OFFICE OF THE PARLIAMENTARY BUDGET OFFICER

BUREAU DU DIRECTEUR PARLEMENTAIRE DU BUDGET

CANADA

Toll Pricing on the Champlain Bridge Replacement

Ottawa, Canada
September 17, 2014
www.pbo-dpb.gc.ca

The mandate of the Parliamentary Budget Officer is to provide independent analysis to Parliament on the state of the nation's finances, the government's estimates and trends in the Canadian economy; and upon request from a committee or parliamentarian, to estimate the financial cost of any proposal for matters over which Parliament has jurisdiction.

The Parliamentary Budget Officer was asked by Mr. Hoang Mai, the Member of Parliament for Brossard-La Prairie, to estimate revenues that could be generated by introducing a toll on the Champlain Bridge replacement in Montréal. This report is in response to that request.

This report makes no attempts to model secondary economic impacts that could arise from implementing a toll and the resulting diversion of traffic. It also makes no attempt to provide an opinion regarding methods of procuring the bridge replacement, or the methods of paying for it.

The estimates and forecasts provided in this report are not official Government of Canada estimates.

The Steer-Davies-Gleave report, prepared exclusively for Transport Canada, was not used in this analysis.

This is a revised version of the originally posted report. References to travel times at 8 am have been removed. This change does not affect any calculations or conclusions.

Prepared by: Duncan MacDonald*

* The author would like to thank the assistance of Tejas Aivalli, as well as other PBO colleagues. The author would also like to thank Professor Eric Miller, as well as Dr. Pavlos Kanaroglou and Dr. Mark Ferguson of the McMaster Institute for Transportation and Logistics for their advice and contributions. For further information, please contact Mostafa Askari (mostafa.askari@parl.gc.ca) or the author (duncan.macdonald@parl.gc.ca) .

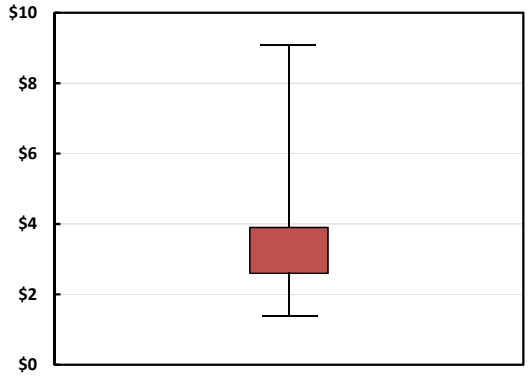
Executive summary

In 2011, the Government of Canada announced that it would replace the Champlain Bridge in Montréal. The Government stated it would do so using a public-private partnership (P3), and that the cost would be at least partially funded with toll revenues.[1]

The Parliamentary Budget Office (PBO) was asked by Mr. Hoang Mai, the Member of Parliament for Brossard-La Prairie, to investigate the potential revenue that could be generated by introducing a toll on the Champlain Bridge replacement, scheduled to be in operation in 2018, and to investigate the cost-recovery potential of such a toll.

Figure E1

Range of Cost Covering Tolls



Source: Office of the Parliamentary Budget Officer

Note: Dollar amounts are in 2013 constant dollars.

PBO was able to infer the 'willingness to pay' of Montréal commuters.[2] It then estimated the proportion of Champlain Bridge commuters who would divert to other routes at various toll rates, as well as those who would subsequently divert to the bridge in an attempt to avoid the resulting congestion on their regular routes.

Table E2

Cost Recovery Toll Rates

Scenario	Toll	Total Revenue (Billions)	Traffic Diversion (%)
O&M only	$0.80	$1.5	1.4%
Construction, O&M	$1.40	$2.5	2.3%
$3B project cost, O&M	$2.60	$4.4	3.4%
$5B project cost, O&M	$3.90	$6.2	10.6%
Revenue-maximizing	$9.10	$10.7	37.9%

Source: Parliamentary Budget Office.

Note: Values in 2013 constant dollars.

PBO used these data to forecast the total revenue that could be obtained from various tolls over the known operating period. This report finds:

- Based on the Government's estimated design and construction cost of between $3 billion and $5 billion, a toll of between $2.60 and $3.90 would be needed for each crossing to break even and cover bridge operations and maintenance.[3] At these rates, 3.4 per cent to 10.6 per cent of total bridge traffic would divert to other routes.

