FROM FREEWAY TO FEEWAY: CONGESTION PRICING POLICIES FOR B.C.'S FRASER RIVER CROSSINGS

by

Peter Wightman
Bachelor of Arts (Honours), Queen's University, 2006

PROJECT SUBMITTED IN PARTIAL FULFILLMENT OF
THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF PUBLIC POLICY

In the
Faculty
of
Arts and Social Sciences

SIMON FRASER UNIVERSITY

Spring 2008

APPROVAL

Name: **Peter Wightman**

Degree: **M.P.P.**

Title of Capstone: **From Freeway To Feeway: Congestion Pricing Policies For B.C.'s Fraser River Crossings**

Examining Committee:

Chair: **Nancy Olewiler**
Director, Public Policy Program, SFU

Jon Kesselman
Senior Supervisor
Professor, Public Policy Program, SFU

Doug McArthur
Supervisor
Professor, Public Policy Program, SFU

Nancy Olewiler
Internal Examiner
Director, Public Policy Program, SFU

Date Defended/Approved: March 4, 2008

SIMON FRASER UNIVERSITY
THINKING OF THE WORLD

STATEMENT OF ETHICS APPROVAL

The author, whose name appears on the title page of this work, has obtained, for the research described in this work, either:

(a) Human research ethics approval from the Simon Fraser University Office of Research Ethics,

or

(b) Advance approval of the animal care protocol from the University Animal Care Committee of Simon Fraser University;

or has conducted the research

(c) as a co-investigator, in a research project approved in advance,

or

(d) as a member of a course approved in advance for minimal risk human research, by the Office of Research Ethics.

A copy of the approval letter has been filed at the Theses Office of the University Library at the time of submission of this thesis or project.

The original application for approval and letter of approval are filed with the relevant offices. Inquiries may be directed to those authorities.

Bennett Library
Simon Fraser University
Burnaby, BC, Canada

Abstract

Greater Vancouver's Fraser River crossings face sizeable traffic demand that results in heavy congestion. This study develops and assesses road pricing policy alternatives that would reduce the economic externalities of congestion on these crossings. Based on current traffic flows, target traffic flows and assumed price elasticities of demand, a simple model is assembled that estimates requisite congestion charge levels by time of day. Case studies of London, Toronto and Orange County (California) provide insights on the effectiveness of different road pricing schemes and highlight the critical factors to be considered when developing a pricing scheme. Pricing policy alternatives that reflect the uniqueness of Greater Vancouver transportation are then built using the estimated required charges and data from the case studies. These alternatives are assessed against a multi-criteria framework. The study recommends a new congestion pricing policy for the George Massey Tunnel, and the Alex Fraser, Pattullo and Port Mann bridges.

Keywords: road congestion; toll; congestion charge; Greater Vancouver; transportation policy; road pricing

Subject Terms: Traffic Congestion; Urban Transportation Policy; Congestion Pricing

Executive Summary

Like many metropolitan areas, Greater Vancouver faces perpetual road congestion. The region's heavy traffic inhibits the flow of people and goods leading to economic efficiency loss. Existing policies have not sufficiently addressed this problem. This study examines whether new pricing policies could and should be used to reduce road congestion in Greater Vancouver. Both the regional municipal authority (Metro Vancouver) and the regional transportation authority (South Coast British Columbia Transportation Authority) have moved in favour of a new approach to road pricing, yet there has been no implementation action to date. The region's worst congestion is located on the George Massey Tunnel and Alex Fraser, Pattullo and Port Mann bridges; this study designs and analyzes alternative road pricing policies aimed at reducing road congestion over these crossings. After determining that congestion-targeting tolls will lead to more efficient traffic flows, I recommend that time of day congestion charges be levied on the four Fraser River crossings listed above.

Two distinct analytical approaches are applied in order to develop and assess policy solutions to road congestion. First, a toll calculation model uses price elasticities of demand, current traffic flows and target traffic flows to estimate the charge levels needed to induce the required traffic reductions. Second, case studies of jurisdictions with unique forms of road pricing are examined to determine the relative effectiveness of each pricing scheme's congestion reduction. Best practices for scheme design are also taken from the case studies.

Four policy alternatives are developed out of the aforementioned processes. They each use different permutations of congestion-targeting time of day tolling, which varies tolls throughout the day based on traffic demand patterns. The pricing alternatives are:

- Toll All Four Crossings
- Leave Untolled Options
- High Occupancy Toll (HOT) Lanes
- Status Quo

Upon implementation, these policy alternatives will have widely different results. In order to determine the most appropriate action for Greater Vancouver, I assess these policy alternatives against a set of evaluation criteria that includes effectiveness in reducing congestion,

the revenue generated, equity impacts and pre-implementation public and political viability. I do not treat the criteria as equal but I also do not attempt to weight them – they are simply used to identify the differing outcomes that each policy alternative will create.

The study also recommends policies that should be implemented under any level of tolling. These include:

- Toll revenue allocation to transportation projects, particularly public transportation
- A significant increase in public transportation provision for the common origins and destinations of the users of the crossings
- Employment of electronic toll collection methods
- Toll exemptions for High Occupancy Vehicles and motorcycles

After evaluating each policy alternative using the criteria set, I determine that because of the large congestion reduction effects, implementing congestion targeting tolls on each of the four crossings is the first-best policy approach. However, this approach comes with significant adoption challenges; public opinion in British Columbia is heavily opposed to tolls when there is no untolled road alternative, and provincial policy reflects this by requiring untolled alternatives in all tolling schemes. The recommended policy also has polarizing equity effects, where individuals with a high value of time (usually high income) reap benefits, as do individuals who primarily use public transit (usually low income), but those who fit in neither of these groups predominantly lose.

Each of the other policy alternatives has drawbacks as well. With untolled routes, congestion either remains or increases as drivers divert their trips to the untolled but congested roadway. Tolling all of the crossings will provide the incentives necessary for drivers to consider alternative modes or to have some flexibility in their trip destination or trip time. I describe several implementation strategies that help with the challenges to adoption.

Road congestion is an ongoing problem in Greater Vancouver. For many years, economists have argued that new pricing structures can be used to efficiently and effectively decrease road congestion. Policymakers often question what road pricing in Greater Vancouver would look like; this study provides answers for some of the region's most congested routes.

Acknowledgements

This project would not have been possible without the support and assistance of many. First and foremost, I thank Dr. Jon Kesselman for his ongoing guidance and comments, and for being so generous with his time. I also thank Dr. Nancy Olewiler for challenging me during my defence and for pulling me out of the ivory tower.

Dr. Raymon Torchinsky has my gratitude for his engaging lectures and discussions on urban transportation and for taking the time to answer my technical questions. Thanks to Brian Mills and his team at TransLink for allowing me access to their brains, and to Joyce Chang at the Ministry of Transportation for helping me navigate the department.

I must recognize the Social Sciences and Humanities Research Council of Canada (SSHRC) for providing scholarship assistance as I completed this research. Likewise, thanks to Dr. Kennedy Stewart, Dr. Ian Cromb and Dr. Nancy Olewiler for helping me secure the SSHRC funding.

Thanks also to those members of my M.P.P. cohort who kept me sane through the long hours in our windowless research room – it was a treat to work alongside you. Last, but certainly not least, thanks to my parents, grandparents, siblings and friends who always supported me in this feat.

Table of Contents

List of Figures

List of Tables

Glossary

407ETR	Highway 407 Express Toll Route, Ontario
GVRD	Greater Vancouver Regional District. See Metro Vancouver
GVTA	Greater Vancouver Transportation Authority. See SCBCTA
HOT	High Occupancy Toll
HOV	High Occupancy Vehicle
LRSP	Livable Region Strategic Plan
Metro Vancouver	The regional authority formerly known as the Greater Vancouver Regional District (GVRD). Alphabetical list of member municipalities: Anmore, Belcarra, Bowen Island, Burnaby, Coquitlam, Delta, Langley, Lions Bay, Maple Ridge, New Westminster, North Vancouver, Pitt Meadows, Port Coquitlam, Port Moody, Richmond, Surrey, Vancouver, West Vancouver and White Rock.
MOT	Ministry of Transportation
MRN	Major Road Network
OCTA	Orange County Transportation Authority
PAYD	Pay-As-You-Drive
SCBCTA	South Coast British Columbia Transportation Authority. Formerly known as the Greater Vancouver Transportation Authority (GVTA). Commonly known as TransLink.
SR91	State Route 91, Orange County, California
TDM	Transportation Demand Management
TfL	Transport for London

1 Introduction

Long lauded by economists but oft rejected by politicians, road pricing enjoys growing policy momentum thanks to some widely publicized schemes that have successfully reduced congestion. Also adding to road pricing's new support are the many empirical studies showing that individuals will respond to road charges by reducing or shifting their demand for travel. While economists see a unique potential to improve efficiencies, internalize externalities and approach social optima, a perceived public distaste – along with equity concerns – make Canadian policy makers hesitant to introduce new road pricing measures. To date, the few Canadian instances of road pricing have less to do with road efficiency and more to do with infrastructure financing.

Road congestion grips Greater Vancouver, stifling the movement of goods and people.[1] In a 2006 survey commissioned by the South Coast British Columbia Transportation Authority (formerly known as the Greater Vancouver Transportation Authority and commonly known as TransLink), 10 percent of respondents listed traffic congestion as the top issue that federal, provincial and municipal leaders should address – more support than any other single issue (Ipsos Reid 2006). 82 percent of respondents considered traffic congestion a "serious problem" or a "very serious problem." Peak commute hours witness the region's worst congestion, and bridges and tunnels remain the Lower Mainland's most congested sites (GVTA 2004b).

Over and above public opinion, congested roads impose real costs on society. As traffic speeds decrease, travel times increase. For individuals, time loss means either lost leisure time or lost work time; each contributes to utility, but travel time itself usually does not. For firms, congestion imposes higher shipping costs while slowing the productivity of employees who must travel for meetings, appointments or between work sites. There is environmental damage when vehicle engines run idle on a congested road and create incremental emissions that contribute to poor air quality and climate change. Finally, congested roads lead to increased accident risk, resulting in higher insurance premiums and inflated health care costs.

---

[1] In this paper, "Greater Vancouver" and "the Lower Mainland" are terms used interchangeably to describe the metropolitan area of Vancouver, British Columbia. "Metro Vancouver" is used to describe the regional regulatory authority comprised of area municipalities.

Generally, estimates of the economic costs of road congestion range between one and three percent of GDP (Jensen-Butler 2001); however, congestion cost estimates are variable and unreliable. Vancouver City Councillor Peter Ladner (2007) reported that many cities around the world estimate their congestion costs to be $1.5 billion annually, including Vancouver, Seattle, Denver, Beijing, Chicago, Sydney and Boston. Ladner notes that the similarity in these cities' estimates is surprising given their urban transportation differences, and he implies that some are unfounded. While my study will not obtain a figure for Greater Vancouver's road congestion costs, suffice to say that there are significant losses from congestion.

Policy makers can choose from a wide array of approaches to solve congestion; here, study is limited to the congestion pricing genre while recognizing the importance of applying other congestion reducing strategies in tandem (e.g. public transit improvements). I assess several road pricing policy proposals aimed at easing road congestion in British Columbia's Lower Mainland. Currently, the Fraser River crossings to the south and east of the City of Vancouver are the most highly congested roads in the region (GVTA 2004b), so I focus on policy approaches for reducing congestion on the George Massey Tunnel and the Alex Fraser, Pattullo and Port Mann bridges.[2]

The study examines solutions to the problem of heavy traffic congestion on the Fraser River crossings. I begin by establishing the situational context of the policy problem. This includes a description of Greater Vancouver's congestion, an outline of the governing institutions responsible for transportation policy and an historical overview of road pricing policy in the region. Then, I offer a brief review of the economic theory of road pricing that was initiated in the mid-twentieth century by William Vickrey and has been expanded upon over time. Third, I present the results of a transportation demand analysis. This analysis applies price elasticities to the congested facilities to predict the pricing needed to achieve traffic flow targets. Fourth, using case studies of London, Toronto and Orange County (California), I assess the relative effectiveness of the pricing schemes in these areas and develop a list of characteristics vital to successful pricing. Fifth, I assess four road pricing options against measures of effectiveness, revenue generation, equity, public acceptability and political viability. My analysis leads to recommendations for congestion charges on bridges and tunnels crossing the Fraser River.

[2] These crossings represent a complete set of road accessibility over the Fraser River. They exclude the crossings of the Fraser River North Arm (Knight Street, Oak Street and Arthur Laing bridges) since, as a set, they are less congested than the southern crossings.

2 Congestion, Geography and Transportation Policy in Greater Vancouver

No two cities are alike where local transportation is concerned, and Greater Vancouver is as unique as any. This section describes the particulars of the Fraser River congestion problem. It provides a basic orientation to those not familiar with Greater Vancouver, explaining the institutions and governing structures responsible for the region's transportation policy and operation. Finally, this section includes a brief discussion of the history of road pricing in British Columbia, including current frameworks and future proposals.

2.1 Fraser River Congestion

Canada's west coast is blessed with an endowment of lush mountains and rivers; the geography is prized by Vancouverites and admired around the world. However, these same geographical features create exceptional challenges for urban transportation. Note Figure 1; Vancouver is the historical central city and suburban areas have grown in all directions, limited only by the mountains to the north and the waters to the west (supplementary map perspectives are available in Appendix A). Traditionally, labour is centred in Vancouver; commuters from suburban communities must use the limited number of bridges and tunnels for their daily travel. Not surprisingly, these classic bottlenecks are oversubscribed during peak hours. Recent land use decisions have resulted in more dispersed employment, and while Vancouver is still the area of highest employment, its share in the region has been decreasing (B.C. Ministry of Transportation 2006a). In terms of travel patterns, commuters now criss-cross the region in all directions. Even so, inter-suburb commuters utilize water crossings a great deal. The crossings of the Fraser River are widely considered the region's most congested routes.

Figure 1: Map of Metro Vancouver

Source: Google Earth

Transportation analysts commonly measure congestion in two ways. Average travel speeds as a proportion of the posted speed limit is usually used to measure recurrent congestion (Bertini 2005). A route with average travel speeds of 25 km/h in a 50 km/h zone is considered more congested than a route with average travel speeds of 60 km/h in a 100 km/h zone (50% of the speed limit versus 60% of the speed limit). To measure non-recurrent congestion, researchers determine the reliability and variability of travel times. As individual routes face increased non-recurrent congestion (caused by anything from weather to accidents and breakdowns), the variability in travel times will increase (Cambridge Systematics 2005). In general, transportation planners focus on solving recurrent congestion problems, given that non-recurrent congestion has a large degree of randomness.

In both the morning and afternoon peak travel hours, the approaches to the George Massey Tunnel and the Alex Fraser, Pattullo and Port Mann bridges experience average travel speeds between 0% and 60% of the posted speed limits. Travellers on the majority of other routes move at over 60% of the speed limit (GVTA 2004b). Of course, other areas face congestion, such as some downtown streets, the North Shore crossings and the bridges between Vancouver and Richmond. But the worst congestion is over the Fraser River, so its crossings are the focus of this study. Because of the interconnectivity of the road network, congestion reduction on one segment can filter to other sections of the network as well; for example, congestion eastbound on the Port Mann Bridge can create congestion right up to and past the Ironworker's Memorial Bridge in North Vancouver. In later sections of this paper, I discuss the relationship between policy on this network sub-section and the network as a whole.

2.2 Transportation Policy Diaspora

In British Columbia, responsibility for road transportation policy is split between municipal, regional and provincial authorities. Below is a brief description of the responsibilities relevant to this study. Relevant responsibilities include planning and maintenance of roads, public transportation provision, and road regulation and operation. Road pricing is a policy area where multi-level coordination is necessary because the policy jurisdictions are not clearly defined.

In B.C.'s Lower Mainland, municipalities are responsible for the provision and operation of the local road network. Municipal accountability encompasses everything from maintenance and parking to traffic signals and cameras. Municipal councils determine policy for these roads; the Fraser River crossings in question connect the municipalities of Surrey, Coquitlam, New Westminster, Delta and Richmond.

TransLink has regional authority over the Major Road Network (MRN), which includes the main arterial surface streets in Greater Vancouver. Of the crossings included in this study, TransLink is responsible for the Pattullo Bridge connecting Surrey and New Westminster. TransLink is also responsible for funding and operating Metro Vancouver's public transportation system. Since 2008, a nine-member board of directors, an independent commissioner and a "Council of Mayors" from the region's municipalities govern TransLink.

The provincial Ministry of Transportation (MOT) regulates and operates the highway system that snakes through the region. Of the congested crossings relevant to the current study, the MOT is responsible for the Port Mann Bridge, the Alex Fraser Bridge and the George Massey Tunnel. As the Crown authority, the MOT also has overall authority for transportation regulation, laws and road rules, and the municipal and regional authorities sit at the will of the Province. As described below, while road pricing implementation requires interaction among these authorities, in the end, the provincial government establishes road pricing policy.

Finally, the board of Metro Vancouver has a degree of influence in transportation policy. While Greater Vancouver's land zoning and land use decisions are made by individual city councils, they are guided by the *Livable Region Strategic Plan (LRSP)*, which is created and managed by the Metro Vancouver board. The LRSP establishes the growth and planning goals for the region; urban economists and urban planners have long known a link between land accessibility and land use. Road modifications alter the accessibility of any particular area and therefore influence its use (O'Sullivan 2003). Because of this relationship, the LRSP advises transportation decisions; therefore, the Metro Vancouver board has transportation policy significance worth noting. Table 1 summarizes the jurisdictional responsibilities outlined above.

Table 1: Transportation Policy Division of Responsibility

Transportation Authority	Responsibilities	Relevant Crossings
Municipalities	• Local road network planning, operations and maintenance, including parking and traffic signals • Land use and zoning	• None
TransLink	• Major Road Network of arterial streets • Public transportation funding and operation	• Pattullo Bridge
Ministry of Transportation	• Provincial highways • Regulation, laws and rules of the road • Municipal and regional governance	• Port Mann Bridge • Alex Fraser Bridge • George Massey Tunnel
Metro Vancouver	• Regional growth strategy: Livable Region Strategic Plan (LRSP)	• None

One can easily become lost amid the jurisdictional details of transportation policy. While a division of responsibilities can create efficiencies in operating the transportation network, the division also complicates planning and policy. There is also often jurisdictional overlap – one group may be responsible for funding a project while another is responsible for managing it, as is the case with many capital-intensive infrastructure projects such as rapid transit lines. Roads are best understood as a network; an individual road cannot be properly appreciated alone but must be seen as a link in a network. When disparate bodies have responsibility for policy on different parts of the overlapping network, effective regional policy and planning can take place only with collaboration, coordination and cooperation among the groups. While the TransLink and Metro Vancouver structures are meant to provide these functions, to date they have been ineffective in reducing congestion.

2.2.1 Provincial Tolling Guidelines

The B.C. Ministry of Transportation's *Guidelines for Tolling* govern road pricing policy in the province. These Guidelines are listed in Table 2; they were developed in 2003 to create a clear framework under which road tolls could be introduced (Blasetti Interview). There was no official government policy on tolling prior to the development of the current Guidelines, though the Guidelines do reflect convention in pre-2003 decisions on tolls. The impact of these Guidelines is discussed in my sections on policy analysis and implementation. In particular, I discuss how these Guidelines restrict congestion pricing implementation, but that there may be room for some flexible interpretation. When it comes to road pricing policy in Metro Vancouver, the buck stops with the Province. Municipal and regional groups may create road pricing policies under the provincial Guidelines but they require the cooperation of the Province to enforce and collect fees (Blasetti Interview).

