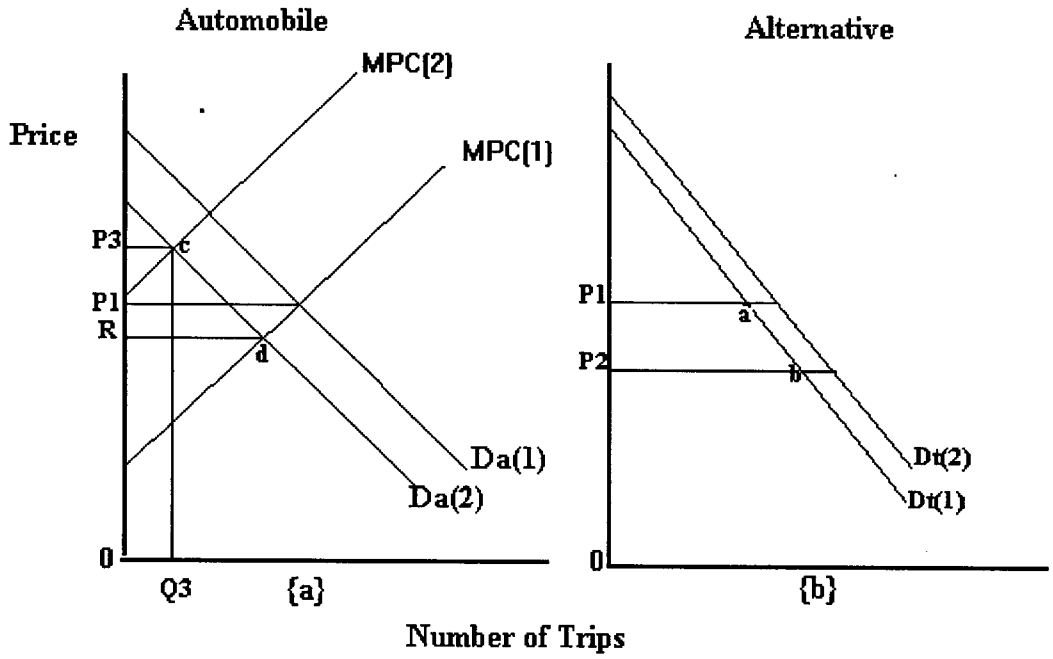
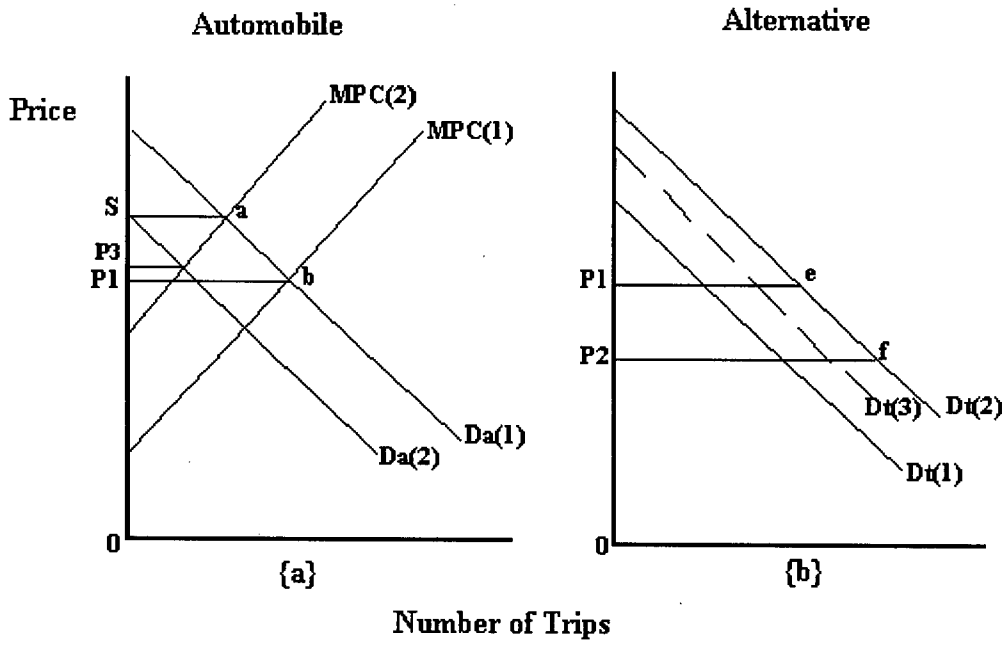