- The minimum potential toll for cost recovery is estimated at $1.40 per crossing. At this rate, the toll would cover only direct bridge construction as well as operations and maintenance costs. It would not cover any financing costs or taxes incurred by the P3 consortium that would be chosen to build and operate the bridge.

[1] Government of Canada. (October 2011). Harper government to proceed with new bridge over the St. Lawrence. Retrieved March 2014.

[2] Willingness to pay is the maximum that a consumer is willing to pay to obtain a product or service.

[3] In 2013 constant dollars.

- The toll that maximizes revenue is estimated at $9.10 per crossing. It is revenue-maximizing because increasing it further would diminish total revenue at no benefit to commuters. At this price, about 38 per cent of total bridge traffic would divert to other routes, causing significant congestion in Montréal's traffic system.

Overview

The Champlain Bridge crosses the St. Lawrence River connecting Montréal to the South Shore. The bridge has significant structural issues, and the Government of Canada intends to replace it. The Government plans to impose a toll to cross the new bridge, which is expected to be operational in 2018.[4] There is currently no toll on the existing bridge.

The Parliamentary Budget Office was asked by Mr. Hoang Mai, the Member of Parliament for Brossard-La Prairie, to estimate the anticipated toll required to cross the replacement bridge and the corresponding revenue that would be generated.

In response, PBO developed an estimate of the traffic that would divert from the bridge as a result of the toll. This estimate was based on commute times, fuel costs, willingness to pay and existing traffic projections.

This estimate allowed PBO to determine the revenue-maximizing toll. It then compared the hypothetical revenue generated from the toll with a rough estimate of the cost of constructing and operating the new bridge to determine a cost recovery toll.

Background: Need for a replacement

The existing Champlain Bridge, one of the vital links between the Island of Montréal and the mainland, opened to the public in June 1962.[5] After over half a century, it has been crossed by roughly 3 billion vehicles.

The bridge was initially designed under the assumption that only sand would be used for winter road maintenance. However, the increased use of salt has accelerated the structure's decay in recent years.[6] As a result, the integrity of the bridge has been compromised and repairs have been increasingly required.[7,8]

Given the bridge's poor condition, the Government of Canada, which is responsible for many of the bridges crossing the St. Lawrence to the Island of Montréal, announced in December 2011 that it would replace the Champlain Bridge.[9] The timeline calls for the new bridge to be in service by 2018.[10] The project's estimated design and construction cost is between $3-billion and $5-billion.[11]

The Government also announced that the procurement would take the form of a public-private partnership (P3). This was chosen in an attempt to reduce the Government's financial exposure and reduce risks associated with a traditional procurement method. (For more details on P3 partnerships, see Box 1).[12,13,14]

[4] Government of Canada (January 2014). "Next steps for the new bridge for the St. Lawrence project". Retrieved June 2014.

[5] Van Der Aa, H. (1962). The Champlain Bridge. Montréal, Quebec, Canada: Porcupine Publications Ltd. Online section retrieved June 2014.

[6] At the time the original bridge was designed, salt was not as commonly used as a de-icing agent as it is today. It is only once the bridge was completed that road salt usage became more common. Accessed July 2014.

[7] Buckland & Taylor Limited. (2013). Champlain Bridge Apporach Spans: Edge Girder Condition Assessment and Rehabilitation Requirements. Prepared for the Jacques Cartier and Champlain Bridges Corporation. Retrieved June 2014.

[8] Declan. (2011). Assessment of the Champlain Bridge. Prepared for the Jacques Cartier and Champlain Bridges Corporation. Retrieved June 2014.

[9] Government of Canada. (October 2011). Harper government to proceed with new bridge over the St. Lawrence. Retrieved March 2014.

[10] Transport Canada, A New Bridge for the St. Lawrence – Project Timelines. Retrieved March 2014.

[11] Questions on the Order Paper. Question No.194 answered March 6th, 2014. Retrieved March 2014.

[12] Transport Canada. A new bridge for the St. Lawrence corridor. Accessed April 2014.