Table 2: Official Guidelines for Tolling in British Columbia

1. Only major projects that result in significant increases in capacity will be subject to tolling.
2. Tolls will be implemented only if there are clear, demonstrable net benefits for the users of the new or improved facilities.
3. Tolls will be implemented only if a reasonable untolled alternative is available.
4. The level of tolls and limits on the amount and frequency of increases will be established in advance.
5. Public consultation will occur in all cases where new tolls are considered.
6. The public will have the same rights to access tolled highways as non-tolled highways.
7. Tolls will be used to generate revenue for transportation projects and provide a return on the investment of private-sector partners.
8. The same maintenance, safety and other standards, and rules of the road, will apply to tolled highways as non-tolled highways.
9. The privacy of personal information used to levy and collect tolls will be protected.
10. A fair and expeditious process will be available for resolving tolling disputes.
11. The consequences of failing to pay tolls will be fair and reasonable.

Source: B.C. Ministry of Transportation (2003)

2.3 Pricing History

Historically, road pricing is not foreign to Greater Vancouver. Before 1970, most bridge and tunnel projects in the region were built, owned and operated by local municipalities, and many crossings used toll charges as a means of financing infrastructure development. Crossings with tolls included the Pattullo Bridge, the George Massey Tunnel (known as the Deas Island Tunnel during its tolling phase), the Queensborough Bridge, the Oak Street Bridge and the Lion's Gate Bridge. In the 1950s and 1960s, the provincial government purchased many of these crossings and removed the tolls (Davis 1997). Toll-free travel remained in Greater Vancouver throughout the 1980s and 1990s.

Contemporary users of Greater Vancouver's bridges and tunnels do not face tolls, but planning has begun for two new Fraser River crossings, for which users will have to pay fees. The Golden Ears Bridge, a new six-lane roadway across the Fraser River between the Surrey-Langley and Maple Ridge-Pitt Meadows areas, is scheduled to open in 2009. The bridge, under the jurisdiction of TransLink, will open with tolls that are designed to allow the project's private partner to gain return on its investment. Second, the Ministry of Transportation intends to twin the Port Mann Bridge as a part of its Gateway infrastructure program, and the Province's proposals include provisions for tolls on the new bridge. The Gateway tolls are also intended for infrastructure financing. It appears certain that road pricing is returning to the Lower Mainland, at least on these new crossings. This paper analyzes how pricing policy should be designed for congestion reduction on the existing ones; the next section explains my rationale for choosing pricing as the primary congestion reduction instrument.

The TransLink and Metro Vancouver boards have each individually moved for the introduction of a new comprehensive road pricing policy for the region (GVRD 2007). However, their desires violate the MOT's Tolling Guidelines – in particular, the requirements that tolls can only be applied to new infrastructure and only in the presence of untolled road alternatives. Consequently, there has been no action. I address jurisdictional concerns below, in a section on implementation.

3 Theory of Congestion Pricing

Economists use simple concepts to explain road congestion. According to economic theory, price distortions send improper cost signals to drivers, creating a failure in the market for roads. Nobel Prize winner William Vickrey is considered the founder of road congestion pricing theory; most of his mid-twentieth century propositions still hold true. Based on Pigou's theory of externalities, Vickrey (1963) explains, in plain language, why transportation pricing is "so irrational, so out of date, and so conducive to waste" (Vickrey 1963, pp. 452). He argues that while differential peak period pricing exists in industries such as theatre, tourism and telecommunications, it is very rare in transportation. Indeed, if transportation pricing was "out of date" in the 1960's then it is certainly antiquated today, because very little has changed.

Figure 2: Congestion Pricing Theory

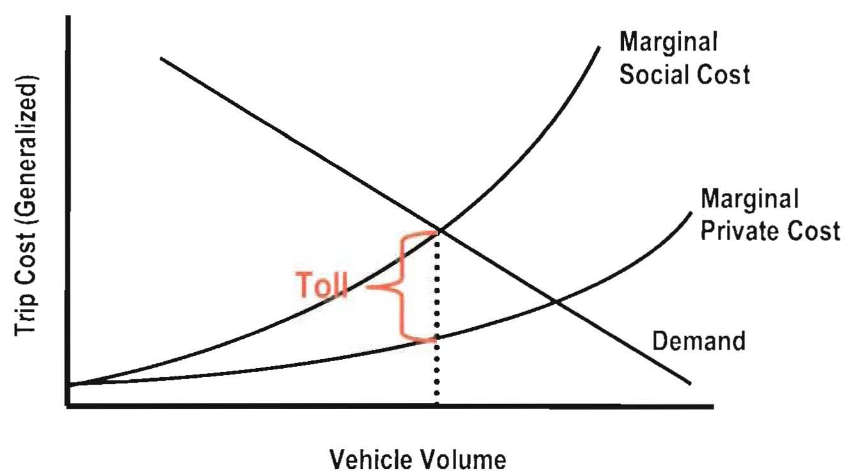


Figure 2 shows how tolls can be used to optimize vehicle flows. The chart plots vehicle volume against the generalized cost of a trip; trip costs include everything from fuel to insurance to time costs. Travel demand is straightforward. It slopes downward and to the right since more individuals use the road when costs are low. The two upwardly sloping curves demonstrate the difference between private and social costs of travel. Social costs include the external costs not felt by the individual traveller; especially, the impact on travel time of other travellers.

With few vehicles on the road, both private and social costs are low, and they do not diverge widely. As vehicle volume increases, the resulting congestion increases trip time, so the marginal private cost (MPC) increases with volume. But each marginal trip creates external costs beyond the private cost valuation. Additional costs include environmental damage, increased accident risk and the imposition of congestion. To understand the external costs of congestion, imagine a road with some level of traffic on it. A private individual faces a personal trip cost, which has a time cost associated with it, and this time cost varies depending on congestion levels. But that individual, by entering the roadway, delays the rest of the users, raising time costs for everyone else. The added delay imposed on others is an external congestion cost that makes the marginal social cost (MSC) greater than the MPC. Societal optimality occurs where the MSC curve meets demand. But because users of the Fraser River crossings make their travel decisions based on private costs and not social costs, current equilibrium rests where MPC meets demand, and the crossings are oversubscribed.

Congestion has unique externality properties. Many forms of externalities are constant or linear, but congestion is non-linear; its external effects are amplified as vehicle volume increases. Consider a simplified example. Assume that a marginal trip adds one minute to the travel time of every driver on the road. If the marginal trip affects ten other drivers, it has an external cost of ten minutes. But with fifty other drivers affected, the trip has an external cost of fifty minutes per traveller. Congestion externalities behave such that the marginal externality effects increase with total vehicle volume.

A conceptually easy solution to any external cost problem is cost internalization. If individual road users assume the external cost of their behaviour, the MPC curve will follow the MSC line, resulting in optimality. A straightforward solution proposes adding a toll, as shown in Figure 2. A toll could ensure an optimal vehicle volume since individual drivers would react to the higher cost of driving and, in aggregate, vehicle volume would decline to the point on the demand curve that reflects the now higher cost.

Because the costs of congestion vary with vehicle flow, internalization costs should do so as well. The first-best implementation mechanism would charge drivers for their external impacts based on real-time congestion levels (a person driving on an empty country road might pay nothing while a person driving over a congested city bridge at rush hour would pay considerably). Technological advances in satellite positioning have made it possible for every vehicle to be tracked as it travels; drivers can then be charged variable rates depending on the marginal congestion costs they impose. Such technology is in test phases in various parts of the world, but jurisdictions have yet to experiment on a large scale. There are large implementation costs associated with affixing a global positioner to every vehicle, and many feel that their privacy is interrupted when their every movement is tracked.[3] Therefore, second-best mechanisms are proposed that lead to some internalization but with less privacy invasion.

Other potential mechanisms for cost internalization include fuel taxes and pay-as-you-drive (PAYD) insurance. Fuel taxes are excellent for targeting environmental externalities but do little for congestion. It has been noted that the main effect of increases in the price of fuel is that individuals drive more fuel-efficient vehicles (Congressional Budget Office 2008). Fuel-efficient vehicles aid the environment but still add to congestion. PAYD insurance is less escapable – drivers would pay incremental insurance fees per-kilometre of travel regardless of the type of vehicle. PAYD insurance can induce overall vehicle use reductions as individuals respond to the per-kilometre charge but PAYD does not target congestion since a ten kilometre trip along an empty road would have the same added cost as a ten kilometre trip on a congested one. Tolls, conversely, have the unique feature that they can easily vary to target congestion. Tolls can change based on the point of travel, the time of day and even the real-time level of congestion; policymakers can set tolls higher during high demand periods and lower in the middle of the night. They can toll frequently congested areas and leave uncongested areas toll-free. This is what Vickrey helped us understand; when demand rises, prices should rise too. Tolls (also referred to as congestion charges or road charges below) are the pricing instrument studied and applied over the remainder of this paper.

Some analysts have extended theories of road pricing to make conclusions about the optimal size of the road network. They argue that once external costs are priced, road expansion decisions can be based on traditional economic supply arguments; revenues that exceed maintenance and operation costs indicate that sufficient demand exists to justify a network expansion. This approach transfers road expansion decisions from the central planners of government departments to the invisible hand of the market, resulting in an equilibrium road supply with an efficient optimum based on road demand and cost. It is important to recognize, however, that congestion is not the only improperly priced cost in road transportation – there are other externalities that must be corrected before network optima can be reached. These other externalities include environmental damage, accident risk, insurance and, importantly, land. Once

[3] In subsequent sections, this paper proposes the use of electronic tolling for the Fraser River crossings. As discussed in the section on policy design, the privacy invasion that occurs when recording a trip on a crossing is much lower than a device that tracks all travel.

all market failures that contribute to road demand are corrected, an optimal road network could be reached through market forces.

Translating congestion pricing theory into meaningful and practical policy solutions means making several assumptions about road demand and optimal traffic flows. Congestion charges are designed to move drivers leftward along their demand curve (reducing vehicle flows), so understanding the price elasticity of this demand is critical to successful congestion reduction. Choosing the optimal vehicle flow will also influence policy development. The next section of this paper addresses these challenges by developing reasonable and appropriate assumptions based on the realities of the region. Then, the assumptions are applied to a model that estimates the tolls required for congestion reduction on the Fraser River crossings.

Internalizing congestion's external costs will lead to optimal vehicle volumes. In the 1960s, William Vickrey introduced the concept of market failures in the pricing of transportation. His theory has since been refined and adapted, but applied in only a few jurisdictions. Vickrey knew that variable pricing could reduce traffic demand and lead to optimal traffic solutions. The remainder of this paper will assess the congestion problem of the Fraser River and develop and evaluate tolling policy solutions based on congestion pricing theory.

4 Estimating Behaviour Under Pricing

The transportation demand management (TDM) effects of road charges are well established for the general case but are relatively unknown for many specific ones, including the Lower Mainland. Developing effective road pricing policy requires a rigorous assessment of the unique effects that prices will have on local travel patterns. This section undertakes a simple price elasticity analysis for the four Fraser River crossings in question. First, I review and analyze several road pricing elasticity estimates established in the literature and determine that a price elasticity of –0.25 is a reasonable starting point for planning. Second, I present a rough model that uses the established elasticities to calculate the charges that would be required to achieve target traffic flows on the crossings. The model uses variable assumptions, and I undertake sensitivity analysis to understand the effects of using different baseline elasticity assumptions. Overall, the toll calculation model will contribute to policy design by guiding the necessary toll levels.

4.1 Elasticities in the Literature

A price elasticity of demand indicates how strongly consumers' consumption of a good or service responds to changes in price. Charging road users for the privilege to occupy road space increases the cost of travel and, intuitively, should reduce the number of cars on the road as drivers shift to other modes, time periods or eliminate trips all together. The elasticity value describes the degree to which road users will reduce their travel; its typically negative value indicates that a higher price will induce a lower demand.[4] I summarize a handful of studies on road pricing elasticities that I believe to be especially pertinent for Greater Vancouver comparison. For various reasons, elasticity values are specific to the type of expense. Here, I look at elasticities for road pricing and neglect other travel costs like parking fees or fuel taxes. I also look exclusively at short term elasticities since long term elasticities are more difficult to measure and are often unavailable because of the large number of variables involved in estimation. I begin with a study by Simon Fraser University researchers Washbrook, Haider and Jaccard (2006), which I believe to be the best local road pricing elasticity estimation developed. I then compare

[4] For example, a price elasticity of –0.5 means that a 10 percent increase in the price of a good will lead to a 5 percent decrease in demand for that good.

the Washbrook elasticities with other non-local studies and determine that the Washbrook estimates are sound behavioural representations of Greater Vancouver drivers.

Washbrook et al. surveyed commuters in the suburban Vancouver communities of Ladner and Tsawwassen and asked respondents to choose between various travel scenarios that differed based on travel time, cost and mode. Regression analysis allowed the authors to determine commuters' reactions to various road charge changes. The overall road charge elasticity of a single occupancy vehicle trip was found to be –0.32. Importantly, their study asked respondents to assume that public transit and carpool alternatives were available. These alternative modes were usually slower than driving, but were true alternatives since they did not require travellers to bear extreme changes in their commute times.[5]

Revealed preference results from Toronto, Spain, New York and Singapore suggest that the Washbrook et al. results are realistic. Toronto's 407 Express Toll Route (407ETR) stretches 108 kilometres through the city's suburbs and electronically charges a per-kilometre toll to users. Mekky (1999) estimates the price elasticity of demand for 407ETR users to be approximately –0.7 at current charge levels, increasing to an extreme –4.0 at very high tolls. Mekky's elasticity of –0.7 is higher than Washbrook's, but reasonably so. A multitude of untolled alternatives are immediately available to 407 users; should prices increase, drivers can easily choose to travel on a different (albeit slower) route. Washbrook did not give respondents the choice of a nearby untolled route. Instead, respondents had to choose between paying a road charge and travelling using an alternative mode. In general, with cheaper substitutes available, consumers are more likely to switch products. When such substitutes do not exist, consumers are less likely to alter behaviour, resulting in less elastic responses.

Matas and Raymond (2003) determined that tolls on Spanish freeways induce elasticities of between –0.21 and –0.83. At their high end, Matas and Raymond's estimates are close to Mekky's 407ETR elasticities. Matas and Raymond also note, however, that they recorded their

[5] A limitation of note is Washbrook's use of a base price for road charges. Elasticity is interpreted as a change in demand resulting from a change in price. Currently, however, tolls do not exist on the crossings, so a percent change calculation is not possible. To compensate, Washbrook adopts a definition of "road charge" that combines parking and toll charges. This allows elasticity to be estimated based on a change in the "road charge", set at $5.00 as a base. In regression estimation, Washbrook does not assume that individuals react to parking charges in the same way that they react to tolls. Instead, the study uses the $5.00 base charge as a current "road charge" and then separately calculates how drivers react to different increases in this charge; notably, how they would react to an added toll. This limitation should not greatly affect the comparison below. While the assumption of a $5.00 base charge does not give the precise estimate that an actual current toll would, it is a sound next-best approach.

lowest observations on Spanish cities' heavily congested bridges – a scenario comparable to the Fraser River crossings. Washbrook's –0.32 estimate falls at the low-end of the Spanish range. Therefore, Matas and Raymond's Spanish estimates suggest that the behaviour of Greater Vancouver bridge users is closer to Washbrook's –0.32 estimate than Mekky's –0.7 estimate for the 407ETR.

New York City charges bridge tolls on most crossings into Manhattan. Litman (2007b) noted that the elasticity of bridge tolls in New York City is –0.1, so these bridge users demonstrate highly inelastic behaviour. I judge the behaviour of New York bridge users to be appropriately more inelastic than bridge users in Greater Vancouver due to measurement differences. Washbrook estimates road price changes as a percentage of the overall road charge but in New York the change in price is only for the toll, not a parking charge. Since parking costs in New York are very high, it is expected that a change in the bridge toll will only minutely affect demand because the toll represents just a small portion of the total cost.

Litman (2007b) also reported that cordon tolls in Singapore create elasticity responses of –0.19 to –0.58. Singapore has unique geographical, cultural and population characteristics that make it difficult to compare to Greater Vancouver. Still, since the Washbrook –0.32 estimate is near the centre of the Singapore range, the Singaporean cordon toll system does not contradict Washbrook and associates' work.

It should be noted that with the exception of Singapore, none of the above studies assess a congestion reduction scheme. Instead, they simply evaluate the choices that individuals make in response to changes in general tolls. More elastic responses may occur if policy makers emphasize interdependent policies that increase service quality for alternative travel modes given congestion reduction goals. In fact, the provision of alternative transportation modes could have a large effect on elasticity values by making it easier to reduce auto use.

Table 3: Road Pricing Elasticity Estimates

Study	Estimate
Washbrook	–0.32
Mekky: 407ETR	–0.7
Matas and Raymond: Spain	–0.21 (for congested bridges)
New York Bridges	–0.1
Singapore Cordons	–0.19 to –0.58

Table 3 summarizes the studies discussed above. These estimates range between –0.1 and –0.7; road users are responsive to price increases. The Washbrook estimates are in the same general range as those of other studies, near the low- to mid-level end. However, in estimating a toll structure, I will use a more conservative –0.25 as the base case for two reasons. First, I believe that the Washbrook study may suffer from some bias from the hypothetical nature of the survey. While individuals may respond that they would switch to transit under the tolls, because there is currently no system in place, the respondent does not know what that transit experience will be like. Likely, some will continue to drive. Second, for policy design it is better to be conservative of the required toll; politically, it is easier to reduce a wrongly estimated toll that is too high than to increase a toll that is initially too low.

4.2 Toll Estimation Model

Price elasticity of demand describes the degree to which consumers will alter their consumption decisions following price changes. Elasticities represent the change in demand that results from a change in price. Equation 1 applies elasticities to estimate the toll charge needed to reduce traffic flows to less congested levels. Given the congestion pricing theory and elasticities considered above, toll increases will deter traffic. The equation's numerator (containing current and target traffic flows) determines the percent change in quantity (traffic) required to achieve congestion targets; the relationship between the toll (T) and current average road charge (C) represents the percent change in price. After inputting a series of values for each variable, the model outputs a toll level that will reduce the number of vehicles over a crossing to target levels.

Equation 1

$$If\ F_C < F_T, \quad T = 0$$

$$If\ F_C > F_T, \quad T = C \times V_t \times \frac{\left(\frac{F_C - F_T}{F_C}\right)}{E}$$

$$Where:$$
$$T = Toll$$
$$F_C = Current\ Flow$$
$$F_T = Target\ Flow$$
$$E = Elasticity$$
$$C = Current\ Avg\ Road\ Charge$$
$$V_t = Value\ Parameter\ at\ Time\ t$$

To run this model, 2004 average hourly traffic flows for each crossing were obtained from TransLink (GVTA 2004a). TransLink compiles the data from automatic traffic counters and reports weekday averages. For target flows, the model run presented below used 1400 passenger car equivalents per lane per hour. While somewhat arbitrary, this level of flow would allow for a significant increase in speeds over the crossings (Litman 2007c).[6] A 1400 vehicles per lane per hour target is also near the "design flow" for the crossings – the level of flow intended by engineers when the crossings were constructed. The model assumes that the current lane counterflow system in the George Massey Tunnel will remain; 3 lanes northbound and 1 lane southbound from 6:00 to 9:00 and 3 lanes southbound with 1 lane northbound from 15:00 to 18:00 (there are 2 lanes in each direction for the rest of day).