Figure 3.4b illustrates the second path of adjustment if HOV lanes without investment are implemented. Now the first effect starts in the automobile market; MC(1) shifts to MC(2) and subsequently price rises from P1 to S. The loss to automobile users is measured off the original demand curve and measured by area (S a b P1). The price increase in the automobile market causes demand in the alternative market to shift out from Dt(1) to Dt(2). Dt(2) is now the relevant curve in the alternative market. Now, MC falls in the alternative market from P1 to P2. The gain to alternative users under Dt(2) is area (P1 e f P2) in panel (b). The price decrease in the alternative market causes a shift in demand in the automobile market from Da(1) to Da(2), and the corresponding new price and quantity is (P3, Q3), but there are no additional welfare to measure in this

market. The net change in welfare under this path adjustment is given by area (P1 e f P2) in panel (b) minus area (S a b P1) in panel (a).

Figure 3.4b: HOV lanes Without Investment



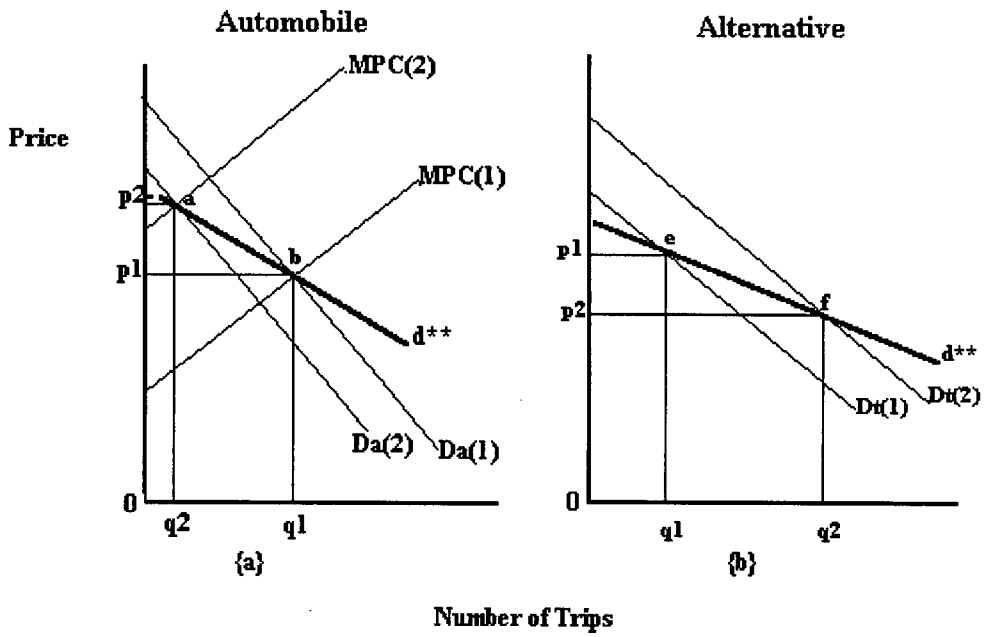
A final consideration of HOV lanes without investment is to measure the welfare changes that would result if the policies worked through joint supply substitution[3]. Figure 3.5 illustrates the welfare changes if the initial and final equilibrium points are used to measure the changes. The *interpolated* demand curve d** is used in both markets to connect the initial and final equilibrium points. It should be noted that Figure 3.2 also uses an *interpolated* demand curve, but they are not the same curve as those used here. The model in Figure 3.5 considers an ASC shift, as well as multiple price changes. MC falls from P(1) to P(2) in the alternative market and ASC(1) shifts to ASC(2) in the automobile market. The price decrease results in demand shifts: Dt(1) to Dt(2) and Da(1) to Da(2) in the alternative and automobile market, respectively. The welfare

[3] "Joint supply substitution" is analogous to simultaneous implementation.

changes are calculated in both markets using areas under the interpolated demand curves, i.e., only looking at the initial and final equilibriums.