[13] Generally accepted risks of standard procurement include the potential to cost overruns and the risk of delays to the building schedule. The use of a P3 mechanism in this case is expected to mitigate this risk by paying a premium to the contractor to bear the risk.-

The competitive procurement process for determining the P3 partner is currently underway, with the request for proposals released in July 2014.[15] A component of the P3 business case is the introduction of a toll to cross the bridge.[16] As there is currently no toll for using the existing Champlain Bridge, introducing one could lead to some diversion of traffic to alternate routes in an effort to avoid the toll.[17]

While other sets of analysis of this issue have been performed, notably by Steer Davies Gleave (SDG) for Transport Canada, these are not publically available.[18]

Without the SDG results for comparison, PBO conducted work to provide a high level and representative analysis using publicly available data sources and broad assumptions of individual behaviors.

This analysis used Google Maps and Montréal origin-destination (O-D) survey data, in conjunction with income assumptions, to determine the toll price that drivers are willing to pay. PBO assumed that tolls beyond this price would motivate drivers to divert to another route.

Methodology overview

This section provides a high-level overview of the methodology. See Annex A for a detailed description of the methodology.

Annex B contains results comparisons and sensitivity analyses. Annex C provides a detailed list of assumptions.

Box 1

Public-Private Partnerships

A public-private partnership is a contracting relationship between government and private industry.

In P3 agreements, the private contractor designs and builds an infrastructure project to public sector specifications, then operates and/or maintains the project for a set period.

The private contractor determines its own means of financing the project, as the government agrees to only pay the contractor at set milestones (or in one lump sum at the end of the period) based on the satisfactory adherence of the standards set out in the contract.

Sources: PPP Canada.

When examining traffic diversion, PBO assumed that the main consideration facing drivers was the added time of taking another route. This took into account commuters' value of time and allowed for an objective measure of the difference between trips.

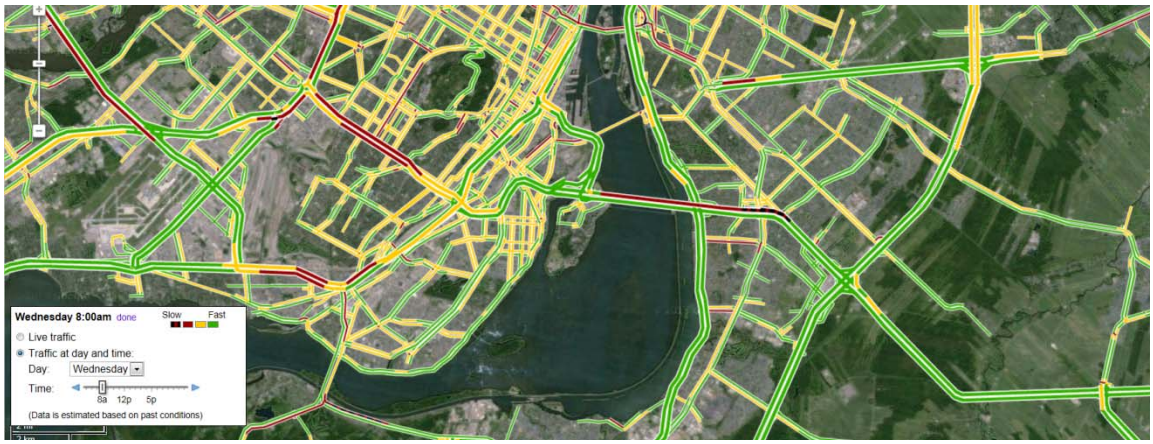
Data on trip times were obtained from the Google Maps Traffic application (Figure 1), which provided data on trip length and distance under various historic traffic conditions. [19,20,21] PBO examined data for trips between 6 a.m. and 9 a.m. This time represented an average weekday morning commute during the morning peak period.[22]

[14] Next steps for the new bridge for the St. Lawrence project - Backgrounder. Accessed August 2014.
[15] New Bridge for the St. Lawrence - Project Timelines. Retrieved on June 2014.
[16] Next steps for the new bridge for the St. Lawrence project – Backgrounder. Retrieved June 2014.
[17] Toll avoidance is summarized by the Sightline Institute. Retrieved June 2014.
[18] New Bridge for the St. Lawrence Business Case Technical Presentation. Retrieved July 2014.