Elasticity is based on the percentage change in the current cost of driving (C). Therefore, it requires C to be a value other than 0. Even though there are no current charges over the crossings, Washbrook based road charges on an average base charge of approximately $5.00 for trips in the Lower Mainland; I apply the same assumption here.

Finally, while pricing will create freer-flowing traffic, the new flow levels will simultaneously make driving more attractive. A fast trip during rush hour is more valuable than a fast trip at other times because demand is higher. Here, I represent the extra attraction through a "value" variable. I use a standard speed-flow calculation to estimate value based on traffic flows; Equation 2 is an adapted version of the Bureau of Public Roads speed-flow relationship (Small 2007). This relationship is commonly used to model the non-linear relationship between flow and congestion. An additional trip on a road near capacity will have a greater congestion impact than an additional trip on a near-empty road. By modelling congestion rather than flow, I determine a relative value parameter for a free flowing trip. Routes that are commonly congested (with magnitude of congestion determined through Equation 2) are more valuable than those with lower congestion. The resulting tolls adapt upwards to compensate for the increased attraction.

[6] The model can easily adapt to various targets, but for simple analysis and presentation was only estimated with this level.

Equation 2

$$V_t = \left[1 + 0.15\left(\frac{F_C}{F_T}\right)^4\right]$$

Where:

V_t = *Value Parameter at Time t*

F_C = *Current Flow*

F_T = *Target Flow*

This Toll Calculation Model is not original to this paper, it is merely an application of long-standing economic and traffic flow theory. Results of three different modelled scenarios are found in Tables 4 to 6. These show the tolls required to decrease traffic to a target flow of 1400 cars per lane per hour given the assumptions above. The scenarios allow for investigation into the role of elasticity and provide guidance for policy development. Results in Table 4 (Scenario 1) have a peak hour elasticity of –0.15 and off-peak elasticity of –0.2, results in Table 5 (Scenario 2) have a peak hour elasticity of –0.2 and off-peak elasticity of –0.25, and results in Table 6 (Scenario 3) have a peak hour elasticity of –0.25 and an off-peak elasticity of –0.3. These scenarios were designed to demonstrate the impact of the elasticity assumption. The elasticities are smaller during peak hours because commuters are least likely to change their behaviour (Button 1993). Note that these tables are presented for comparison and guidance, not as policy proposals. Section 6 contains the pricing proposals of this study.

Table 4: Scenario 1, Tolls Given Peak Hour Elasticity of –0.15, Off-Peak Hour Elasticity of –0.2

	George Massey Tunnel		Alex Fraser Bridge		Pattullo Bridge		Port Mann Bridge	
Time	Northbound	Southbound	Northbound	Southbound	Eastbound	Westbound	Eastbound	Westbound
0:00	0	0	0	0	0	0	0	0
1:00	0	0	0	0	0	0	0	0
2:00	0	0	0	0	0	0	0	0
3:00	0	0	0	0	0	0	0	0
4:00	0	0	0	0	0	0	0	0
5:00	0	0	0	0	0	0	0	0
6:00	0	0	5.34	0	0	6.32	0	14.23
7:00	8.63	2.97	8.33	0	0	7.66	0	10.43
8:00	1.23	3.93	8.32	0	0	1.82	0	14.26
9:00	4.44	0	0	0	0	0	0	9.00
10:00	2.37	0	0	0	0	0	0	5.25
11:00	0.64	0	0	0	0	0	0	4.60
12:00	0	0	0	0	0	0	0	4.26
13:00	0	0	0	0	0	0	0	5.43
14:00	0	4.54	0	0	0	0	1.92	7.57
15:00	18.93	0	0	8.77	4.30	0	8.41	15.33
16:00	6.44	5.32	0	12.56	5.48	0	9.68	15.98
17:00	4.85	5.37	0	14.18	0.19	0	7.82	14.45
18:00	0	6.62	0	4.46	0	0	0.51	5.18
19:00	0	0	0	0	0	0	0	0
20:00	0	0	0	0	0	0	0	0
21:00	0	0	0	0	0	0	0	0
22:00	0	0	0	0	0	0	0	0
23:00	0	0	0	0	0	0	0	0

Table 5: Scenario 2, Tolls Given Peak Hour Elasticity of −0.2, Off-Peak Hour Elasticity of −0.25

	George Massey Tunnel		Alex Fraser Bridge		Pattullo Bridge		Port Mann Bridge	
Time	Northbound	Southbound	Northbound	Southbound	Eastbound	Westbound	Eastbound	Westbound
0:00	0	0	0	0	0	0	0	0
1:00	0	0	0	0	0	0	0	0
2:00	0	0	0	0	0	0	0	0
3:00	0	0	0	0	0	0	0	0
4:00	0	0	0	0	0	0	0	0
5:00	0	0	0	0	0	0	0	0
6:00	0	0	4.01	0	0	4.74	0	10.67
7:00	6.48	2.23	6.25	0	0	5.74	0	7.82
8:00	0.92	2.95	6.24	0	0	1.37	0	10.70
9:00	3.55	0	0	0	0	0	0	7.20
10:00	1.89	0	0	0	0	0	0	4.20
11:00	0.51	0	0	0	0	0	0	3.68
12:00	0	0	0	0	0	0	0	3.41
13:00	0	0	0	0	0	0	0	4.35
14:00	0	3.63	0	0	0	0	1.53	6.06
15:00	14.20	0	0	6.58	3.22	0	6.31	11.50
16:00	4.83	3.99	0	9.42	4.11	0	7.26	11.99
17:00	3.64	4.03	0	10.64	0.14	0	5.86	10.84
18:00	0	5.30	0	3.57	0	0	0.41	4.15
19:00	0	0	0	0	0	0	0	0
20:00	0	0	0	0	0	0	0	0
21:00	0	0	0	0	0	0	0	0
22:00	0	0	0	0	0	0	0	0
23:00	0	0	0	0	0	0	0	0

Table 6: Scenario 3, Tolls Given Peak Hour Elasticity of –0.25, Off-Peak Hour Elasticity of –0.3

	George Massey Tunnel		Alex Fraser Bridge		Pattullo Bridge		Port Mann Bridge	
Time	Northbound	Southbound	Northbound	Southbound	Eastbound	Westbound	Eastbound	Westbound
0:00	0	0	0	0	0	0	0	0
1:00	0	0	0	0	0	0	0	0
2:00	0	0	0	0	0	0	0	0
3:00	0	0	0	0	0	0	0	0
4:00	0	0	0	0	0	0	0	0
5:00	0	0	0	0	0	0	0	0
6:00	0	0	3.21	0	0	3.79	0	8.54
7:00	5.18	1.78	5.00	0	0	4.59	0	6.26
8:00	0.74	2.36	4.99	0	0	1.09	0	8.56
9:00	2.96	0	0	0	0	0	0	6.00
10:00	1.58	0	0	0	0	0	0	3.50
11:00	0.43	0	0	0	0	0	0	3.06
12:00	0	0	0	0	0	0	0	2.84
13:00	0	0	0	0	0	0	0	3.62
14:00	0	3.03	0	0	0	0	1.28	5.05
15:00	11.36	0	0	5.26	2.58	0	5.04	9.20
16:00	3.86	3.19	0	7.53	3.29	0	5.81	9.59
17:00	2.91	3.22	0	8.51	0.11	0	4.69	8.67
18:00	0	4.42	0	2.97	0	0	0.34	3.46
19:00	0	0	0	0	0	0	0	0
20:00	0	0	0	0	0	0	0	0
21:00	0	0	0	0	0	0	0	0
22:00	0	0	0	0	0	0	0	0
23:00	0	0	0	0	0	0	0	0

As expected, due to a combination of lower peak-hour elasticities and higher peak-hour demand, tolls are highest during peak hours. Across scenarios, tolls naturally increase as elasticity decreases. Overall, the tolls range from a low of $0.11 to a high of $18.93. Many periods do not require tolls because the crossing is already operating below the target flow. The Port Mann Bridge is the most oversubscribed crossing and needs tolls for more hours than any of the other crossings. Afternoon tolls tend to exceed morning tolls due to higher traffic demand in the afternoon. Demand is lower in the morning because morning trips tend to include mostly commute trips, whereas in the afternoon they include many other types of trips; on the whole, individuals do not make many social or shopping trips during the morning peak, but these are fairly common over the afternoon peak.

Changing elasticities (comparing scenarios) affects the toll. The variance is small in some cases, but during some periods of high demand, tolls fluctuate between about $9.00 and $15.00 given different elasticity assumptions. This is significant in terms of policy implementation and public acceptability. While it is difficult to know precisely what elasticity to assume *ex ante*, policy makers can use this model to understand the consequences of over- or underestimating elasticities.

There are limitations to this model. First, it does not account for a dynamic diversion of trips. A driver who is attracted (by lower tolls) from the George Massey Tunnel to the Alex Fraser Bridge is counted as an avoided trip in the tunnel but not as an additional trip on the Alex Fraser. The extent that drivers will opt for less expensive routes is unknown (cross-elasticities of demand are needed). Some charges on the lower priced crossings may need to increase to further discourage drivers from seeking those routes and to maintain target flows. Similarly, the model does not account for drivers who change their travel to new time periods; the tolling structure may need to adjust these tolls upward once trips redistribute throughout the day.

Further limitations are associated with the model's assumptions. Elasticity levels vary depending on many factors including alternatives available, flexibility of workplace start times and income levels. The inputs for average road charge and target flow per lane also influence results. These inputs were assumed equivalent for each crossing, but it is just as likely that they vary by crossing (Khisty and Lall 1998).

The results presented in the summary tables above are meant to show the effects that different elasticities have on congestion-reducing tolls. They will be used in the section on policy design to develop tolling structures. The results show that elasticity matters in tolling policy development. If toll regulators assume initial elasticities of Scenario 1 but find they are actually closer to those under Scenario 3, traffic levels will decrease more than desired. Additionally, higher elasticities can be achieved with better mode alternatives, since drivers would more easily adapt their behaviour. If investment were made in public transit and other modes, it would be possible to charge lower tolls, like those in Scenario 2, and still achieve a target flow.

Very complicated traffic models exist and are used every day by transportation planners; these models rely heavily on hundreds of assumptions. Here, I employ a simple model that is based on drivers' average responses to road charges and has few assumptions. The model has its limitations but is supported by the reasonableness of the results (maximum tolls of $18.93, but most in a lower range). This model is made to inform pricing policy development, indicating a general range of toll levels that serve as starting points for construction of a tolling system.

5 Case Studies

Congestion pricing is not limited to the realm of academic thought; several road pricing and congestion charging schemes have been successfully implemented. In this section I describe, assess and compare three road pricing cases. First, using data from operational documents including annual reports, traffic assessments and evaluations, I report on their respective abilities to reduce congestion. Second, the cases are used to identify the particular critical factors that ensure success. These factors include measures that make congestion pricing policies acceptable, equitable and effective.

The experiences in London, Toronto, and Orange County (California) will be reviewed in detail. Each region has a congestion pricing scheme with a unique congestion outcome; London has a cordon scheme, Toronto has per-kilometre charges with untolled alternatives, and Orange County utilizes High Occupancy Toll (HOT) lanes. The schemes have sufficient variation in their designs to allow inference of the impacts that individual design characteristics contribute. These studies suggest that congestion is influenced by the presence of untolled road alternatives. I also determine that alternative mode provisions, pricing structures and fee exemptions can contribute to successful congestion-reducing schemes.

5.1 London

London, England, is perhaps the most famous example of congestion charging. Its scheme received a large amount of worldwide publicity upon implementation and, at the time, was the most ambitious form of congestion charging in the Western world. London provides a good case for analysis because it began as a novel policy idea, faced large opposition and has met its chief objectives.[7] London, long a bustling metropolis, has recognized for decades that its transportation demand has outgrown its network. Starting in 2003, any vehicle crossing into the congestion charge zone of the city's central core was assessed a fee of 5 GBP (10 CAD). The effects on traffic flows were almost immediate; on central London's streets, congestion fell. In the

[7] I considered Singapore as a case in London's stead because Singapore has had a scheme in place since the 1970's. Singapore was rejected as inferior because of London's closer similarity to Vancouver in governance and culture. As well, Singapore combined its congestion charging with a series of very heavy-handed policy measures such as a lottery for the right to own a vehicle, which reduces Singapore's applicability in the B.C. context.

five years since implementation, the charge area has expanded, the fee has increased, and the results have been maintained.

London's congestion charging zone now covers approximately 42 square kilometres (Evans and Firth 2007). Between the hours of 7:00 and 18:00, drivers who enter the congestion zone must pay 8GBP (16CAD). Gantries with digitized cameras scan every vehicle's registration plates; drivers can then pay the charge using a variety of methods including telephone and Internet payments. Importantly, fees are charged per day, not per entry. Therefore, after entering the central zone once, drivers can cross the boundaries as many times as they wish. There are notable exemptions and discounts. Anyone who resides within the zone pays only 10% of the charge (0.8GBP). All taxis, two-wheeled vehicles, vehicles with 9 or more seats and recovery vehicles (e.g. tow trucks) pay no charge. Electrically propelled and other "alternative fuel" vehicles also pay no charge; some hospital trips are given discounts. One "free" route allows drivers to traverse the zone without charge. There is no parking along this route, so it is only useful to drivers with a final destination outside the charge zone.

5.2 Toronto

In 1997, Ontario's provincial government opened the world's first all electronic toll highway – the 407 Express Toll Route (407ETR). Meant to be an alternative option to its heavily congested southern route, Highway 401, the 407ETR has remained mostly uncongested. The highway spans 108 east-west kilometres through the suburbs of Greater Toronto, varying between 4 and 8 lanes. Users are charged tolls based on the distance they travel on the highway. A private consortium *407 International* currently operates the highway under a long term lease agreement with the provincial government. Toronto was selected as a case because it provides a Canadian context in a setting with an unpriced alternative.

Some price variance occurs for peak demand periods; prices increase by approximately 7% during peak periods. Gantries scan vehicles electronically at the entry and exit points of the highway. As of February 1, 2008, tolls are as follows.[8] During peak hours, users are charged \$0.1925/km on the heavily travelled central zone (approximately half of the highway), and \$0.19/km on the lighter zone. Off peak charges are \$0.18/km for both zones. Single-unit trucks up to 5000 kg are charged \$0.3850/km for peak period heavy zone, \$0.38/km for the peak period light zone and \$0.36/km off peak. Multiple-unit trucks pay \$0.5775/km for peak period heavy zone, \$0.57/km for the peak period light zone and \$0.54/km off peak. There is no way to travel

[8] www.407etr.com/About/tolls.htm

the 407 without paying the fee (no exemptions). The rate variations are very small between the peak and off-peak times, and the 407ETR charges fees even when traffic is very light. Peak-hour prices do target congestion, but *407 International's* primary goal in levying tolls is cost recovery.

The process of setting tolls on the 407 has remained controversial, mostly because users have faced rising tolls almost each year since 1997 (Lai 2006). Legally, each year, the *407 International* may increase tolls to a level it desires, so long as the average vehicle flow per lane per hour do not drop below 1500 (407 International 2007). As a revenue-maximizing firm with a monopoly on the road, one would expect tolls to increase as much as legally possible. Therefore, the 407ETR practices pseudo-congestion targeting; 1500 vehicles is a relatively freely flowing traffic level.

The 407ETR is a tolled highway among a set of untolled alternatives. Drivers can plan routes with identical origins and destinations that avoid toll payment. In London, the origin or destination must change to avoid the charge and still drive. The untolled Toronto routes, however, are not perfect substitutes for the 407ETR. For example, a person with an origin near the 407ETR who is travelling to a destination 10 kilometres to the east would view Highway 401 as a cumbersome alternative requiring a 5 kilometre (approximately) trip south, a 10 kilometre trip east and another 5 kilometre trip north. Taking the 407ETR is more direct. For a long trip that will span the entire length of the 407ETR, however, the relative addition of the extra travel to get to and from the 401 is lower. In other words, congestion is not the only difference in 407ETR use. The utility of the 401 as an untolled option depends on the nature of the trip and it increases as the trip length increases. Another imperfect substitute is the surface street network. While surface streets do traverse the 407's route almost identically, they present drivers with much longer travel times, even when uncongested. By and large, for any origin and destination, there are a series of alternatives to the 407ETR, but these are not perfectly substitutable nor simply an identical highway sans tolls.

5.3 Orange County

To deal with heavy congestion on their State Route 91 (SR91) freeway, California added High Occupancy Toll (HOT) lanes – "91 Express Lanes" – along 16 kilometres of the freeway.[9] Two HOT lanes travel along the median of the freeway in each direction; they are nestled between four to five lanes of freeway in either direction. Vehicles containing three or more

[9] While there are some other examples of HOT pricing in the United States, Orange County was chosen because it was the original and has therefore had the most time for its effects to emerge.

persons (high occupancy) may use the express lanes without charge, but any other vehicle can gain access to the lanes only by paying a fee, which varies depending on the time of day and the day of the week.[10] Some fee exemptions exist for motorcycles, low emission vehicles, vehicles with drivers who are disabled, and veterans.

At the time of writing, tolls for the 91 Express Lanes ranged from a low of $1.20 to a high of $9.50.[11] Vehicles are scanned electronically upon entry and gain the right to travel the length of the express lanes by paying the toll. Tolls are set with the goal of ensuring an uncongested alternative; the Orange County Transportation Authority (OCTA) uses a target flow of 3128 vehicles per hour (1564 vehicles per lane per hour) as a ceiling (OCTA 2003). When average traffic levels exceed this target for any given time period, tolls are increased for that time of day. SR91 does not use dynamic tolling structure; tolls are not set based on real-time traffic information rather they are set based on average traffic flows over a six month period and these tolls are sign-posted and well advertised. Tolls are highest during periods of peak demand and lowest when demand is low; rush hour travellers pay the highest tolls.

5.4 Congestion Results

The above-described tolling structures have unique impacts for congestion, which are explained in two categories: congestion on the tolled area or facility and congestion on the surrounding network. The former refers to how well the toll structure ensures congestion-free travel on or within the tolled area. For London, this means congestion within the charging zone, for Toronto and Orange County this means congestion on the 407ETR and 91 Express Lanes, respectively. The other impact category refers to the congestion of the overall nearby road network, including surrounding routes and roads. In the Fraser River context, congestion reduction is important along the bridges and tunnels, but understanding the effects on the surrounding network is critical. Both categories are used since success in one area does not necessarily mean success in another, but each is important for policy analysis.

5.4.1 Congestion on Tolled Facility/Area

Transport for London (TfL), the authority responsible for managing the city's transportation system (including its buses, subways, roads and the congestion scheme) monitors congestion within their charge zone in two important and nuanced ways. First, TfL measures the

---

[10] From 4-6 pm in the eastbound direction, high occupancy vehicles must pay 50% of the fee.

[11] www.91expresslanes.com/tollschedules.asp

number of vehicles that cross the cordon into the charge zone. This measure allows TfL to determine the level of demand for entry into the zone. Absolute traffic levels, however, are not the only determinant of congestion; road maintenance, traffic signal optimization and illegal parking are some other variables that can increase congestion while leaving traffic levels constant. Therefore, TfL also uses travel times to understand how well traffic is flowing through the streets of the zone.