Alternative users gain area (P1 e f P2) in panel (b) and automobile users lose area (P2 a b P1)in panel (a).

Figure 3.5: HOV lanes Without Investment--Joint Supply Substitution



3.5 Other TDM Policies

Parking Charges: In general, regulatory parking policies influence numbers of trips, but are unable to differentiate according to trip length and route, because parking is paid at the end of a trip. Verhorf (1993) claims that parking charges can set up perverse substitutions--long trips in favour of short trips. For instance, emission of pollutants (say, CO2) are proportional to the length of the trip. Parking charges imply that each individual road user will be charged some weighted average of the individual marginal external costs generated rather than by the actual value. The reason is that parking

establishments are unable to differentiate fees based on trip length. Essentially parking charges create incentives in favour of long trips for short trips (Verhorf 1993). Parking fees are also unable to differentiate between routes. If the goal is to lessen traffic along specific routes, parking fees are not appropriate.

However, restricting parking in an urban core will lower the actual number of SOV trips made to that area. The increased costs now associated with driving downtown will price marginal people out of their cars, (a consumer loss) and into less expensive modes of transportation. Remaining drivers will also experience a loss due to the higher costs but they will also experience a gain as there is less congestion(as noted above). If the policy goal is to relieve congestion and pollution in an urban core that has relatively little throughput traffic, specifically a major trip destinations, then parking instruments can be effective. Another advantage to parking restrictions is that they can differentiate between times; in other words, they can be effective at lowering peak period demand. Also, parking charges have little capital costs and are relatively easy implement.

Gas Taxes: Taxes raise the operating cost of automobiles, thereby lowering demand. Fuel taxes achieve this by providing incentives for shortening trips. However, gas taxes cannot differentiate between commuting times; users pay during off-peak as well as peak periods. If fuel increases are to be used as a TDM tool only, then mechanisms to ensure that "alternative" mode users are exempt from these increases must be established. If only automobile users are taxed, the same results explained for parking charges will occur. The difference between the two policies lie in the incentives created. The *Transport 2021* study concludes that gas taxes do lower demand. However, the example of Sweden in Chapter 2 indicated that, unless adequate substitutes are provided along with the tax, consumers will remain in their vehicles.

A final scenario is that fuel taxes may be capitalised into property values, thereby increasing the costs of housing closer to the central business district (CBD) and creating incentives for commuters to live further away from their place of work. An increase in a

gas tax could have the opposite desired effect, and shift demand outwards in the automobile market as commuters substitute driving time/costs for housing costs. This situation could be exacerbated by the fact that the further away from the CBD, the less prevalent is public transportation (Verhorf 1993).

CHAPTER FOUR:

EMPIRICAL ESTIMATES

4.1 TDM Policies: Effects on Automobile User Costs in a Single Market

Chapter four is comprised of two parts. Part one introduces new data and material taken from the *Transport 2021* study. This data is used to construct several, single market models. The *Transport 2021* study uses EMME2[4], a large scale, urban transportation programming model used to forecast traffic volumes. Traffic volumes were forcasted in the Lower Mainland before, and after four TDM policies were implemented. Using this data, in conjunction with forcasted cost increases, the welfare changes for the four TDM policies under five different elasticites are measured.

The second part of chapter four, section 4.2, uses the conceptual models developed in chapter three to calculate the potential welfare changes resulting from road pricing and HOV lanes. Sensitivity analysis is also conducted on the models.

The Data: Section 4.1

Oum, Waters and Yong (1992) conducted a survey and literature review of demand elasticities for automobile use (Table 4.1). They found estimates to range from -0.09 to -0.52; usually the long-run elasticities were higher, although not significantly higher.[5] All estimates were done from single-mode studies and used household survey data. Many of the studies were from different countries, yet they all produced remarkably similar results; demand for automobiles is relatively inelastic. None of the studies involved Canadian data.

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[4] For a complete description of the EMME2 model see GVRD 1993b.

[5] Waters, Oum and Yong felt that the insignificance may have been the result of improper modelling techniques to take long run factors into account.