[19] Google Blog: The bright side of sitting in traffic: Crowdsourcing road congestion data. Accessed June 2014.
[20] Google Maps Application.
[21] Google Maps imagery data at least partially provided by TerraMetrics. Copyright 2013, TerraMetrics, Inc. www.terrametrics.com.
[22] The traffic literature sometimes refers to the morning and night peak periods as AM peak and PM peak, respectively.

Figure 1

Google Maps Traffic Data



Source: Google and TerraMetrics map data

Times were obtained for trips across the St. Lawrence River based on origins and destinations corresponding to the 2008 O-D survey conducted by Agence métropolitaine de transport (AMT).[23,24] This is a large phone survey that provides a general picture of transportation needs in the Greater Montréal Area by asking respondents questions about their trips.

Based on the survey, PBO examined trips taken across the St. Lawrence River, and considered various bridge routes. The resulting times and distances were calculated for each possible bridge crossing using the Google Maps application. The difference in time and distance relative to alternate routes was compared.
In addition to the Champlain Bridge, alternate routes examined included the Jacques Cartier Bridge, the Victoria Bridge, the Honoré-Mercier Bridge, and the Louis Hippolyte Lafontaine Tunnel.[25]

PBO then calculated the reservation price—the price at which drivers would take another route. The reservation price is determined by a combination of individual income, trip time, trip distance and the origin and destination of the trip (Figure 2). For each toll, PBO assumed that if the toll was greater than a commuter's reservation price, they would divert to another route.

For the purpose of this analysis, PBO assumed that the toll facility would consist of a camera-based system implementing a two-way tolling structure free of physical barriers. This assumption was based on the implementation of recent toll systems in other jurisdictions, and that commuters

[23] AMT 2008 O-D Survey. Accessed June 2014.
[24] The trips examined consisted of origins and destinations between the South Shore and Montréal Island.

[25] During the AM peak period the Victoria Bridge lane leaving Montréal Island reverses direction. This results in two possible routes across the Victoria Bridge. In this analysis only one route to Montréal Island was examined, and the Victoria Bridge was excluded from the list of viable South shore bound morning routes.

Figure 2

Reservation Price Inputs

Source: Office of the Parliamentary Budget Office.

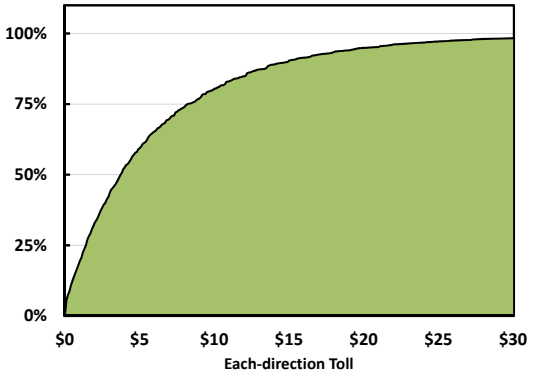
could avoid a one-way toll by using the new bridge only in the direction with no toll.[26]

As a further consideration, it was assumed that the congestion added to alternate routes would motivate drivers on those routes to divert to the new bridge. This amounted to a swapping of drivers from an alternate route to the new bridge, and vice versa, depending on the reservation prices of the individual drivers.

Figure 3

Gross Diversion – Without Congestion

Per cent (%)



Source: Office of the Parliamentary Budget Officer.

The result of the analysis was calculation of a percentage diversion from the new bridge at various toll prices, which was projected over the minimum 30-year operation period of the tolls outlined by the Government. With this diversion estimate, the corresponding revenue for each toll was calculated.

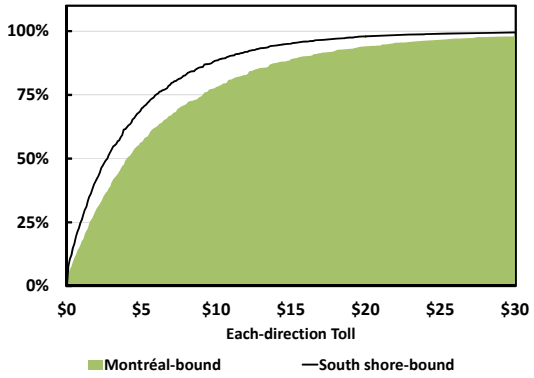
Results: Overall traffic diversion

This report presents the resulting traffic diversion in two steps: gross diversion calculated without consideration of other drivers replacing those who leave the new bridge, and net diversion that includes it.