In the implementation year of London's congestion charge, TfL observed a decrease of 18% in absolute traffic levels. By 2006, traffic levels were 21% lower than pre-charge flows. Initially, travel times also improved, and in 2003, trips were 20-30% shorter than the previous year. These travel time savings remained similar through 2004 and 2005, but in 2006, travel times were only 8% shorter than pre-charge levels, despite constant traffic flows (Transport for London 2007). TfL attributes 2006's poor travel time measure to a large increase in road maintenance through the year. The 2007 data may validate this explanation but it is important to recognize that this measure of congestion indicates lower success. Overall, the scheme is regarded as a success for congestion in Central London (Transport for London 2007).

While the principal objective in building the 407ETR was congestion relief for the 401, and tolls were added to recover construction costs, the tolling structure that was developed for the 407 has resulted in an uncongested highway. For much of the day traffic moves at free flow speeds. During times of peak demand, traffic does approach the target maximum of 1500 vehicles per hour per lane. Even though this level of flow does not represent freely moving traffic, it still represents speeds of 70-80% of the speed limit – a level most travellers consider uncongested. Since the 407's lease agreement allows tolls to increase when traffic exceeds target levels, it must be the case that the tolls discourage traffic. Otherwise, tolls would continually increase as the revenue-maximizing firm increased prices without seeing a decrease in traffic.

The OCTA advertises travel time savings of approximately 30 minutes each way when drivers use the 91 Express Lanes (Parsons Brinkerhoff 2003). Over 25.75 kilometres (16 miles), this means an average increased speed of 51.6 km/hour compared the congested regular route.[12] Like the 407ETR explanation above, it must be the case that traffic levels remain below the target flow (1564 vehicles per lane per hour), otherwise tolls would be further increased to reduce demand, as per the route's fee policy. Table 7 summarizes the congestion outcomes for each tolled facility or area.

[12] 25.75 km/30 min is an average of an extra 0.86 km/min, or 51.6 km/hour.

Table 7: Congestion on Tolled Facility/Area

Case	Congestion on Tolled Area/Facility
London	• 2006: 21% reduction in charge zone traffic counts over pre-charge levels • 20-30% reduction in travel times within the charge zone (2006: 8% travel time reduction)
Toronto	• Maximum average of 1500 vehicles/lane/hour. At this maximum, vehicles travel at a speed of 70-80% of speed limit
Orange County	• 30 minutes travel time savings over distance of 25.75 km; increased speeds of 51.6 km/hr. • Maximum average of 1564 vehicles/lane/hour. At this maximum, vehicles travel at a speed of 70-80% of speed limit

5.4.2 Congestion on the Surrounding Networks

London's congestion charge zone represents only a very small proportion of the overall area of the city. Nonetheless, London's congestion improvements since 2003 are not limited to traffic in the charge zone. As a result of decreased demand for road trips to Central London, the flow of vehicles along the arterial routes towards the centre has simultaneously decreased. This has resulted in small congestion improvements along these routes (Transport for London 2007). Additionally, while the Inner Ring Road (which surrounds the original congestion zone) has seen small increases in traffic flows (vehicles getting as close to Central London as possible without paying the charge), congestion on this road has been mostly contained. Through improvements such as tougher parking restrictions and increased traffic signal optimization, the Inner Ring Road is not worse off than pre-implementation congestion (Transport for London 2007). While the congestion charge zone enjoys significant congestion improvements, its surrounding network has also experienced some minor improvements because of the scheme.[13]

The 407ETR's tolling system provides little congestion relief over the entire network. When built, the 407ETR initially took some of the pressure off the 401 (due to the increase in road capacity) but the 401 quickly returned to its congested ways as automobile use in the city grew. The parallel surface routes also remain congested, showing a lack of willingness to pay tolls. The 407ETR's tolling structure does not decrease congestion on the surrounding roads, but it does provide an uncongested alternative.

[13] In Greater London overall, congestion continued to increase, as any city with increasing population and wealth would expect (Transport for London 2007).

Orange County's experience is similar to Toronto's. The untolled lanes of SR91 remain congested, with speeds approximately 51km/hr slower than the express lanes. In fact, the 91 Express Lanes rely on this scenario; if the regular lanes were not congested, there would be no reason for drivers to pay to use the Express Lanes. In contrast, the 407ETR is in some instances better option regardless of congestion on the alternatives. There are also no surface roads that present a similar alternative route. As a result, the 91 Express Lanes remove a maximum of 3128 vehicles per hour from each direction of SR91, which does very little for the congestion of the freeway, meaning the surrounding route remains highly congested.

Table 8: Congestion on Entire Network

Case	Congestion on Surrounding Networks
London	• Small to medium reduction in surrounding network congestion
Toronto	• Surrounding networks very congested
Orange County	• Surrounding networks very congested

5.4.3 Comparing Outcomes

The clearest result of the above case studies is that Toronto's 407ETR and Orange County's 91 Express Lanes exhibit similar congestion patterns. On each, congestion is low; on their surrounding networks, congestion is high. I did not initially expect the congestion results of these two cases to be so similar, but their similarity can be easily explained. Each freeway uses a similar method for determining toll increases, which is dependent upon traffic flows. For each, when traffic exceeds a particular target, the congestion levels are deemed unacceptable and tolls are increased to further reduce demand. This creates flowing traffic on each facility. Due to the availability and proximity of untolled alternatives, drivers who are priced off the tolled highway choose to make their trip using the surrounding network where demand remains unmanaged, leading to no change in its congestion.

An important difference between Toronto and Orange County is how they use time of day pricing. While traffic targets are similar, the use of hourly and daily variance on SR91 means that the HOT lanes can create a more efficient outcome. OCTA can set different rates for Monday at 11:00, Tuesday at 8:00 and Wednesday at 14:00, aiming for approximately 1500 vehicles per hour per lane. The 407ETR, however, restricts itself to targeting only peak demand overall. Therefore, if the peak occurs eastbound Monday morning at 8:00, the toll is set to reach the target at that time; the other time periods will mostly have excess capacity. The variance by time of day on SR91 allows similar traffic flows through the day, whereas the 407ETR's structure means only hitting the target twice: once for the peak-hour toll level and once for the off-peak toll. Toronto does use economically efficient per-kilometre tolling, recognizing that longer trips impose more external costs.

London contrasts with the Toronto and Orange County cases. Congestion within London's charge zone is not as low as congestion on the tolled facilities of the 407ETR and 91 Express Lanes, but London does succeed at somewhat reducing congestion throughout its surrounding network. Four potential reasons that congestion within the charge zone is not reduced the same amount as the freeway facilities are discussed here. First, trips with a destination in Central London do not have an untolled road alternative they can choose to avoid the charge zone. A driver who wants to terminate his or her trip in Central London must enter the charge zone; any destination along the 407ETR or SR91 can be reached using an untolled route. Therefore, it is simple for a driver in Toronto or Orange County to avoid the toll since the only difference is time. In London, to avoid the toll, a transportation mode switch is required, arguably a less attractive choice for the driver. Second, London has a multitude of exemptions to its charge scheme, including residents of the zone, low emission vehicles, taxis and more. While these cars do not make up the majority of pre-charge trips, they do constitute a large number of vehicles that use the zone each day without facing price constraints. Third, leading up to the charge implementation, Transport for London made a concerted effort to increase the number and frequency of public buses serving the Central London area (Richards 2006). These buses absorb some of the travellers who no longer drive, but also use up road space and increase traffic volume. Finally, the 407ETR and SR91 routes were additions to the existing road network, meaning that people were already used to travelling the routes without them; London tolled an existing road network where transportation and land use patterns were longstanding and therefore difficult to change.

London has the success of reduced congestion on its surrounding network that Toronto and Orange County do not. London's result likely indicates that trips are being avoided or shifted to other modes; Toronto and Orange County's results indicate that trips are instead shifting to the "free" routes. As trips in London shift to other modes, not only is a reduction of traffic seen in the core, but it is also seen along the routes that drivers use to get to the core. London's congestion scheme is regarded as a major success with respect to congestion reduction. Not only has congestion in the charging zone improved, but the improvements have been sustained. The zone itself, and the areas surrounding it, has seen congestion reduction from the pricing scheme. Toronto and Orange County each provide a premium, uncongested route for travellers who wish to pay. They do not, however, reduce the overall congestion of the network. The role of alternatives was found to be most important, and there appears to be a trade-off between large reductions in congestion on the tolled road space and the provision of an untolled route.

5.5 Lessons Learned

While congestion results are arguably the most important outcome of any charging scheme, it is clear that implementing a congestion charging scheme is ambitious, controversial and entails many considerations. Success rests on factors that enhance the scheme's acceptability, equity and efficiency. Here, important lessons from each case are described with respect to their contribution to the scheme. London's include alternative mode provision, parallel congestion reduction policies and exemptions; Orange County has important pricing structure and exemption features. Toronto's success factors include its pricing structure and charging of out-of-province vehicles.

City planners in London recognized that individuals' overall demand for travel is very difficult to change, but what is easier to change is how people travel. Rather than using a congestion charge to decrease total trips, London planners chose to use congestion charges to shift demand from one mode to another. As the costs of car travel increase, alternative modes become relatively cheaper and more attractive. TfL knew that the best alternative they could offer to car users was public transportation, and with most public transit operating at capacity, expansion was necessary (Richards 2006). Given that London's subway network was plagued with frequent service disruptions and aging infrastructure, and that expansion would be expensive and slow, TfL chose to invest heavily in bus service improvements. Throughout London, bus frequency was increased, new vehicles were added and new routes were introduced in the run up to congestion charging implementation (Richards 2006). Expansion was quick and noticeable and allowed for flexibility. It also provided the opportunity for a virtuous circle of improvements; while bus improvements gave vehicle users an alternative mode, the decrease in congestion as a result of the charge allowed buses to move more freely along their routes, improving travel time and schedule reliability, which increased the attraction of buses. In Toronto and Orange County, public transit service is poor along the routes, but surrounding roads are free. In all cases, individuals who are priced off the tolled road opt for alternatives; in Toronto and Orange County, they opt for other roads. In London, a great majority opt for public transportation, and network road congestion is lower.

Taxis are an important complement to any transportation system since they can provide a crucial link at any stage of a trip. Therefore, while taxis use up road space and contribute to congestion, their provision also encourages drivers to use alternative transportation modes by incorporating taxis as part of a trip. For example, employees who drive to work because they use their car to attend meetings can use a taxi for the meetings and public transportation for their commute. Exempting taxis from congestion charges was important to ensuring drivers had a robust array of alternative modes of travel, including multi-mode trips that include a taxi link. Exemption from the fee ensures a continued taxi presence in Central London, which is a part of the success of the scheme (Litman 2006).

London's other exemptions are important to recognize as well. For the most part, they have helped with the public acceptability of (and potential legal opposition to) the charging scheme (Richards 2006). Providing discounts to residents of the zone is not required or desirable from an optimization standpoint but is crucial to creating an acceptable scheme. While drivers living outside of the zone protested the charge, those living inside the boundaries would have had the added emotional and equity legitimacy of location in their argument; providing the discount neutralized this opposition. Exemptions for drivers with disabilities ensure these individuals keep their mobility and showed the regulators to be compassionate. Scanning motorcycles electronically is much more difficult than cars so exempting these travellers is wise. Overall, the exemptions were critical to the public acceptability and operability of the scheme.

Exemptions are also a key component in Orange County. First, the ability of high occupancy vehicles to use the express lanes at no charge encourages drivers to carpool, reducing some congestion overall as users reduce their driving. High occupancy exemptions also increase the perceived equity and public acceptability of the system; drivers will not complain as much about "Lexus Lanes" when low income drivers can access these lanes in other ways. Exemptions for veterans and individuals who are disabled are further attempts to increase public acceptability. Motorcycles and low-emission vehicles do not pay, and as in London, these mean better operability, incentives to purchase low-emission vehicles, and increased public acceptability.

In Toronto, per-kilometre tolling allows for increased economic optimization over flat charges; *ceteris paribus*, a person who drives ten kilometres imposes more externalities than a person who drives one. This toll structure also provides extra incentives for distance reduction and therefore congestion reduction. The 407ETR varies their charges slightly based on the peak periods, by about 7%. Again, because negative social costs are higher during peak periods, higher charges are called for. This small variance in 407 fees likely does not reflect the variance in externalities. Per-kilometre fees increase public acceptability and equity considerations as well; users like to know that if they are going to pay for using the road, they only pay based on the amount that they use it. The long distance of the highway combined with many entry and exit points means that per-kilometre tolling is feasible. The efficiency of time of day pricing in Orange County was discussed above (in Section 5.4.3), but is also noted here as a central feature of success on that route.

A further public acceptability and equity measure that the 407ETR uses is the billing of out-of-province drivers. While out-of-province vehicles in Toronto are not likely to add significant congestion to the highway, the public does not think it is equitable for residents to pay while non-taxpayers can ride free. The 407ETR sends bills to out-of-province travellers; these bills are relatively unenforceable, but the public perception of equity is clear.

The cases of London, Toronto and Orange County provide insight into the congestion-reducing ability of various pricing configurations. I demonstrated above that untolled road alternatives are critical to determining congestion levels on the tolled facility or area as well as the surrounding network. The conclusions and lessons from these case studies inform the development and analysis of the policy alternatives proposed below.

6 Policy Design

The main policy goal sought here is congestion reduction. Pricing is the instrument that I propose using to achieve that goal. As the above case studies evidence, road pricing can take a number of different forms; pricing policy design can only be successful by taking into consideration the uniqueness of Greater Vancouver. I proceed with policy development in two steps. First, I describe four distinct proposals for congestion pricing in Greater Vancouver. They are: (1) charges on all four Fraser River crossings, (2) charges on two of the four crossings, (3) HOT lanes on each crossing and (4) the status quo. These policy options have been fine-tuned using the toll estimation model and best practices drawn from the case studies. The different effects and merits of these policy options are explained and evaluated in my later policy analysis section.

After describing the policy alternatives, I discuss some policy design characteristics that should be common to any road pricing initiative – a base case that all the policy options should include. I touch upon the use of revenue, charging mechanism selection, the provision of alternative transportation modes, exemptions and the pricing structure. These considerations generally affect each policy's outcomes equivalently. Recommendations for these characteristics are based on experiences from the case studies as well as theoretical and empirical principles.

6.1 Pricing Alternatives

Four alternative pricing schemes for the Fraser River crossings are described below. Each description contains pricing tables depicting the proposed time of day charges for each crossing. Prices were calculated using the elasticity model described in Section 4.2 as guidance. The elasticity inputs vary between each policy alternative, anticipating drivers' response to tolls. For each crossing and option, the average base charge per trip was assumed as $5.00, and the target flow was 1400 vehicles per hour per lane. Hourly optimal prices were rounded to the nearest $0.50 in order to add some simplicity to the schemes; where model outputs changed only slightly from one period to the next, prices were smoothed. Since the model does not include a dynamic diversion of trips to new time periods or crossings, some toll values may need to upwardly adjust to maintain traffic flows given the added demand. Such toll adjustment should occur during the policy review stages explained below. Finally, the pricing development incorporates the current lane counterflow system in the George Massey Tunnel.

6.1.1 Policy Alternative 1: Toll All Four Crossings

Under this option, congestion charges would be placed on each of the Port Mann Bridge, Pattullo Bridge, Alex Fraser Bridge and George Massey Tunnel. The only way to drive across the river without paying a charge would be to take the very slow route of the Albion Ferry to the Pitt River Bridge, which, due to the time costs, is far from a substitutable alternative route.[14] To develop prices for this option, inelastic behaviour was assumed; this reflects, as shown in Sections 4 and 5, normal behaviour when there are no untolled alternatives.[15] Elasticities of –0.2 (peak) and –0.25 (off-peak) were applied. Tables 9 to 12 show the proposed pricing under this policy option.

Placing charges on each of the Port Mann Bridge, Pattullo Bridge, Alex Fraser Bridge and George Massey Tunnel would essentially create a congestion cordon across the Fraser River. During periods of high demand, users would not be able to cross without paying some level of toll. Therefore, this policy alternative is similar to the London congestion charge scheme because it does not offer a road alternative. Yet, while there is no untolled alternative during peak periods, there would be lengthy periods of "free" travel. London's scheme is in a very different setting from the Fraser River and the schemes do differ; some of the outcomes in London will guide analysis of this policy option, while others are not applicable. Of all the policy options, this option requires the highest tolls because of the inelastic behaviour assumption, with the maximum toll at $14.00.

---

[14] The Golden Ears Bridge will replace the Albion Ferry in 2009.

[15] The inelastic behaviour assumption is partially based on the elasticity findings of Washbrook et al. In their study, these researchers assumed a level of transit provision higher than is currently provided. Below I propose increased transit services given pricing, so the Washbrook-based assumption holds.