Table 4.1: Demand Elasticities of Automobile Usage[a]

Country	*Short Run*	*Long Run*
United States	0.23	0.28
Australia	0.09-0.24	0.22-0.31
United Kingdom	n.a	n.a

a: All elasticities are in negative values
Source: Oum, Waters and Yong 1992, p.148

Data from *Transport 2021* that were generated by the EMME2 transportation model were used to calculate the base scenario. The average number of vehicle trips that originated and ended in the Lower Mainland during a.m. peak hours was considered the base scenario for "number of trips". The base case scenario for "average total cost per automobile trip" are the 1991 average total costs to drive an automobile from home to work in the a.m peak hour. This includes all out-of-pocket costs such as fuel, maintenance and parking, as well as the dollar value of personal time. Although there are no elasticity estimates for BC, available estimates (Table 4.1), and some assumed elasticities, were used in conjunction with the base case estimates of "number of trips" and "average total cost per trip" to construct linear demand curves.

The first scenario does not consider the effects of other markets in determining net benefits. The data from the study concludes that each of the four policies cause an increase in average cost per trip and thus reduces number of trips. A verbal description of the four TDM policies analysed by the EMME2 model is presented in Table 4.2. What the EMM2 model estimated was a percent-change in number of trips and trip costs from the base scenario. For the EMME2 model predictions, a spreadsheet model was constructed to estimate changes in consumer surplus resulting from changes in "number of trips" and "driver cost" under different elasticites.

Several simplifying assumptions are made in order to interpret the changes in consumer surplus. Marginal cost is considered to be constant and equal to price. If marginal social costs were included then the subsequent reduction in number of trips

would translate into benefits to society. For the purpose of this discussion, price increases will be interpreted as consumer losses.

Table 4.2: Transport 2021 Policies Analysed

Policy	*Assumptions*
Parking Charges	Assume a 50% increase in Central Business District (CBD) parking rates. Raise regional town centre parking charges to 75% of the average 1991 CBD rate
Gas Tax	Double the gas tax, which corresponds to approximately a 50% increase in fuel costs at the pump.
Bridge Tolls	All trips destined to or travelling through the Burrard Peninsula in the AM peak hour will be charged a $2.00 toll.
CBD Licensing Fee	All trips destined to the CBD in AM peak hours will be charged a $3.00 fee.

Source: GVRD 1993a

Table 4.3 illustrates the changes in consumer surplus that result from the same policy under different elasticities. The figures in Table 4.3 represent total daily costs for the a.m peak hours. The seemingly small differences between elasticities can have huge impacts on forecasting the costs to users of transportation policies. Gas taxes appear to have the highest costs to users, while CBD licences have the lowest costs to users.

Table 4.3: Welfare Changes Under Different Elasticities[a]

Policy Options	Change in Consumer Surplus in $ *Elasticities*				
	0.09	*0.24*	*1.0*	*1.2*	*1.5*
Parking Charges	60,260	60,034	58,886	58,584	58,131
Gas Tax	156,112	154,581	146,842	144,782	141,720
Bridge Toll	60,260	60,034	58,886	58,584	58,131
CBD Licence	24,136	24,100	23,917	23,868	23,796

a: Welfare changes are dollars for the a.m.commute.

4.2 Road Pricing and HOV Lane Estimates

The conceptual models developed in chapter three look at how a price change in one transportation market can affect a demand for a substitute mode of transportation. To calculate these changes, linear demand and marginal private cost (MPC=ASC) curves were constructed in a spreadsheet model using data from the GVRD and transportation literature.

The Data

There is little information available for cross price elasticities between transportation modes. As well, many of the cross-price elasticities available are for public transit variables with respect to car ownership, not automobile use. No cross-price elasticity estimates are available for the Lower Mainland of British Columbia. Own-price elasticities used in the model are from Oum and Waters and Yong (1992) (see Table 4.1). The cross-price elasticities come from a variety of studies summarised by Rickard and Larkinson (1991, p.415). Rickard and Larkison reviewed numerous studies and reported that the average cross-price elasticity for automobile use with respect to changes in public

transit fare and service levels (i.e., time costs) to be +0.17. However, Lewis (1977, 1978) found these cross-price elasticities to be much lower for peak service levels +0.084. Goodwin (1988) found the average cross-price elasticity for transit use with respect to changes in automobile costs to be +0.34. Chan (1977) found this number to slightly higher at +0.62. Frankena (1978) found the income elasticity with respect to public transit to be -0.16, indicating that transit is an inferior good. The income elasticity with respect to automobile use is assumed to be elastic, and a value of 1.3 is used in the base model.