Table 9: Tolls for the George Massey Tunnel Under Policy Alternative 1

<table>
<tr><th colspan="3">George Massey Tunnel</th></tr>
<tr><th>Time</th><th>Northbound</th><th>Southbound</th></tr>
<tr><td>0:00 – 7.00</td><td>$0</td><td>$0</td></tr>
<tr><td>7:00 – 8:00</td><td>$6.50</td><td>$2.00</td></tr>
<tr><td>8:00 – 9:00</td><td rowspan="3">$3.00</td><td>$3.00</td></tr>
<tr><td>9:00 – 11:00</td><td rowspan="5">$0</td></tr>
<tr><td>10:00 – 11:00</td></tr>
<tr><td>11:00 – 12:00</td><td>$0.50</td></tr>
<tr><td>12:00 – 13:00</td><td rowspan="3">$0</td></tr>
<tr><td>13:00 – 14:00</td></tr>
<tr><td>14:00 – 15:00</td><td>$3.50</td></tr>
<tr><td>15:00 – 16:00</td><td>$14.00</td><td>$0</td></tr>
<tr><td>16:00 – 17:00</td><td>$5.00</td><td rowspan="2">$4.00</td></tr>
<tr><td>17:00 – 18:00</td><td>$3.50</td></tr>
<tr><td>18:00 – 19:00</td><td rowspan="2">$0</td><td>$5.00</td></tr>
<tr><td>19:00 – 0:00</td><td>$0</td></tr>
</table>

Table 10: Tolls for the Alex Fraser Bridge Under Policy Alternative 1

<table>
<tr><th colspan="3">Alex Fraser Bridge</th></tr>
<tr><th>Time</th><th>Northbound</th><th>Southbound</th></tr>
<tr><td>0:00 – 6:00</td><td>$0</td><td rowspan="10">$0</td></tr>
<tr><td>6:00 – 7:00</td><td>$4.00</td></tr>
<tr><td>7:00 – 8:00</td><td rowspan="2">$6.00</td></tr>
<tr><td>8:00 – 9:00</td></tr>
<tr><td>9:00 – 10:00</td><td rowspan="11">$0</td></tr>
<tr><td>10:00 – 11:00</td></tr>
<tr><td>11:00 – 12:00</td></tr>
<tr><td>12:00 – 13:00</td></tr>
<tr><td>13:00 – 14:00</td></tr>
<tr><td>14:00 – 15:00</td></tr>
<tr><td>15:00 – 16:00</td><td>$6.50</td></tr>
<tr><td>16:00 – 17:00</td><td>$9.50</td></tr>
<tr><td>17:00 – 18:00</td><td>$10.50</td></tr>
<tr><td>18:00 – 19:00</td><td>$3.50</td></tr>
<tr><td>19:00 – 0:00</td><td>$0</td></tr>
</table>

Table 11: Tolls for the Pattullo Bridge Under Policy Alternative 1

<table>
<tr><th colspan="3">Pattullo Bridge</th></tr>
<tr><th>Time</th><th>Eastbound</th><th>Westbound</th></tr>
<tr><td>0:00 – 6:00</td><td rowspan="10">$0</td><td>$0</td></tr>
<tr><td>6:00 – 7:00</td><td>$5.00</td></tr>
<tr><td>7:00 – 8:00</td><td>$6.00</td></tr>
<tr><td>8:00 – 9:00</td><td>$1.50</td></tr>
<tr><td>9:00 – 10:00</td><td rowspan="10">$0</td></tr>
<tr><td>10:00 – 11:00</td></tr>
<tr><td>11:00 – 12:00</td></tr>
<tr><td>12:00 – 13:00</td></tr>
<tr><td>13:00 – 14:00</td></tr>
<tr><td>14:00 – 15:00</td></tr>
<tr><td>15:00 – 16:00</td><td>$3.00</td></tr>
<tr><td>16:00 – 17:00</td><td>$4.00</td></tr>
<tr><td>17:00 – 18:00</td><td>$0.50</td></tr>
<tr><td>18:00 – 0:00</td><td>$0</td></tr>
</table>

Table 12: Tolls for the Port Mann Bridge Under Policy Alternative 1

<table>
<tr><th colspan="3">Port Mann Bridge</th></tr>
<tr><th>Time</th><th>Eastbound</th><th>Westbound</th></tr>
<tr><td>0:00 – 6:00</td><td rowspan="9">0</td><td>0</td></tr>
<tr><td>6:00 – 7:00</td><td>$10.50</td></tr>
<tr><td>7:00 – 8:00</td><td>$8.00</td></tr>
<tr><td>8:00 – 9:00</td><td>$11.00</td></tr>
<tr><td>9:00 – 10:00</td><td>$7.00</td></tr>
<tr><td>10:00 – 11:00</td><td rowspan="4">$4.00</td></tr>
<tr><td>11:00 – 12:00</td></tr>
<tr><td>12:00 – 13:00</td></tr>
<tr><td>13:00 – 14:00</td></tr>
<tr><td>14:00 – 15:00</td><td>$1.50</td><td>$6.00</td></tr>
<tr><td>15:00 – 16:00</td><td rowspan="3">$6.50</td><td rowspan="3">$11.50</td></tr>
<tr><td>16:00 – 17:00</td></tr>
<tr><td>17:00 – 18:00</td></tr>
<tr><td>18:00 – 19:00</td><td>$0.50</td><td>$4.00</td></tr>
<tr><td>19:00 – 0:00</td><td>0</td><td>0</td></tr>
</table>

6.1.2 Policy Alternative 2: Leave Untolled Options

Economists know that pricing each crossing creates the most efficiency, but there are significant equity and public acceptability consequences to doing so (further explored below). Policy Alternative 2 leaves two untolled options, more closely abiding by the Provincial Tolling Guidelines and increasing the perception of equity. Under this alternative, only drivers on the George Massey Tunnel and Port Mann Bridge would be assessed charges.

The Alex Fraser and Pattullo bridges have been chosen as the untolled alternatives because they currently have the largest amount of spare capacity. Excess capacity should be a main determinant since, as Toronto and Orange County demonstrate, the untolled alternatives are likely to see congestion. With some capacity to absorb new traffic (albeit, not at peak times), congestion might be minimal, or at least lower than the alternate configurations. Selecting these crossings also provides geographic equity by allocating untolled crossings to both the eastern and western parts of the region.

Tables 13 and 14 show the proposed pricing structures under this scheme. Elasticity assumptions of –0.3 for the peak hour and –0.35 for the off-peak hour were used to develop these prices. These elasticities are only modestly larger than those under Policy Alternative 1 because there is some question as to the substitutability between the tolled and untolled crossings. The untolled bridges provide alternative "free" routes for drivers, which usually means a high toll elasticity. There are many trips, however, where drivers would experience a significant increase in time by detouring to these routes, even under free flow conditions. Therefore, while elasticity is likely to increase over Policy Alternative 1, due to the low substitutability between the crossings, elasticity will not increase to a large degree. Based on these elasticities, the estimated tolls have a maximum of $9.50.

Table 13: Tolls for the George Massey Tunnel Under Policy Alternative 2

<table>
<tr><th colspan="3">George Massey Tunnel</th></tr>
<tr><th>Time</th><th>Northbound</th><th>Southbound</th></tr>
<tr><td>0:00 – 7.00</td><td>$0</td><td>$0</td></tr>
<tr><td>7:00 – 8:00</td><td>$4.50</td><td rowspan="2">$2.00</td></tr>
<tr><td>8:00 – 9:00</td><td rowspan="3">$2.00</td></tr>
<tr><td>9:00 – 10:00</td><td rowspan="5">$0</td></tr>
<tr><td>10:00 – 11:00</td></tr>
<tr><td>11:00 – 12:00</td><td>$0.50</td></tr>
<tr><td>12:00 – 13:00</td><td rowspan="3">$0</td></tr>
<tr><td>13:00 – 14:00</td></tr>
<tr><td>14:00 – 15:00</td><td>$2.50</td></tr>
<tr><td>15:00 – 16:00</td><td>$9.50</td><td>$0</td></tr>
<tr><td>16:00 – 17:00</td><td>$3.50</td><td rowspan="2">$2.50</td></tr>
<tr><td>17:00 – 18:00</td><td>$2.50</td></tr>
<tr><td>18:00 – 19:00</td><td rowspan="2">$0</td><td>$4.00</td></tr>
<tr><td>19:00 – 0:00</td><td>$0</td></tr>
</table>

Table 14: Tolls for the Port Mann Bridge Under Policy Alternative 2

<table>
<tr><th colspan="3">Port Mann Bridge</th></tr>
<tr><th>Time</th><th>Eastbound</th><th>Westbound</th></tr>
<tr><td>0:00 – 6:00</td><td rowspan="9">0</td><td>0</td></tr>
<tr><td>6:00 – 7:00</td><td>$7.00</td></tr>
<tr><td>7:00 – 8:00</td><td>$5.00</td></tr>
<tr><td>8:00 – 9:00</td><td>$7.00</td></tr>
<tr><td>9:00 – 10:00</td><td>$5.00</td></tr>
<tr><td>10:00 – 11:00</td><td rowspan="4">$3.00</td></tr>
<tr><td>11:00 – 12:00</td></tr>
<tr><td>12:00 – 13:00</td></tr>
<tr><td>13:00 – 14:00</td></tr>
<tr><td>14:00 – 15:00</td><td>$1.00</td><td>$4.00</td></tr>
<tr><td>15:00 – 16:00</td><td rowspan="3">$4.50</td><td rowspan="3">$7.50</td></tr>
<tr><td>16:00 – 17:00</td></tr>
<tr><td>17:00 – 18:00</td></tr>
<tr><td>18:00 – 19:00</td><td>$0.50</td><td>$3.00</td></tr>
<tr><td>19:00 – 0:00</td><td>0</td><td>0</td></tr>
</table>

Because there are "free" road alternatives, this policy alternative is somewhat analogous to the 407ETR in Toronto. Two main differences that are critical for analysis remain. First, due to geographical differences, the number of similar untolled routes in Toronto is much higher than the number here. Second, the alternatives are more substitutable in Toronto than the Fraser River. The outcomes of the Toronto case study will be adapted for the particulars of Greater Vancouver and used to guide the analysis of this option.

6.1.3 Policy Alternative 3: High Occupancy Toll (HOT) Lanes

Another feasible option is to provide High Occupancy Toll (HOT) lanes in each direction on each crossing, replicating the approach that is spreading through many jurisdictions in the United States. HOT lanes would give users an immediate option of paying a fee for faster service, but they can continue to use the regular unpriced lanes otherwise. As was exhibited through the case study of Orange County's SR91, HOT lanes can provide drivers with a considerably less congested option.

As with the other policy options, 1400 vehicles per hour per lane was used as the target flow to determine prices. User demand is assumed to be more elastic here than both previous alternatives because the unpriced option is directly adjacent and therefore easily substitutable. To develop the prices below, I assumed a peak elasticity of –0.4 and an off-peak elasticity of –0.45. Tables 15 to 18 exhibit the tolls proposed for priced lanes on each crossing. The highest HOT fee is $7.00.

Table 15: Tolls for HOT lanes in the George Massey Tunnel

<table>
<tr><th colspan="3">George Massey Tunnel</th></tr>
<tr><th>Time</th><th>Northbound</th><th>Southbound</th></tr>
<tr><td>0:00 – 7.00</td><td>$0</td><td>$0</td></tr>
<tr><td>7:00 – 8:00</td><td>$3.00</td><td>$1.00</td></tr>
<tr><td>8:00 – 9:00</td><td rowspan="3">$1.50</td><td>$1.50</td></tr>
<tr><td>9:00 – 11:00</td><td rowspan="5">$0</td></tr>
<tr><td>10:00 – 11:00</td></tr>
<tr><td>11:00 – 12:00</td><td>$0.50</td></tr>
<tr><td>12:00 – 13:00</td><td rowspan="3">$0</td></tr>
<tr><td>13:00 – 14:00</td></tr>
<tr><td>14:00 – 15:00</td><td>$2.00</td></tr>
<tr><td>15:00 – 16:00</td><td>$7.00</td><td>$0</td></tr>
<tr><td>16:00 – 17:00</td><td rowspan="2">$2.00</td><td rowspan="2">$2.00</td></tr>
<tr><td>17:00 – 18:00</td></tr>
<tr><td>18:00 – 19:00</td><td rowspan="2">$0</td><td>$3.00</td></tr>
<tr><td>19:00 – 24:00</td><td>$0</td></tr>
</table>

Table 16: Tolls for HOT lanes on the Alex Fraser Bridge

<table>
<tr><th colspan="3">Alex Fraser Bridge</th></tr>
<tr><th>Time</th><th>Northbound</th><th>Southbound</th></tr>
<tr><td>0:00 – 6:00</td><td>$0</td><td rowspan="9">$0</td></tr>
<tr><td>6:00 – 7:00</td><td>$2.00</td></tr>
<tr><td>7:00 – 8:00</td><td rowspan="2">$3.00</td></tr>
<tr><td>8:00 – 9:00</td></tr>
<tr><td>9:00 – 10:00</td><td rowspan="11">$0</td></tr>
<tr><td>10:00 – 11:00</td></tr>
<tr><td>11:00 – 12:00</td></tr>
<tr><td>12:00 – 13:00</td></tr>
<tr><td>13:00 – 14:00</td></tr>
<tr><td>14:00 – 15:00</td></tr>
<tr><td>15:00 – 16:00</td><td>$3.00</td></tr>
<tr><td>16:00 – 17:00</td><td rowspan="2">$5.00</td></tr>
<tr><td>17:00 – 18:00</td></tr>
<tr><td>18:00 – 19:00</td><td>$2.00</td></tr>
<tr><td>19:00 – 23:00</td><td>$0</td></tr>
</table>

Table 17: Tolls for HOT lanes on the Pattullo Bridge

<table>
<tr><th colspan="3">Pattullo Bridge</th></tr>
<tr><th>Time</th><th>Eastbound</th><th>Westbound</th></tr>
<tr><td>0:00 – 6:00</td><td rowspan="10">$0</td><td>$0</td></tr>
<tr><td>6:00 – 7:00</td><td rowspan="2">$2.50</td></tr>
<tr><td>7:00 – 8:00</td></tr>
<tr><td>8:00 – 9:00</td><td>$0.50</td></tr>
<tr><td>9:00 – 10:00</td><td rowspan="10">$0</td></tr>
<tr><td>10:00 – 11:00</td></tr>
<tr><td>11:00 – 12:00</td></tr>
<tr><td>12:00 – 13:00</td></tr>
<tr><td>13:00 – 14:00</td></tr>
<tr><td>14:00 – 15:00</td></tr>
<tr><td>15:00 – 16:00</td><td>$1.50</td></tr>
<tr><td>16:00 – 17:00</td><td>$2.00</td></tr>
<tr><td>17:00 – 18:00</td><td rowspan="2">$0</td></tr>
<tr><td>18:00 – 23:00</td></tr>
</table>

Table 18: Tolls for HOT lanes on the Port Mann Bridge

<table>
<tr><th colspan="3">Port Mann Bridge</th></tr>
<tr><th>Time</th><th>Eastbound</th><th>Westbound</th></tr>
<tr><td>0:00 – 6:00</td><td rowspan="9">0</td><td>0</td></tr>
<tr><td>6:00 – 7:00</td><td>$5.50</td></tr>
<tr><td>7:00 – 8:00</td><td>$4.00</td></tr>
<tr><td>8:00 – 9:00</td><td>$5.50</td></tr>
<tr><td>9:00 – 10:00</td><td rowspan="5">$2.00</td></tr>
<tr><td>10:00 – 11:00</td></tr>
<tr><td>11:00 – 12:00</td></tr>
<tr><td>12:00 – 13:00</td></tr>
<tr><td>13:00 – 14:00</td></tr>
<tr><td>14:00 – 15:00</td><td>$1.00</td><td>$3.50</td></tr>
<tr><td>15:00 – 16:00</td><td rowspan="3">$3.50</td><td rowspan="3">$5.50</td></tr>
<tr><td>16:00 – 17:00</td></tr>
<tr><td>17:00 – 18:00</td></tr>
<tr><td>18:00 – 19:00</td><td>$0.50</td><td>$2.00</td></tr>
<tr><td>19:00 – 23:00</td><td>0</td><td>0</td></tr>
</table>

Counterflow in the George Massey Tunnel requires a particular HOT policy adaptation because at certain points of the day in certain directions, there is only one lane available, meaning the tunnel cannot provide a choice. HOT lanes recognize the provision of "free" roads while offering a priced and uncongested alternative. Applying charges to this lane runs against the HOT principle that these lanes are an alternative to a regular route. I believe it is important to continue to offer "free" routes under an HOT scheme. Therefore, I recommend leaving the single lane untolled even through it will have additional impacts on congestion and will create some inconsistency in the scheme.

6.1.4 Policy Alternative 4: Status Quo

Greater Vancouver's roads are highly congested, particularly at peak hours. Nonetheless, the region has tolerated the externalities from improperly priced roads for many years and could feasibly continue to do so. Market failure and economic loss arise under the current road system, but there is some question as to whether the public is willing to accept a transformation in how we price our roads. The current system is popular because it is seen as fair and equitable, and users like the perception of "free" service and infrastructure. The economic solution suggests that roads should be priced based on the demand for the road at the time of use. How Greater Vancouver's population will respond to the alternative systems proposed and whether the region's transportation system will adapt is discussed in the section on policy analysis below. Prior to this analysis, I discuss some common policy characteristics that are necessary for the success of any of these alternatives (except the status quo).

6.2 Common Underlying Policies

6.2.1 Use of Revenue

While revenue generation is not a core policy objective here, policy design cannot ignore the issue of toll revenue use. Economic theory suggests that congestion reduction will lead to economic improvements regardless of revenue use. That is, the tolls could be spent on digging holes and filling them back in and the economy would still be better off because congestion's negative impacts of wasted time, harmful pollution and road maintenance are reduced to social optima. Other economists frame the problem as a Potential Pareto Improvement: the gain by the winners is larger than the loss by the losers. The former could compensate the latter and the overall economy gains. Unfortunately, the intersection of economic theory and reality is in gridlock and arranging compensation to those who are priced off the road would be a cumbersome, highly administrative and ultimately expensive process.

Two other major options exist for revenue use. First, funds could be added to the general treasury of the Province or Region. Public finance theory suggests that this is the best use of the funds since society can then put the cash towards projects of highest priority, such as tax reductions in other areas (a "revenue neutral" approach) or spending on programs and projects that bring the greatest benefits. Regrettably, this makes the entire scheme seem like more of a tax grab than a congestion plan, which can lead to public opposition. Hypothecating the funds for transportation projects, particularly public transportation, is the second option. This has three positive effects. First, it helps with the public acceptability of the plan. By increasing public transportation service in the regions that are most highly affected by road pricing, the public directly sees the benefit of the tolling revenue. Jaensirisak (2005) found through stated preference surveys that the acceptability of a road pricing scheme was 30% when funds went to general revenue, but that acceptance increased to 57% when funds were dedicated to public transportation. Second, earmarking to transportation helps the effectiveness of the plan by increasing the provision of transportation alternatives; increased transit service would mean better alternatives for drivers. Third, the use of the tolling revenues to improve public transit does, in part, implement the Pareto Principle: the drivers who lose from tolling are at least partially compensated by the access to improved public transit.

Four former TransLink directors indicated in interviews that they would only favour tolls if the revenues were used for transportation projects and they did not imagine a scheme being feasibly implemented otherwise (Ladner, Anton, Trasolini and Wright Interviews). Drivers are more likely to favour tolls that go to roads, but others will champion public transportation investments. This paper does not have the scope to fully analyze which transportation projects should receive the greatest priority. Below, however, I argue that revenue should be allocated to public transit improvements since they will assist with system operability. Lastly, throughout policy implementation, it must be communicated that revenue generation is a secondary objective to the congestion reducing aspects of pricing.

6.2.2 Charge Collection

Traditional tollbooths dot many priced roads in North America, but with the oncoming of the electronic age, collecting tolls has become more efficient. Now, users can pay their fees without stopping to dig for change, which is critical for congestion reduction. London, Toronto and Orange County all use electronic toll mechanisms, as do many other jurisdictions. Different systems use monthly billing or pay-as-you-go structures, with little difference in congestion-targeting. The main difference between these private systems is the cost of service delivery; that is, the administrative cost of the system. I recommend a cost assessment of the various possible systems and adopting the system that will deliver pricing of each vehicle at the lowest administrative cost.

There is a small public acceptability loss from using electronic tolls. Electronic systems record the movements of drivers, often perceived as a "Big Brother" tactic by the state. Measures such as data encryption and access regulation can be utilized to ensure the protection of privacy, but there is always a risk that these systems will fail and someone will use the information for sinister purposes.[16] There are current plans in the region to use electronic tolling (on the Golden Ears Bridge and Port Mann Bridge), so privacy concerns are not a policy show-stopper. Regardless, the perception of privacy invasion will continue to exist.

A further drawback of electronic systems arises with out-of-province vehicles. Because regulators in B.C. do not have immediate access to vehicle registration information of out-of-province vehicles, it is difficult to assess fees from them electronically. In Toronto, the 407ETR bills out-of-province vehicles, but these bills are largely unenforceable. It is possible that B.C. could establish agreements with Alberta and Washington – the jurisdictions with the most non-local vehicles on Greater Vancouver roads – that allow for enhanced enforcement. Overall, I recommend the use of electronic tolls since the additional effectiveness of electronic tolling systems outweighs the loss due to public acceptability and jurisdictional issues.

6.2.3 Provision of Public Transportation

The Fraser River crossings serve low-density, suburban regions that, like most North American communities of similar design, are poorly served by public transportation. Increasing public transportation service in the areas south of the Fraser River is important for congestion pricing policy for several reasons. First, it contributes further effectiveness to the pricing scheme by offering drivers alternative transportation. Currently, increasing public transit service alone does not divert a sufficient number of drivers away from their cars to justify investment. But when the price of driving increases with tolls, users will reconsider their travel mode choices. Ensuring adequate public transit links for the origins and destinations of drivers will mean better

[16] Still, an individual's movements can already be traced through credit and debit card use, or simply by tracing a cellular phone.

congestion reduction by increasing the probability that drivers will shift to public transportation for their trips.

Increasing public transportation provision also adds to public acceptability. If the funds from tolling are earmarked directly for transit service increases, residents directly see the effects of the revenue generation. Those who resist road pricing often claim that pricing is unfair because there are few other transportation options. Increasing public transportation provision moderates this complaint. Similarly, low-income individuals often lose because of pricing since they are less likely to pay the toll. Improving public transportation can help smooth some of the equity implications of pricing.

A critical success factor in London's congestion pricing scheme is the increase in public transportation (Richards 2006). Public transportation enhancement can increase the effectiveness, acceptability and equity of any pricing scheme, and Greater Vancouver must include a large investment in public transportation that is attractive to drivers who use the Fraser River crossings. Likely, this investment involves an increase in bus service on routes that drivers south of the Fraser commonly travel. Full development of an exceptional transit plan must be completed.

6.2.4 Exemptions

Exemptions are critical to system operability and public acceptability in London. Orange County also relies on exemptions to ensure their system is acceptable to the public; the 407ETR does not provide any exemptions. There are both positive and negative impacts from exemptions. On the positive side, exemptions can increase the operability, acceptability and equity of pricing systems. On the negative side, however, exemptions could add to congestion and decrease the effectiveness of pricing. Still, in some cases, exemptions may make it easier to reduce congestion by providing incentives for alternative modes of travel.

Greater Vancouver should consider exemptions for motorcycles and high occupancy vehicles. It is difficult to design electronic tolling systems that include motorcycles. This is a technical and operability aspect of the tolling schemes. While electronic transponders can be affixed to motorcycles under some systems, those systems that scan licence plates do not adapt well to motorcycles. Since the total share of trips by motorcycle is very low in the region, exempting them will have little effect on flows while including them would involve great costs in system development. Exemptions for high occupancy vehicles (HOV) will have two effects. First, the exemption will increase the relative attractiveness of carpooling, giving drivers further encouragement to leave their vehicle behind, thereby reducing congestion. Second, the exemption will increase the public acceptability of pricing by offering additional choices to drivers. If HOV exemptions encourage drivers who would otherwise avoid their trip to now cross the bridge, the exemption may add to congestion. If, on the other hand, the drivers would have driven individually but are now convinced to carpool, then the exemption helps with congestion. Overall, the benefits of exempting High Occupancy Vehicles are large but should be done only if further analysis finds that users will not switch from transit to carpooling.

Taxis can be a vital link in multi-modal trips since they allow individuals to make connections that are otherwise not well served. This is part of the case for their exemption in London; exempting taxis encourages individuals towards alternative modes of transportation. Across the Fraser River, however, it is unlikely that a taxi would be a part of a multi-modal trip. It is more likely an entire trip unto itself. With a policy objective of decreasing congestion on the crossing, encouraging drivers to switch to a taxi will likely do nothing to assist with congestion reduction: the vehicle trip across the bridge still occurs, just in a taxi. The Greater Vancouver situation is different from London in that taxis in London prevent car trips in the zone; a user may use a taxi for one quarter of their trips, for example. Here, a taxi user would use the taxi for all of their trips across the facility, meaning no reduction in trips.

Other exemptions represented in the case studies include individuals with disabilities, veterans and low emission vehicles; each of these has a clear trade-off between congestion reduction and scheme acceptability. In Greater Vancouver, it is likely that the amount that these vehicles will add to congestion is small, but the enhancement to public acceptability is also small. I suggest that these vehicles be treated just like all other vehicles to ensure efficient congestion reduction. Should it be shown that the effectiveness/acceptability trade-off weighs heavily in favour of acceptability, this recommendation could be revisited. Nonetheless, policy design should include exemptions for high occupancy vehicles and motorcycles.

6.2.5 Pricing Structure

Above, time of day (TOD) pricing was used in pricing design because economic theory suggests that the efficient allocation of roadspace will occur if prices vary based on demand; more congested time periods face higher prices. The case studies represent a good cross-section of the available congestion pricing structure options. London has a fixed toll, Orange County varies tolls based on time of day and Toronto varies tolls with distance and slightly for peak demand. Distance charges can add efficiency because they ensure that users pay for the relative benefits they incur; uniform tolls, such as those in London, allow for the least amount of efficient targeting because drivers must pay regardless of the current demand for the road. The externalities imposed by a driver on an empty road are much smaller than the externalities imposed by a driver on a nearly congested road; unvarying tolls do not compensate for the differences in externalities imposed.

One drawback of the TOD pricing structure is that it creates abrupt changes in tolls. The price schedules above include some price smoothing, but substantial differences still exist for other adjacent time periods. Under Policy Alternative 1, for example, tolls for the George Massey Tunnel change from $0 to $14 in one jump. These changes make it attractive for drivers to arrive just prior to or just following the time change, leading to possible over demand adjacent to the hour (:00). On the other hand, current high congestion levels suggest that it already is more attractive to arrive before the period of heavy demand; the toll would be a manifestation of that attraction, not a cause. For example, the large toll increase at 15:00 northbound on the George Massey Tunnel results from a shift of two lanes northbound to one at 15:00; there are current benefits to arriving at 14:55. Nonetheless, it is possible to institute price-smoothing mechanisms whereby 10 minutes prior to a price increase and 10 minutes following a price decrease, drivers pay an additional 50% of the difference in tolls, decreasing the attraction to arrive right at the boundary of a time change.

Another drawback is the complexity that TOD pricing creates. Lindsay (2007) argues that simple pricing models are preferred over complex ones because they ensure public comprehension, which assists with system operation and public acceptability. Still, Orange County and Toronto operate successfully with fairly complex pricing structures. Greater Vancouver residents have some experience with more complex pricing structures since the public transportation system operates on a time of day and zone system, and some of the roads operate on time of day counterflow systems. I believe that Greater Vancouver residents would be able to understand a complex pricing structure for road pricing in the region and have proposed time of day pricing as a result.

Overall, any road pricing scheme must consider many policy facets. Considerations within the scope of this study were analyzed above, yielding several recommendations. These include: earmarking of revenue towards transportation, use of electronic tolling, large increases in public transportation services for the areas served by the Fraser River crossings, exemptions for motorcycles and high occupancy vehicles, and time of day pricing. B.C.'s Lower Mainland requires a scheme that suits the unique transportation characteristics of the region; these common policy design themes are important for policy effectiveness, operability, equity and acceptability.

7 Analytical Framework

Each of the policy alternatives presented above carries unique outcomes. I apply a straightforward evaluation framework to analyze, compare and ultimately recommend policy actions. Effectiveness, revenue generation, equity, public acceptability and political viability are the evaluation categories used for analysis. These criteria are explained in detail below. I also discuss the interdependence and trade-offs between the criteria. The analytical framework described here is applied in the next section on policy analysis.

Effectiveness evaluates each policy alternative's ability to meet the goals and objectives of the policy action – the policy's ability to reduce congestion. Two types of congestion reduction will be analyzed under this criterion. First, the level of congestion reduction on the priced facility will be examined; this is where time savings are notable for the facility user. Second, congestion over the surrounding network of roads must also be considered. Both effectiveness categories are important in understanding how congestion will be reduced. Success in just one does not necessarily mean success overall. Effectiveness will be determined using arguments from the economic theory of congestion and through the results of the case studies.

Revenue generation is assessed next. As described above, revenue generation is not a core policy objective but it must be considered since it is an effect with high relevance in the public domain. Each policy alternative will carry implementation and operation costs, but I do not evaluate these.[17] Instead, I assume that they will be more than offset by the revenue. I also assume that the implementation and operation costs will be proportional to the size of each alternative's tolling area.[18] Revenues are estimated using the elasticity model from Section 4.2; I multiply the target flow by the assessed charge and expand the figures for 250 regular commute days. Expanded calculations are shown in Appendix B.

As with all policy initiatives, equity implications are vital with road pricing. While the efficiency-enhancing effects of road pricing could theoretically eliminate equity concerns through

[17] Implementation costs will include infrastructure changes such as the installation of electronic gantries, the erection of signage and minor roadway improvements like striping or "escape" lanes. Operating costs will include all incremental costs resulting from the pricing scheme such as maintenance of the tolling system itself, the labour required to administer the scheme or the added policing and enforcement costs.

[18] But overall, it is likely that Alternative 2, which tolls two of the four crossings will have roughly half the implementation and operations costs of Alternative 1, which tolls all four crossings.

compensation of those who lose, reality is that compensation is difficult and expensive. I use a theoretical analysis to assess equity on socio-economic and geographic grounds. Based on individuals' behavioural change, socio-economic groups will be identified and attributed a "win" or "lose" label. Geographic equity will identify those policy alternatives that unequally impact the regions along the east-west gradient.

Public acceptability will evaluate the level of approval that citizens hold for a policy alternative prior to implementation. Cases in London and Stockholm show that the public acceptability of pricing generally increases following implementation, but I deem pre-implementation acceptability most relevant because it is far more likely to influence whether a particular policy alternative goes ahead (Litman 2007a). Two types of acceptability are of note. First, acceptability throughout the Lower Mainland must be measured. Second, acceptability among users of the facility must be determined; users' acceptability will likely follow the "win" and "lose" equity lines described above. Assessment of public acceptability will be through previously published opinion polls, discussions with policymakers and case studies.

Finally, I will determine the political viability of each alternative. Political viability is particularly important because it highlights some key barriers to policy adoption. This criterion will be assessed based on the stated positions of the provincial government as well as the regional authorities – TransLink and Metro Vancouver. The Province's position is based on the Provincial Tolling Guidelines outlined earlier, which represent the current government's policy for tolls. The position of the regional authorities is determined through previous motions by the bodies' boards. Currently, the provincial government acts as the enabler of tolling policy, but it is unlikely that any new tolling policy would move ahead without agreement between both regional and provincial authorities.

In the following section, patterns emerge that reflect the interdependence of the aforementioned criteria. Public acceptability is the most interdependent criterion listed; effectiveness, revenue generation and equity will all influence the level of public acceptability. Effectiveness is also itself interdependent with equity. Because effectiveness is aiming for an economically efficient outcome, and economic outcomes are often achieved without an eye for equity, very effective policy options often have strong impacts on various groups. Some of these impacts can be mitigated with appropriate policy design, as discussed in various sections of this paper. Finally, political viability is heavily influenced by public acceptability.

Table 19: Summary of Criteria

Criterion		Description
Effectiveness	*Facility reduction*	How much is congestion reduced on the crossing that is priced?
	Network effects	What is the change in congestion on the network of Fraser River crossings, as well as the surrounding roads?
Annual Revenue		What level of revenue is expected from the pricing scheme?
Equity	*Socio-economic*	Will one socio-economic group benefit at the cost of another?
	Geographical	Does the policy inequitably favour citizens living in one area to the detriment of another?
Public Acceptability	*Metro Vancouver*	Will the population of Metro Vancouver accept the policy?
	Facility users	Will current facility users accept the policy?
Political Viability	*Province*	What is the provincial government's position on the policy?
	Region	What are the positions of TransLink and Metro Vancouver?

8 Policy Analysis

In order to assess each policy alternative, this section applies the cited analytical framework to the proposed policies. For consistent analysis, I examine each alternative against the standard set of criteria. Subsequently, I discuss the evaluation trade-offs and make a recommendation for congestion charges on the Fraser River crossings. A summary of the policy evaluation is found in Table 20.

8.1 Evaluation of Policy Alternative 1: Toll All Four Crossings

Tolling all four crossings has the most potential to reduce congestion both on and off the facilities, but it requires the highest tolls to do so and may carry some risk. Pricing was developed to ensure target flows of 1400 vehicles per lane per hour. If the elasticity analysis is correct, given the toll structure proposed, traffic on all the crossings will be reduced to the target flow, resulting in less congestion. Nonetheless, a discussion with Frank Blasetti, an Assistant Deputy Minister in B.C.'s Ministry of Transportation, revealed that there is some risk to this target being reached. The Ministry of Transportation conducted traffic simulations for the Port Mann Bridge using the EM/ME2 transportation model.[19] These simulations found traffic to be "unstable" past a $7.50 toll, a level lower than the tolls proposed under this alternative. Mr. Blasetti's interpretation of the term "unstable" was that the toll could continue increasing with no change in traffic levels. The Ministry's results, therefore suggest that congestion will remain under this alternative. MOT's assessment is important to recognize, but I disagree with it. While the EM/ME2 model is highly regarded in transportation planning, it is difficult to imagine that tolls over $7.50 would not influence traffic. Taken to the extreme, one could imagine a toll of $50; at this level, of course, the only trips over the crossing would be critical ones. Between $7.50 and $50, it is likely that drivers exhibit some response with respect to tolls and that the elasticity is not 0 at $7.50. I believe that tolling each crossing can decrease congestion on the crossings, and it is likely that drivers will respond to the prices as outlined above. I do recognize that this option carries the most risk that congestion will not be decreased since it requires the highest amount of behavioural

[19] The EM/ME2 model is an origin-destination transportation model used by many planners, including those in the Lower Mainland. For the AM peak, it determines how a multitude of trips distribute over the road network depending on their origin, destination and various other inputted assumptions.

change. Nevertheless, I believe that the risk is minimal and pricing can create less congested roads.

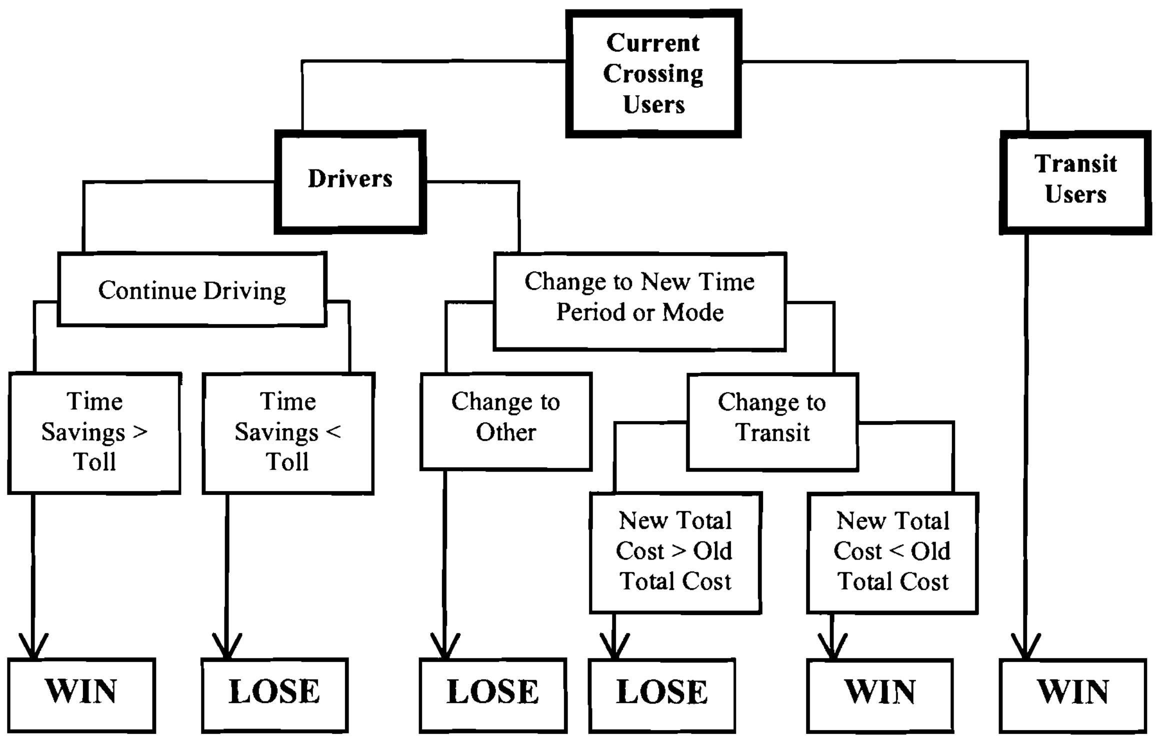
For the surrounding road network, this alternative has significant potential for congestion improvements. London provides comparison because their scheme does not provide a road alternative for a trip with a destination within the charge zone; similarly, Policy Alternative 1 does not provide a road alternative for a trip across the Fraser River. London witnessed congestion improvements along its main arteries towards the congestion zone. Tolling all four crossings of the Fraser River would see similar results; as fewer vehicles use the crossings, fewer vehicles will use the roads to get to the crossings. Some increased demand for surface streets may occur as drivers opt to use those crossings with lower tolls, or drivers change their destination to ensure routes do not require a water crossing; for example, a diner may choose to visit a restaurant on their same side of the river rather than one that would require a toll payment. Without cross-elasticity estimations showing how trips distribute between new crossings, new modes or new time periods after a price change, it is difficult to determine what these effects will mean for overall surface street congestion. Evidence from London suggests that congestion can be decreased both on and around the crossings.

Because this alternative levies high tolls on many drivers, it results in a large amount of revenue generation. I estimate that this alternative will raise approximately $191 million in gross annual revenue (calculations disaggregated in Appendix B). If these funds are put towards public transportation, as recommended, significant increases in service south of the Fraser River can be made; such an increase in service will help reduce congestion further by providing alternatives to driving.

Policy Alternative 1 has polarizing socio-economic equity impacts. Figure 3 represents the behavioural change impacts of tolling (this figure is relevant for all of the policy options). Users are divided and sub-divided into groups; welfare will depend on individuals' reactions to tolls. The figure notes whether a group will "win" or "lose" in comparison to the status quo. Individuals who were initially transit users are straightforward; they are better off since they will see improved service with increased funding and lower travel times when buses enjoy less congested conditions. Drivers' welfare outcomes, however, are more nuanced and depend on individual traits. Drivers who continue driving will be made better off if their time savings are worth more than the toll itself; otherwise, they are worse off. Drivers who change to public transit will be made better off if their new total cost of travel (including time, fare, etc.) is lower than their old total cost of travel (include time, vehicle costs, etc.); otherwise, they are worse off.

Drivers who change to another mode, crossing or time period (or who choose not to make the trip at all) are worse off than under the status quo, since otherwise they would have made the change prior to toll implementation.[20]

Figure 3: Impacts of Tolling on Groups of Users



[20] New transit users can be made better off because there will be significant service changes that make it more attractive that it previously was.

Socio-economic equity evaluation requires some generalization. The benefiting groups outlined above are transit users (including all of the pre-toll users and some of the new users) and those with high values of time. In general, transit users tend to have lower incomes. Individuals with high values of time, in general, tend to have high incomes. Therefore, this policy alternative provides benefits, in general, to both those with high incomes as well as those with low incomes. Conversely, those who are worse off are those who continue to drive but do not experience benefits relative to their additional costs, and those who switch to transit but had lower overall trip costs before the tolls were implemented. These groups tend to include a mixture of incomes, but mainly comprise middle-income earners. In general, tolling all four crossings will give benefits to those with high incomes and those with low incomes; those at middle income are most likely to lose. Geographically, this policy alternative is equitable. Drivers who regularly use the Pattullo and Alex Fraser bridges will pay lower tolls, but these individuals already have the benefit of lower congestion, so they will experience little redistribution.