The following equations were constructed using own and cross-price elasticities, aggregate, average number of trips taken in the Lower Mainland during peak a.m. hours and private costs per trip for both automobile and public transit (see GVRD 1992a). The data and corresponding coefficients for each of the derived linear curves is listed in Table 4.4. The demand functions are as follows:

Automobile Demand = $a_0 + a_1 P^A + a_2 P^T + a_3 I$

Public Transit Demand = $\beta_0 + \beta_1 P^T + \beta_2 P^A + \beta_3 I$

MPC for Automobiles = $g_0 + g_1 P^A$

MPC for Transit = P^T

Table 4.4: Data and Coefficients for Base Case Scenario #1

Data	Automobile	Transit	
User costs	$6.12	$3.28	
Number of Trips	606,100	95,900	
Income	$31,500	$23,000	
Elasticity of Demand	-0.23	-0.41	
Elasticity of MPC*	1	1	
Cross-price Elasticity	0.17	0.34	
Income Elasticity	1.2	-0.16	
Coefficients	Automobile Demand	Automobile MPC	Transit Demand
Price of Auto	-2.28	10.89	-1.19
Price of Transit	9.23		0.53
Income	0.002		-0.0004
Constant	-34.54	-6.061	11.89

Demand for automobiles is a function of the costs of automobile transportation, the costs of substitute transportation and income. In these models the substitute transportation is considered to be public transit. The demand for public transit is a function of the cost of using transit, the cost of using automobiles (a substitute), and income. The MPC (ASC) curve for the automobile market is upward sloping and a function of the costs associated with using that particular mode. The MPC (ASC) curve slopes upwards because of congestion; the more trips that are made, the more congestion that exists and the higher the time costs to the user. The MPC curve in the public transit market is held constant and equal to price to simplify the model. Theoretically, transit ASC curve would also be upward sloping to represent congestion and time costs.

The two markets are linked through cross-price elasticities, thereby a price shift in one market causes an intercept demand shift in the substitute market. The four equations were solved for their reduced forms and then solved simultaneously for given a changes in price. It should be reiterated that these models differ from the elasticity simulation conducted in 4.1. The automobile market has upward sloping MPC (ASC) so that

changes in price can represent both consumer losses (gains) and gains (losses) to society in the form of lower total costs.

Results: Base Case Scenario #1

Road Pricing: To estimate this policy, the cost per trip was increased by two dollars. This charge is assumed to be applied to all commuters during the a.m. peak period.

HOV Lanes with investment: To simulated this policy, the cost of using transit was halved, the price fell from $3.28 per transit trip to $1.50 per trip. The cost savings result from travel time in transit being greatly reduced due to the HOV lane.

HOV Lanes with no investment--sequential application and joint supply substitution: The first scenario, Figure 3.4a, assumes that initially, the cost of using transit falls from $3.28 per trip to $1.50 per trip, and then, secondly, the MPC curve in the automobile market shifts upwards by 50% (essentially the slope and intercept are halved). Figure 3.4b assumes the reverse scenario. Initially the MPC curve in the automobile market is halved, and then, secondly, the cost of using transit falls to $1.50 per trip. The final HOV scenario, Figure 3.5, assumes joint supply substitution. The MPC curves shifts inwards by 50% at the same as the price of using transit is decreased. Table 4.5 contains the welfare changes for road pricing and HOV lane policies under base case scenario number one (see Table 4.4).