Ipsos Reid polled British Columbia residents in 2002 and asked the following question:

> With many types of public-private partnerships, the private company needs to charge a toll or a user fee to provide the service. Generally speaking, would you be willing to pay a toll or user fee to a private company for a service that was previously paid for by the government through tax dollars?

49% of Lower Mainland residents responded "Yes" and 48% responded "No" (Ipsos Reid 2002). While this poll is somewhat dated, it does indicate that the pubic is not overwhelmingly opposed to paying for a service that was previously provided without charge. But compared to the other alternatives, it is easy to see why opposition would be highest under Policy Alternative 1; the tolls for this option are the highest and there is no "free" road alternative available. The provision of a road alternative is certainly a sticking point for many within the public and it is guaranteed by the Provincial Tolling Guidelines because of public opinion (Blasetti Interview). With much congestion reduction, those who rarely use the crossing may approve due to the economic and environmental benefits. But the equity assessment showed that this policy option polarizes users. I believe that even some of the "winners" from tolling will be initially opposed; prior to implementation, it will be difficult for them to understand the benefits they will be receiving. For example, individuals who will switch from driving to public transit are likely to be opposed to the policy until they experience the benefits. London and Stockholm both learned this. Overall, opposition to strict tolling is high prior to implementation. Once citizens see and experience the effects of reduced congestion, approval may increase.

The provincial government is opposed to this policy alternative while regional authorities are in favour. The Provincial Tolling Guidelines only allow pricing of new infrastructure in the presence of an alternative "free" route. These Guidelines were developed to coincide with what the public regards as acceptable tolling structures; therefore, they are only likely to change if public opinion leads them to. The regional authorities of TransLink and Metro Vancouver, however, have each moved in favour of tolls on crossings in the Lower Mainland and therefore would be receptive to this policy. Overall, political viability is low because the provincial government has the final say on tolling.

8.2 Evaluation of Policy Alternative 2: Leave Untolled Options

With the Alex Fraser and Pattullo bridges left untolled, drivers will respond to tolls more readily and tolls for Policy Alternative 2 are lower than Policy Alternative 1 as a reflection of users' more elastic behaviour. Nonetheless, the target traffic levels on the George Massey Tunnel and Port Mann Bridge should be achieved, and pricing will be effective at congestion reduction on these crossings. This is confirmed through the study of Toronto, which has untolled alternatives available and consistently meets its congestion targets on the 407ETR. There is no doubt, however, that the untolled crossings will be heavily congested; they currently face congestion, and this congestion is likely to increase. The untolled alternatives are not perfectly substitutable for the tolled ones, but some drivers will go out of their way to utilize them. This is evidenced by the relative congestion on Toronto's 401 and 407ETR. Surface streets near the Fraser River crossings will likely see congestion increase as some drivers will choose to spend the extra time diverting to a new crossing instead of paying a toll. For example, east Surrey drivers who want an untolled option will have to use arterial roads to get to the Pattullo Bridge; Ladner drivers who want an untolled bridge will clog routes to get to the Alex Fraser. The two tolled crossings will see congestion improvements, but congestion on the surrounding network will certainly not decrease and is likely to increase.

I anticipate that Policy Alternative 2 will generate $88 million of gross annual revenue (see Appendix B). These funds could finance about half the level of public transportation service increase that Alternative 1 would provide. A targeted transit increase under this policy option should go towards the origins and destinations of travellers using the George Massey Tunnel and the Port Mann Bridge. Such targeting will give regular users of these crossings an alternative to driving and paying tolls, increasing both the effectiveness of congestion reduction over those crossings and the public acceptability among users of the crossings.

Tolling just two crossings will have the same winners and losers as exhibited in Figure 3, but the effects for most groups will be diminished. Transit users (mostly low income) will not gain as much because there will be less revenue for service enhancements; the number of drivers who are benefactors will also decrease since only half the crossings will be freely flowing. Those who lose under Policy Alternative 2 will be fewer for two reasons. First, not as many users will change their driving habits. Second, because only drivers of the Port Mann Bridge and George Massey Tunnel will pay tolls, the number of individuals paying tolls without offsetting time savings will be smaller. Therefore, tolling just two crossings is less polarizing than tolling all four crossings. Geographic equity, though, is poor. Drivers' accessibility to the different types of crossings (congested or uncongested) will be heavily determined by the east-west location of their origin or destination. Individuals' costs and benefits will depend on proximity to preferred type of crossing, tolled or untolled. For example, those who regularly use the Alex Fraser or Pattullo but wish to pay for reduced congestion will lose. Conversely, those who regularly use the Port Mann or George Massey but do not wish to pay will be priced off their crossing and be worse off than those already using the untolled alternative

Public acceptability will be higher for this alternative than the former. Acceptability of tolling increases when there are untolled alternatives available. In 2006, the Ministry of Transportation found that 56% of public consultation attendees would be in favour of tolls up to $2.50 on the Port Mann Bridge exclusively (B.C. Ministry of Transportation, 2006).[21] Facility users would still be split along equity lines, but given lower polarization, the magnitude of opposition would be lower. It is likely that because two crossings remain untolled, Policy Alternative 2 is favourable to the public prior to implementation. But, contrary to Policy Alternative 1, as individuals experience its partial applicability and its lack of overall congestion reduction, their views may turn more cynical.

Congestion-targeting tolls on just the George Massey Tunnel and Port Mann Bridge will fit within the provincial guideline requiring untolled road alternatives but still contradicts the directive that only new infrastructure can be tolled. Therefore, the Province opposes this option, but to a lesser degree than Policy Alternative 1. The regional authorities are in favour of placing tolls on these crossings.

[21] There is some question as to whether the high level of tolls required for congestion reduction (in some cases much higher than $2.50) would change the survey's outcome.

8.3 Evaluation of Policy Alternative 3: High Occupancy Toll (HOT) Lanes

Priced lanes will create an uncongested route for those wishing to pay, and because a higher elasticity results under HOT conditions, this alternative dictates the lowest tolls. The Orange County example shows that it is possible to keep priced lanes uncongested by setting flow targets and varying tolls. HOT lanes not only result in congestion on the non-priced lanes, they require it. With HOT lanes, the only reason that an individual would pay for HOT use is if the regular lanes are congested, because the only difference between the unpriced and priced routes is congestion. Network congestion will not improve with HOT lanes, but those paying will experience uncongested conditions.

I estimate that this policy alternative will generate $38 Million in annual revenue (see Appendix B), which would likely be best put towards a bus system for commuters. These buses could take advantage of the freely flowing HOT lanes.

Equity implications of HOT lanes further diminish polarization. With less revenue for public transit provision, low income individuals will not gain much. The volume of tolled vehicles will be lower, meaning fewer high income winners. Individuals will be less inclined to fundamentally change their behaviour so the degree of loss will also be softened. In fact, Poole and Orski (2000) report that drivers in all income levels use Orange County's 91 Express Lanes. HOT lanes would distribute evenly between crossings so would offer good geographical equity; this policy option is rather geographically neutral.

In comparison to Policy Alternative 2, HOT lanes are more publicly acceptable in Greater Vancouver; the untolled alternative is very substitutable. Citizens are already familiar with the concept of reserved lanes (HOV, bus, etc.) so they do not have to comprehend a major change to support this policy. Equity impacts are less polarized than with both Alternatives 1 and 2, likely yielding some level of acceptance among facility users. In terms of visibility, however, individuals may dislike this policy. It is one thing to accept that someone is paying for better service when you cannot physically see the result of that service, but when you are sitting in traffic watching others drive the uncongested HOT lane, your acceptance may wane.

The Province will be opposed to HOT lanes to the same degree that they are opposed to Policy Alternative 2. While there are untolled options, there is no new infrastructure. Again, the regional authorities would not oppose HOT lanes.

8.4 Evaluation of Policy Alternative 4: Status Quo

The status quo does nothing for congestion on the crossings and raises no revenue. Compared to Policy Alternative 2, the status quo may be better for surrounding network congestion. This is because Alternative 2 encourages drivers to use the surrounding network between crossings. However, both the crossings and the surrounding network will be highly congested under the status quo. The status quo may be perceived as equitable because it treats all drivers the same; it is the least polarizing of the options. Geographically, the status quo results in congestion on each crossing, although some more than others. Public acceptability with current traffic congestion is falling, since people do not like to waste time in traffic, as evidenced by the Ipsos Reid (2006) polls. Still, there is high opposition to tolling schemes. As Vancouver City Councillor Peter Ladner noted, drivers need to be asked, "Do you want to pay in cash or do you want to pay in time?" With public transportation struggling to generate enough revenue, road pricing can create less congestion while providing additional public transit options. Each of the other alternatives adds tolls without any increase in capacity while tradition has dictated that tolls are only for new infrastructure. Assessing tolls without increasing capacity will be difficult for the public to accept, making the status quo popular in comparison. The Province accepts the status quo over the other alternatives, but regional authorities would prefer some level of tolling.

Table 20: Summary of Policy Evaluation

Criterion		Policy Alternative 1: Toll All Four Crossings	Policy Alternative 2: Leave Untolled Options	Policy Alternative 3: High Occupancy Toll (HOT) Lanes	Policy Alternative 4: Status Quo
Effectiveness	*Facility Reduction*	**Target flow achieved on all crossings** (Highest risk of non-achievement)	Target flow achieved on George Massey Tunnel and Port Mann Bridge	Target flow achieved on one lane in each direction of each crossing	*Current high level of congestion*
	Network Effects	**Reduction in network congestion**	*Alex Fraser and Pattullo bridges remain congested or become more congested. Surface street congestion increase*	Unpriced lanes of crossings remain congestion or become more congested. Surface street congestion remains	Current high level of congestion
Annual Revenue		**$191 Million**	$88 Million	$38 Million	*Zero*
Equity	*Socio-economic*	*Large polarization: high and low income benefit, others lose. Benefits largest, as are costs*	Medium-high polarization	Medium-low polarization	**No polarization – equal economic access to crossings**
	Geographic	**No congestion on any crossing. Some areas have higher tolls**	*Different benefits and costs depending on proximity to tolled or untolled crossing*	**Even distribution of HOT lanes. Some lanes have higher tolls**	**Congestion on every crossing. Some with higher congestion**

Criterion		Policy Alternative 1: Toll All Four Crossings	Policy Alternative 2: Leave Untolled Options	Policy Alternative 3: High Occupancy Toll (HOT) Lanes	Policy Alternative 4: Status Quo
Public Acceptability	*Facility Users*	*Big wins and losses but winners likely do not realize benefits until implementation*	Wins and losses moderated	Wins and losses small	**Public is not satisfied but more accepting than other alternatives**
	Metro Vancouver	*Poor acceptance given high tolls*	Moderate acceptance given untolled alternatives	Moderate acceptance given untolled alternatives	**Public acceptability falling, but more accepting than alternatives**
Political Viability	*Province*	*Contrasts tolling guidelines requiring new infrastructure and untolled alternatives*	Contains untolled options but contrasts new infrastructure requirement	Contains untolled options but contrasts new infrastructure requirement	**Viable over other alternatives**
	Regional Authorities	**Voted in favour of tolls on crossings**	**Voted in favour of tolls on crossings**	**Voted in favour of tolls on crossings**	*Policies indicate preference towards tolling*

Blue (bold) = Best in category

Red (italics) = Worst in category

Black = Neither best nor worst

9 Trade-off Assessment, Recommendation and Implementation

9.1 Policy Trade-offs

Table 20 presents a Goeller scorecard of policy impacts (Patton and Sawicki 1986). Blue (bold) indicates the alternative that ranks best under each criterion, while red (italic) indicates which ranks worst. Black indicates those that are neither best nor worst. None of the policy options is dominated by any other, so none should be immediately eliminated. While it appears, just from examining the colours, that Alternative 3 dominates Alternative 2, there are some criteria where 2 is better than 3 (e.g. revenue generation) but no colour is attributed.

The above scorecard provides the ability to quickly determine where particular options excel and others fail. Simply adding the number of "best" and subtracting the number of "worst" results in a victory for the status quo. But that result assumes the criteria should all carry the same weight in decision making, which is an oversimplified aggregation. Instead, the table is a useful tool to understand the trade-offs between and within the policies.

Tolling each crossing excels in congestion reduction and revenue generation but fares poorly under equity, public acceptability and provincial political viability. The status quo is poor on congestion but excels in acceptability and is least polarizing. Alternatives 2 and 3 are each assortments that create varying results across the criteria; Alternative 3 is better for network congestion but worse for facility reduction. HOT lanes are great for allowing those who wish to pay to save time do so. But HOT lanes do not eliminate the major externalities of congestion; they merely allow some to travel faster while slowing the travel for others.

All over the world, public resistance to tolling is its largest impediment to implementation (Lindsay 2007). Public acceptability tends to trade-off with congestion reduction; provincial political viability mirrors public acceptability. Policy Alternative 1 decreases congestion the most but is least acceptable. Policy Alternative 4 does nothing for congestion but is most acceptable. TransLink directors confirmed that public acceptability is the biggest hurdle for toll implementation in Greater Vancouver, but they expressed hope that political leadership could improve acceptability with public education (Anton, Ladner, Trasolini and Wright Interviews).

9.2 Recommendation

Policy Alternative 1 is the first-best approach to meet the main policy objective of congestion reduction. It does, however, face significant challenges with respect to public acceptability, socio-economic equity and political viability, and overcoming these challenges will not be simple. Public acceptability must overcome four major hurdles. First, the majority of the public does not understand the congestion reducing abilities of time of day pricing. Without a clear understanding of the benefits that a time of day pricing model contributes, the public is likely to see the scheme as a tax grab rather than a congestion reduction plan and is hesitant to lend their support. Second, most individuals underestimate the costs of congestion. With a toll of $5.00, the average individual would have to save just 15 minutes (given average wages of $20/hour) to be better off. Often, though, drivers are not explicit about the value of their time. Third, most individuals have trouble accepting that they should pay for a service that was previously provided at no charge. These policy alternatives would add tolls without any added infrastructure; while in theory you do not need expanded infrastructure for tolls, the precedent in B.C. is to toll only new roads. Fourth, the majority of the public firmly believe in their right to untolled road alternatives, regardless of the negative impact they have on system effectiveness. Only after these public opinion challenges are overcome are the political barriers to comprehensive tolling likely to fall.

It has been proven that the public acceptability of congestion charging can change and evolve, as evidenced through London and Stockholm (Litman 2007a). To create some policy momentum, those in favour of congestion-targeting tolls should ally and bring their cause to the public. TransLink and Metro Vancouver should employ the assistance of the Greater Vancouver Gateway Council and the B.C. Chamber of Commerce, two well-known and respected stakeholder groups that publicly support a new approach to tolling and congestion management policy in Greater Vancouver (GVTA 2007a, 2007b). In London, Mayor Ken Livingstone is credited with personally creating the political environment needed for congestion charging. Should a capable champion emerge in the Lower Mainland, a person who can open a policy window using the support of diverse groups, then, it may be possible to toll all four crossings. In the meantime, small steps can be taken to demonstrate the benefits of congestion pricing.

As a start, congestion-targeting charges can be introduced following the expansion of the Port Mann Bridge. The project plan already calls for tolls, but all indications point away from time of day tolling. As a "pilot project" congestion-targeting tolls on the twinned bridge will fit within the Province's Tolling Guidelines and will help individuals realize the benefits of time of day tolls. While this strategy may further solidify the mindset that tolls should only be placed on new infrastructure, it will at least allow drivers and residents to experience the effects that congestion-targeting tolls have. Through this experiment, transportation authorities may subsequently be able to convince the public that time of day tolls are acceptable on other crossings; given current traffic flows, the Pattullo Bridge and Alex Fraser Bridge only require time of day tolls for the peak hours. The interventions on these bridges will be small, so, combined with the realized benefits of time of day tolling on the Port Mann, proponents may be able to convince the public that pricing these crossings can bring benefits even without new infrastructure.

Within the Guideline requiring untolled road alternatives, there may be room for interpretation. There is some question as to how substitutable the provided alternatives must be (would the George Massey Tunnel serve as an alterative to the Port Mann Bridge?), how different the level of service can be (does one untolled lane next to three tolled lanes suffice?) and, importantly, whether the alternative must be available during the same time period. An argument could be made that under time of day tolling there would be substantial lengths of time that do not require tolls, representing untolled alternatives. Instead of substituting untolled routes, users would be able to substitute time periods. Granted, it will be difficult for some to change time periods, but others have just as much difficulty changing routes; a driver from North Delta does not necessarily see the George Massey Tunnel as an alternative to the Alex Fraser Bridge. Highlighting lower demand periods as untolled alternatives may allow for additional flexibility in public acceptability and therefore may make congestion-targeting tolls more adoptable.

Policy Alternative 1 creates the most congestion reduction and should be the ultimate long-term policy goal; its benefits are large and while it does change socio-economic equity, there are solutions, such as public transit improvements, that can make it an overall success. In the short term, however, to deal with issues of public acceptability and political viability, a step-wise approach is more realistic. Starting with the Port Mann Bridge will show the benefits of pricing, and gradually spreading implementation to the remaining crossings could collect support for tolling. This approach does have drawbacks, but it is a good way to ensure that the dialogue around congestion-targeting tolls gains momentum, since Greater Vancouver's institutions are not quite ready for the paradigm shift that an immediate move to Policy Alternative 1 would require.

9.3 Implementation

Establishing congestion charges would be revolutionary for Greater Vancouver's transportation policy. Implementation of the proposals in this study requires several steps and considerations. Below, I present some guidance for policy implementation; my discussion covers strategies for jurisdictional navigation, public engagement and system functionality. At the end of this section I argue that strong leadership is needed for policy realization.

Section 2.2 titled "Transportation Policy Diaspora," demonstrated that no single body regulates the four crossings in question. Instead, policy jurisdiction is divided among provincial, regional and municipal authorities. I believe that a single policy owner is best for a congestion charging scheme because coordination can be expensive and could lead to a reduction in policy effectiveness. A single regulator and operator of the congestion charge scheme would be best for system administration, effectiveness and operability. This is not to say that other groups should be excluded. The policy owner should consult and liaise with other transportation groups. But overall, authority must rest with one body, and I argue that body should be TransLink. No single municipality borders all crossings so municipalities can be ruled out. TransLink has advantages over the provincial government because it already has authority over local transportation areas such as public transportation and the major road network. TransLink can integrate congestion charging policy into the rest of its transportation decisions, simultaneously planning transit service and congestion reduction on the crossings. It can also combine its ability to price the crossings with their authority over the surrounding roads to plan maintenance and operation of the surrounding major road network. TransLink would rely on the Province for vehicle registration information necessary under the electronic toll collection system. TransLink would also want to ensure that, wherever possible, policy was designed for optimal operation of municipal systems. For these reasons, TransLink should plan and operate the proposed congestion charging scheme.

Ultimately arriving at congestion charges on all four crossings requires a modification of the Provincial Tolling Guidelines. The recommended pricing scheme conflicts with current Guidelines #1 and #3 in Table 2 on page 8. Guideline #1 allows tolling only on new projects that increase road capacity. Vickrey (1963) discussed the "peculiar logic" behind the similar pricing practices of his time in the Brooklyn/Long Island area. Then (just as in contemporary British Columbia), older bridges were considered paid for and were toll-free, but newer bridges levied tolls. Guideline #1 reflects the common public ideology that tolling is only justified for cost recovery of construction capital. It fails to recognize that proper pricing schemes can correct congestion's market failures. Additionally, Guideline #3 requires the provision of an untolled road alternative. Above, I discussed how creative interpretation of untolled time periods as untolled alternatives may allow some flexibility.