Table 4.5: Summary of Welfare Changes for Base Case #1

	CHANGES IN CONSUMER SURPLUS *(Values in '0000 of Dollars per Day)*		
POLICY	**AUTOMOBILE MARKET**	**ALTERNATIVE MARKET**	**GOVERNMENT REVENUE**
Figure 3.2 Road Pricing	+18.44	N.A	+135.55
Figure 3.3--HOV With Investment	+ 140.19	+19.14	N.A.
Figure 3.4a--HOV Without Investment	-52.29	+18.96	N.A.
Figure 3.4b--HOV Without Investment	-220.54	+21.68	N.A
Figure 3.5--HOV Without Investment (joint supply substitution)	-90.59	+20.01	N.A.

In order to test the sensitivity of the various models, four different base scenarios were generated using different automobile demand elasticities. Using the data found in Table 4.4, the automobile demand elasticity was increase by 10% (model 2), then by 20% (model 3), next the elasticity was decreased by 10% (model 4), and finally an arbitrarily chosen value of 0.8 was used to generate model 5. The price increases and decreases used in model number one were used in models two through five.

Table 4.6: Summary of Automobile Market Welfare Changes for Models One Through Five

CHANGES IN CONSUMERS SURPLUS ACROSS DEMAND ELASTICITIES: AUTOMOBILE MARKET *(Changes are in '0000 dollars per day)*					
Policy	BASE MODEL (-0.23)	MODEL 2 (-0.253)	MODEL 3 (-0.276)	MODEL 4 (-0.207)	MODEL 5 (-0.8)
Figure 3.2	+ 18.44	+20.56	+22.21	+17.16	+49.26
Figure 3.3	+140.19	+148.06	+153.14	+127.67	+153.30
Figure 3.4a	-52.29	-80.63	-60.19	-152.64	-123.32
Figure 3.4b	-220.54	-213.21	-206.19	-228.74	-117.21
Figure 3.5	-90.59	-148.06	-153.13	-127.67	-153.30

Table 4.7: Summary of Alternative Market Welfare Changes for Models One Through Five

CHANGES IN CONSUMERS SURPLUS ACROSS DEMAND ELASTICITIES: ALTERNATIVE MARKET *(Changes are in '0000 dollars per day)*					
Policy	BASE MODEL (-0.23)	MODEL 2 (-0.253)	MODEL 3 (-0.276)	MODEL 4 (-0.207)	MODEL 5 (-0.8)
Figure 3.2	n.a.	n.a.	n.a.	n.a.	n.a.
Figure 3.3	+19.14	+19.20	+19.27	+19.07	+20.31
Figure 3.4a	+18.96	+19.20	+19.27	+19.07	+20.31
Figure 3.4b	+21.68	+24.19	+24.36	+23.85	+28.27
Figure 3.5	+20.01	+19.20	+19.27	+19.07	+20.32

CHAPTER FIVE:

CONCLUSIONS AND FURTHER RESEARCH

5.1 Summary of Methodology

The factors affecting the demand for light vehicle transportation in the Lower Mainland were identified and described. General demand relationships and trends indicate that the demand for automobile use has been steadily increasing, and will continue to increase into the future. The GVRD and the Ministry of Transportation are considering several policies aimed at reducing the demand for automobile transportation. These policies are known generically as economic instruments, and more specifically as traffic demand management (TDM) policies. Conceptual models for two of these instruments, road pricing and HOV lanes, were developed.

Linear demand and supply curves were used to model a two market scenario, the automobile market and the alternative transportation market. It was hypothesised how the various policies would interact within the markets, and what the subsequent welfare changes would be. Data generated by the *Transport 2021* studies was used to calculate empirical estimates subsequent to the policies changes.

5.2 Summary of Results

The measurements considered in Section 4.1 indicate that there are substantial losses to automobile commuters as a result of the four TDM polices. The majority of lost consumers' surplus is in the form of transfers to the government. Table 5.1 indicates the percentage of total dollars, lost to commuters, that are being transferred to the government. The remaining amount (less than 1%) is the actual "deadweight loss to society. This has several implications, first that the actual losses to society resulting

from road pricing are very small. Second, it is the motorists who are losing as their money is transferred to the government. These losses/transfers are the major obstacle to implementing road pricing. If motorists could be compensated, in the form of rebates or guarantees, then road pricing advocates may have some leverage in bargaining. As almost all of the losses are transferred to government, assurances to invest the money in public transportation could also be guaranteed.

Table 5.1: Percent of Consumer Surplus Loss (Table 4.3) That is in the Form of Transfers to Government.

Elasticities	-0.2	-0.5	-1	-1.2	-1.5
Park Charges	99%	99%	99%	97%	96%
Gas Tax	99%	97%	99%	92%	89%
Bridge Toll	99%	99%	97%	97%	96%
CBD	100%	99%	99%	99%	98%

A second consideration of the results generated in Section 4.1 is that demand elasticities can play a large role in the cost-benefit analysis of a project. The more inelastic demand for automobile use, the higher the losses to motorists. This supports the philosophy that road pricing and other TDM policies must be accompanied with investment in realistic automobile substitutes. A final consideration from this analysis supports the argument that "blunt" instruments such as gas taxes are more costly to users than user pay instruments.

Results From the Conceptual Models: Road Pricing and HOV Lanes

Empirical results from the road pricing and HOV models illustrate that assumptions about demand elasticities are not as straightforward when two markets are considered. The discussion below will be referring to Tables 4.6 and 4.7. The estimates for road pricing scenario are consistent with the results found in Section 4.1, probably

resulting from single market calculations (no welfare changes are considered in the alternative market). As the demand elasticity increases so do the gains to remaining automobile users.

The results for HOV lanes with investment (Figure 3.3) are not unexpected. An additional lanes generates a gain for existing automobile users and alternative users. This gain increases in both markets as elasticity increases, and decreases if demand becomes more inelastic.

The results for HOV lanes with no investment (path a--figure 3.4a) are not quite as straight forward. However the greatest loss to motorists is experienced under the most inelastic demand curve, and the greatest gain to alternative users is under the most elastic demand. The same conclusions can be reached about the alternative path (figure 3.4b). However, it is interesting to note the differences that arise resulting from which policy is implemented first. When the price is first lowered in the alternative market there is a calculated greater loss of welfare, than if the MC is first shifted upwards. This could have important policy implications and should be considered, when possible, during future evaluations.

The results from figure 3.5 indicate the largest losses to automobile users, as a result of HOV implementation, occurs under joint-supply substitution and an elastic demand. The largest gain to alternative users also occurs under this scenario.

5.3 Further Research and Limitations

Little work has been done on the methodology of measuring the costs and benefits of TDM, and there are few categorical answers to what the impacts of TDM instruments will be. Conceptual models as well as empirical analysis is needed on all the TDM instruments. Some examples of more specific research topics include:

- Quantification of the private and social cost curves for automobile costs for the Lower Mainland.
- Quantification of the relationship between automobile congestion and such externalities as air pollution, traffic accidents, noise pollution and energy consumption.
- How do the external costs of travel vary with different strategies for internalising them in decisions to consume land and travel?
- Better elasticity estimates are required for the Lower Mainland for demand for automobiles, including current estimates of cross price elasticities.

Another point for further research are the possible incentives that may arise from the various TDM policies. Road pricing, toll booths and CBD licensing all work on the same economic principals yet they have important differences. Road pricing and bridge tolls provide incentives for private sector involvement is the form of private roads and bridges, while CBD licenses do not. It has been suggested, Evans (1992), that user-pay policies can set up perverse incentives for the government. The government has a natural monopoly of the supply of roads. However, they have been unable to charge users and thus exploit monopoly rents. User-pay policies the mechanism in place to collect rents from users. Evans (1992) illustrates that if government set prices to generate revenue needs and not at road economic levels, users are much worse off than without any congestion pricing. Planners and politicians should be aware that these incentives can create are important implications for financing and equality issues.

The most important area for further research stems from the fact that TDM programs must be specifically tailored to a region. Conceptual frameworks must be developed that link existing geographical, economic, social and political characteristics to various TDM instruments. TDM instruments have been ranked by primary and secondary implementation levels according to various goals (GVRD 1993). These models provide a framework for achieving various goals (i.e. congestion or pollution reduction), however they assume all TDM measures are feasible for region. More research needs to be done

on which TDM instruments are going to be most effective in each region. "Effective" in terms of efficiency and actual welfare gains within the region.

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