The Province's initial intention when establishing these Tolling Guidelines was to set the stage for reintroduction of tolling of some form to the Lower Mainland (Blasetti Interview). For this the provincial government should be commended, since they have at least initiated a discussion about transportation pricing. Both of the problematic Guidelines are important from a public acceptability point of view, and changing them will mean public opposition. But to implement congestion charges on all four crossings, the provincial government must change their policy and allow a comprehensive congestion reduction scheme.

In all likelihood, the drivers that regularly use the Fraser River South Arm crossings will not accept comprehensive tolling unless crossings in other areas such as the Burrard Inlet and the Fraser River North Arm also use congestion-targeting tolls. This study's scope was narrowed to allow study of the most congested routes in Greater Vancouver, but these other crossings also endure congested conditions. It is probable that congestion charges will bring benefits to these other crossings, and they should be considered during policy development.

Further, the plan must be ensure credibility. Policymakers cannot approach the public, speak about the major benefits of congestion pricing, and then not deliver. Headway in public acceptability can quickly be lost if promises are broken. Vancouver residents are currently sceptical about transportation commitments due to controversy over the disruptive construction of a new rapid transit line. Consistent credibility is critical to implementation success.

To smooth system functionality, I propose two further implementation strategies. First, the public transit service improvements discussed above should be operational at least one month prior to activating the charge scheme. This will carry costs that will not be offset by toll revenue, but it creates two main benefits. It will allow the public to experiment with the new alternatives before congestion fees are charged; once charges are implemented, drivers will more easily adapt to the new fees. It will also demonstrate TransLink's commitment to service increase, developing a level of trust and credibility.

Second, the scheme must undergo a complete and regular technical review process to ensure correct functionality, and these results should be made public to increase transparency and decrease public scepticism. Immediately, reviews should occur monthly, checking that congestion targets are met and that the elasticities and tolls have been correctly estimated. Reviews can subsequently become annual, and will help with credibility to the public by ensuring that the scheme is reaching its goals.

Adoption and implementation of the policy recommendations of this paper requires leadership. Many believe that congestion charging implementation would never have been possible in London without the leadership and commitment of Mayor Ken Livingstone. Because my proposal represents a dramatic policy change from the status quo, and because it requires consideration of so many policy facets, it needs a champion to push it politically, publicly and institutionally. TransLink and Metro Vancouver each supported new bridge tolls, but we have seen no action because they have yet to convince the Province of the merits (Anton Interview). Former TransLink director Peter Ladner noted in an interview that policymakers still remember TransLink's 2003 attempt to implement a vehicle levy, which resulted in a political standoff (and subsequent political loss for TransLink); policymakers are now discouraged from changing transportation's pricing structure. It is possible that the new TransLink governance structure, through its independence and expertise, will provide a formula where congestion charging policy can be championed.

10 Conclusion

Excess demand on Greater Vancouver's Fraser River crossings has created costs that are endured by many. This study examined congestion on the George Massey Tunnel and Alex Fraser, Pattullo and Port Mann bridges. It determined that pricing can be used to reduce traffic flows and alleviate congestion on these crossings. By applying data from a simple demand elasticity model, as well as case studies, several variations of congestion charging structures were developed into feasible policy alternatives. After assessing these alternatives based on multiple criteria, I recommend congestion charges on all four crossings while recognizing that implementation may need to come about gradually to gain public and political support.

The policy package proposed can significantly reduce congestion over the Fraser River. It carries considerable equity and public acceptability impacts; these impacts can be minimized using the strategies discussed. Several policy features that are critical to Greater Vancouver were discussed above. Allocating toll revenue to public transportation, using electronic tolling mechanisms and providing targeted exemptions are all important considerations. If absent, the acceptability or functionality of the tolling system may suffer to the point of failure. I also proposed some implementation strategies that are designed to give congestion charging a regulatory grounding and sufficient momentum to complete the policy process.

Given further opportunities to study this topic, research should focus on refining the pricing schemes and parallel policy proposals to ensure they best reflect the behaviour of Greater Vancouver travellers. This would include estimation of the cross-elasticities of demand showing the distribution of avoided trips; we know that trips on the crossings will decrease, but the dispersion between new modes, time periods or routes is unknown. Such estimates will ensure accurate toll levels and help with planning for alternative modes. Additionally, researchers interested in this topic should establish, through surveys or other methods, the limits of public acceptability to tolling. Focus group research could establish what happens to public acceptability as individuals learn more about the congestion effects of tolling, and surveys could narrow down the characteristics (such as geographical or socio-economic traits) that generate the most opposition. Once established, policies can be strategically adapted to gain acceptability.

The status quo in transportation policy has led to continual road congestion. Improper pricing of roads has led to excess demand, which brings significant costs. Individuals and firms waste crucial productive hours sitting in traffic. Environmentally friendly public transportation cannot compete with private vehicles when the marginal cost of road use is so low. Many believe that the Province's current plans to double the capacity of the Port Mann Bridge will create short-term congestion relief but that congestion will return in a few years time (McMartin 2007). Tolling the crossing using congestion charges rather than fixed tolls can ensure a continuance of freer flowing traffic. Congestion reducing fees will make businesses better off as they save on shipping costs and individuals better off as the economy gains efficiencies. Adopting congestion charges presents challenges to public acceptability and equity, but policy adaptations can serve to mitigate these. With leadership and determination, congestion charges can be implemented effectively, prudently and fairly.

Appendix A: Supplementary Maps of Metro Vancouver

Figure 4: Supplementary Map of Metro Vancouver (1)

Source: Google Earth

Figure 5: Supplementary Map of Metro Vancouver (2)

Source: Google Earth

Appendix B: Revenue Under Each Policy Alternative

Each policy alternative will differ in its revenue generation. Revenue levels depend on the toll price and the number of vehicles that are assessed charges. During periods of tolling, I assume the traffic flow to be 1400 vehicles per lane per hour – the target flow that the charging scheme aims to achieve. To calculate the daily revenue, each time period's tolls are multiplied by the hourly traffic flow of 1400 vehicles per lane and summed for a daily total. The crossings' daily totals then aggregated, producing a daily revenue total for each Policy Alternative. Daily revenue is expanded to an annual revenue figure by multiplying it by 250, roughly the number of regular commute days in a year.

Tables 21 to 23 show the revenue calculations and results for each Policy Alternative. The George Massey Tunnel operates on a counterflow system, so its hourly flow changes during the AM and PM peak periods. The remaining crossings have constant target flows, determined by multiplying 1400 vehicles per hour per lane by the number of lanes on the crossing. Under Policy Alternative 3, only one lane in each direction is tolled as an HOT lane.

Table 21: Revenue Under Policy Alternative 1

Policy Alternative 1	George Massey Tunnel		Alex Fraser Bridge		Pattullo Bridge		Port Mann Bridge	
Time Period	NB Tolls	SB Tolls	NB Tolls	SB Tolls	EB Tolls	WB Tolls	EB Tolls	WB Tolls
6:00	$0	$0	$4.00	$0	$0	$5.00	$0	$10.50
7:00	$6.50	$2.00	$6.00	$0	$0	$6.00	$0	$8.00
8:00	$3.00	$3.00	$6.00	$0	$0	$1.50	$0	$11.00
9:00	$3.00	$0	$0	$0	$0	$0	$0	$7.00
10:00	$3.00	$0	$0	$0	$0	$0	$0	$4.00
11:00	$0.50	$0	$0	$0	$0	$0	$0	$4.00
12:00	$0	$0	$0	$0	$0	$0	$0	$4.00
13:00	$0	$0	$0	$0	$0	$0	$0	$4.00
14:00	$0	$3.50	$0	$0	$0	$0	$1.50	$6.00
15:00	$14.00	$0	$0	$6.50	$3.00	$0	$6.50	$11.50
16:00	$5.00	$4.00	$0	$9.50	$4.00	$0	$6.50	$11.50
17:00	$3.50	$4.00	$0	$10.50	$0.50	$0	$6.50	$11.50
18:00	$0	$5.00	$0	$3.50	$0	$0	$0.50	$4.00
AM Peak Flow (per hour)	4200	1400	-	-	-	-	-	-
PM Peak Flow (per hour)	1400	4200	-	-	-	-	-	-
Regular Flow (per hour)	2800	2800	4200	4200	2800	2800	4200	2800
Daily Revenue	$89,600	$64,400	$67,200	$126,000	$21,000	$35,000	$90,300	$271,600
Total Daily Revenue:	$765,100							
Total Annual Revenue:	**$191,275,000**							

NB – Northbound, SB – Southbound, EB – Eastbound, WB –Westbound

Table 22: Revenue Under Policy Alternative 2

Policy Alternative 2	George Massey Tunnel		Alex Fraser Bridge		Pattullo Bridge		Port Mann Bridge	
Time Period	NB Tolls	SB Tolls	NB Tolls	SB Tolls	EB Tolls	WB Tolls	EB Tolls	WB Tolls
6:00	$0	$0	$0	$0	$0	$0	$0	$7.00
7:00	$4.50	$2.00	$0	$0	$0	$0	$0	$5.00
8:00	$2.00	$2.00	$0	$0	$0	$0	$0	$7.00
9:00	$2.00	$0	$0	$0	$0	$0	$0	$5.00
10:00	$2.00	$0	$0	$0	$0	$0	$0	$3.00
11:00	$0.50	$0	$0	$0	$0	$0	$0	$3.00
12:00	$0	$0	$0	$0	$0	$0	$0	$3.00
13:00	$0	$0	$0	$0	$0	$0	$0	$3.00
14:00	$0	$2.50	$0	$0	$0	$0	$1.00	$4.00
15:00	$9.50	$0	$0	$0	$0	$0	$4.50	$7.50
16:00	$3.50	$2.50	$0	$0	$0	$0	$4.50	$7.50
17:00	$2.50	$2.50	$0	$0	$0	$0	$4.50	$7.50
18:00	$0	$4.00	$0	$0	$0	$0	$0.50	$3.00
AM Peak Flow (per hour)	4200	1400	-	-	-	-	-	-
PM Peak Flow (per hour)	1400	4200	-	-	-	-	-	-
Regular Flow (per hour)	2800	2800	4200	4200	2800	2800	4200	2800
Daily Revenue	$61,600	$44,800	$0	$0	$0	$0	$63,000	$183,400
Total Daily Revenue:	$352,800							
Total Annual Revenue:	**$88,200,000**							

NB – Northbound, SB – Southbound, EB – Eastbound, WB –Westbound

Table 23: Revenue Under Policy Alternative 3

Policy Alternative 3								
	George Massey Tunnel		Alex Fraser Bridge		Pattullo Bridge		Port Mann Bridge	
Time Period	NB Tolls	SB Tolls	NB Tolls	SB Tolls	EB Tolls	WB Tolls	EB Tolls	WB Tolls
6:00	$0	$0	$2.00	$0	$0	$2.50	$0	$5.50
7:00	$3.00	$1.00	$3.00	$0	$0	$2.50	$0	$4.00
8:00	$1.50	$1.50	$3.00	$0	$0	$0.50	$0	$5.50
9:00	$1.50	$0	$0	$0	$0	$0	$0	$2.00
10:00	$1.50	$0	$0	$0	$0	$0	$0	$2.00
11:00	$0.50	$0	$0	$0	$0	$0	$0	$2.00
12:00	$0	$0	$0	$0	$0	$0	$0	$2.00
13:00	$0	$0	$0	$0	$0	$0	$0	$2.00
14:00	$0	$2.00	$0	$0	$0	$0	$1.00	$3.50
15:00	$7.00	$0	$0	$3.00	$1.50	$0	$3.50	$5.50
16:00	$2.00	$2.00	$0	$5.00	$2.00	$0	$3.50	$5.50
17:00	$2.00	$2.00	$0	$5.00	$0	$0	$3.50	$5.50
18:00	$0	$3.00	$0	$2.00	$0	$0	$0.50	$2.00
AM Peak Flow (per hour)	1400	0	-	-	-	-	-	-
PM Peak Flow (per hour)	0	1400	-	-	-	-	-	-
Regular Flow (per hour)	1400	1400	1400	1400	1400	1400	1400	1400
Daily Revenue	$11,200	$12,600	$11,200	$21,000	$4,900	$7,700	$16,800	$65,800
Total Daily Revenue:	$151,200							
Total Annual Revenue:	**$37,800,000**							

NB – Northbound, SB – Southbound, EB – Eastbound, WB –Westbound

Bibliography

Works Cited

407 International. 2007. *Annual Information Form.*

British Columbia Ministry of Transportation Gateway Program. 2006a. *Pre-Design Consultation Summary Report.*

British Columbia Ministry of Transportation. 2006b. *Gateway Program: Program Definition Report.*

British Columbia Ministry of Transportation. 2003. *Guidelines for Tolling.*

Bertini, Robert L. 2005. *You are the Traffic Jam: An Examination of Congestion Measures.* Paper presented at the Transportation Research Board Annual Meeting ed. Portland State University.

Button, Kenneth. 1993. "The Demand for Transport." *Transport Economics.* 2nd ed. Cambridge: Edward Elger Publishing, 39-65.

Cambridge Systematics. 2005. *Traffic Congestion and Reliability: Trends and Advanced Strategies for Congestion Migration.* Prepared for the U.S. Department of Transportation, Federal Highway Administration.

Congressional Budget Office. 2008. *Effects of Gasoline Prices on Driving Behavior and Vehicle Markets.*

Davis, Chuck, ed. 1997. *The Greater Vancouver Book: An Urban Encyclopedia.* Surrey: Linkman Press.

Evans, Jeremy, and Dan Firth. 2007. "Central London Congestion Charging Western Expansion - Early Results." *Transport for London.*

Greater Vancouver Regional District. 2007. *Road Pricing: An Overview of Current Practice.* Vol. 3.

Greater Vancouver Transportation Authority. 2004a. *2004 Greater Vancouver Screenline Survey - (Mechanical Counts), Count Stations 9-1, 9-2, 10-2, 10-3.*

Greater Vancouver Transportation Authority. 2004b. *Summary and Results of the 2003 Greater Vancouver Travel Survey.*

Greater Vancouver Transportation Authority. 2007a. *British Columbia Chamber of Commerce's Perspective on Transport 2040.* November 2007.

Greater Vancouver Transportation Authority. 2007b. *The Greater Vancouver Gateway Council's Perspective on Transport 2040.* November 2007.

Ipsos Reid. 2002. *British Columbians Think Public-Private Partnerships are a Good Idea.*

Ipsos Reid. 2006. *GVRD Transportation Improvements Survey: Public Opinion Update, Final Report.*

Jaensirisak, S., M. Wardman, and A. D. May. "Explaining Variations in Public Acceptability of Road Pricing Schemes." *Journal of Transport Economics and Policy*, 39.2 (2005): 127-53.

Jensen-Butler, Christopher. 2001. *Urban Congestion: A Charging Solution.* http://www.royalsoced.org.uk.proxy.lib.sfu.ca/public_policy/congestion_charging.htm.

Khisty, C. Jotin, and B. Kent Lall. *Transportation Engineering: An Introduction.* 2nd ed. New Jersey: Prentice Hall, 1998.

Ladner, Peter. 2007, 13-19 March. "Why does Congestion always Cost $1.5 Billion?" *Business in Vancouver.*

Lai, Tim. 2006, 30 December. "Toll Fees for 407 Climbing again in 2007." *The Toronto Star*, GTA: B01.

Lindsey, Robin. 2007. "Congestion Relief: Assessing the Case for Road Tolls in Canada." Commentary No. 248. *C.D. Howe Institute.*

Litman, Todd. 2006. "London Congestion Pricing: Implications for Other Cities." *Victoria Transport Policy Institute.*

Litman, Todd. 2007a. "Congestion Pricing, Value Pricing, Toll Roads and HOT Lanes." *Victoria Transport Policy Institute.*

Litman, Todd. 2007b. "Congestion Reduction Strategies: Identifying and Evaluating Strategies to Reduce Traffic Congestion." Online TDM Encyclopaedia. *Victoria Transport Policy Institute.*

Litman, Todd. 2007c. "Transportation Elasticities: How Prices and Other Factors Affect Travel Behavior." *Victoria Transport Policy Institute.*

Matas, Anna, and Jose-Luis Raymond. 2003. "Demand Elasticity on Tolled Motorways." *Journal of Transportation and Statistics.* 6.2/3: 91-108.

McMartin, Pete. 2007, 6 October. "Port Mann Twinning Will Only Likely Lead to Tripling it Later." *Vancouver Sun*, B1.

Mekky, Ali. 1999. "Forecasting Toll Revenues for Fully Electronic Highways Operating Under Transponder and Video-Imaging Systems." *Transportation Research Record,* 1659: 11-22.

Orange County Transportation Authority. 2003. *91 Express Lanes Toll Policy.*

O'Sullivan, Arthur. 2003. *Urban Economics.* 5th Edition ed. London: McGraw-Hill/Irwin.

Parsons Brinkerhoff. 2003. *A Guide for HOT Development.* U.S. Department of Transportation: Federal Highway Administration.

Patton, Carl V., and David S. Sawicki. 1986. "Chapter 8: Displaying Alternatives and Selecting among them." *Basic Methods of Policy Analysis and Planning.* 260-299.

Poole, Robert W., and C. Kenneth Orski. 2000. "HOT Lanes: A Better Way to Attack Urban Highway Congestion." *Regulation,* 23.1: 15-20.

Richards, Martin G. 2006. *Congestion Charging in London: The Policy and the Politics.* New York: Palgrave Macmillan.

Santos, Georgina, and Gordon Fraser. 2006. "Road Pricing: Lessons from London." *Economic Policy,* 21.46: 263-310.

Small, Kenneth, and Erik T. Verhoef. 2007. *The Economics of Urban Transportation.* New York: Routledge.

Transport for London. 2007. *Central London Congestion Charging Impacts Monitoring.* Fifth Annual Report.

Vickrey, William S. 1963. "Pricing in Urban and Suburban Transport." *The American Economic Review,* 53.2, Papers and Proceedings of the Seventy-Fifth Annual Meeting of the American Economic Association: 452-65.

Washbrook, Kevin, Wolfgang Haider, and Mark Jaccard. 2006. "Estimating Commuter Mode Choice: A Discrete Choice Analysis of the Impact of Road Pricing and Parking Charges." *Transportation,* 33: 621-39.

Yin, Robert K. 2003. *Case Study Research: Design and Methods.* Third Edition Vol. 5. Thousand Oaks, California:

Interviews

Anton, Suzanne. 2007. Greater Vancouver Transportation Authority Board of Directors. Vancouver, British Columbia.

Blasetti, Frank. 2007. Ministry of Transportation. Victoria, British Columbia (via telephone).

Ladner, Peter. 2007. Greater Vancouver Transportation Authority Board of Directors. Vancouver, British Columbia.

Trasolini, Joe. 2007. Greater Vancouver Transportation Authority Board of Directors. Port Moody, British Columbia.

Wright, Wayne. 2007. Greater Vancouver Transportation Authority Board of Directors. New Westminster, British Columbia.