Figure 4

Gross Each Direction Diversion – Without Congestion

Per cent (%)



Source: Office of the Parliamentary Budget Officer.

Gross diversion is shown in Figures 3 and 4. In the absence of any replacement commuters, diversion increases as the toll price increases as a function of commuters' reservation price. Even at low tolls, the

[26] Evidence suggests that toll traffic projections tend to overestimate observed traffic due to avoidance. While PBO's analysis cannot claim to be immune from this bias, this assumption eliminates one form of toll avoidance from the model. See the Sightline Institute. Retrieved June 2014.

diversion from the new bridge is substantial. For example, when considering the reservation price only, a $1 toll would prompt a diversion of 20 per cent of total traffic.

However, Figures 3 and 4 represent an incomplete model that does not implicitly factor in the constraints on the entire traffic system. These figures depict only the desire of commuters to leave the new bridge. In many cases, the decisions of other drivers make such actions infeasible.

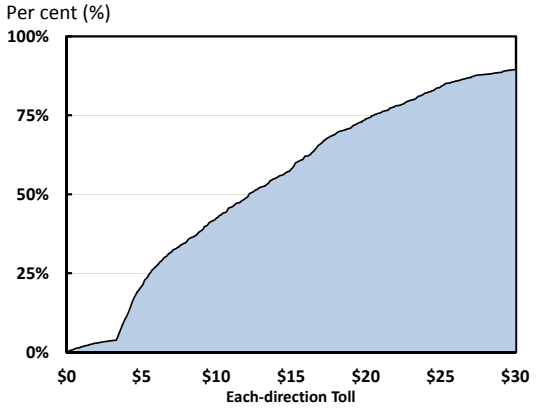
Results: Net traffic diversion

The net diversion of traffic from the bridge at various tolls is shown in Figures 5 and 6. These figures depict a more complete model in which the feasibility of diverting is examined. The resulting diversion suggests that a number of commuters are willing to move to the new bridge at the same time that others are moving away from it.

As a result, diversion is limited when the toll is low because many commuters are willing to pay to avoid the congestion created on other routes by those who choose to divert. As the toll increases, fewer commuters are willing to take the new bridge; instead, they either endure the added congestion on alternative routes or make another change to their trip.[27,28]

Figure 5

Net Diversion – With Congestion

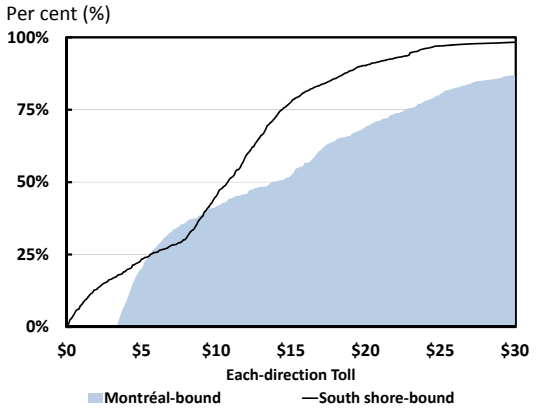


Source: Office of the Parliamentary Budget Officer.

For example, with a $2.50 toll, similar to that of Autoroute 25, all Montréal-bound commuters that divert from the new bridge would be replaced, resulting in no net diversion. However, the model also indicates that at this toll rate, there would be a net diversion of 15 per cent of South Shore-bound commuters.[29]

Figure 6

Net Each Direction Diversion – With Congestion



Source: Office of the Parliamentary Budget Officer.

Those who would choose to divert are predominantly low-income earners. Figure 7 shows the proportion of each income group choosing to remain with the new bridge at various tolls. As the toll increases,

[27] Other trip changes were not modelled here, but could entail changing the time of the trip (e.g. head to work earlier in the morning), or changing the mode of transportation (e.g. take rail or a bus). There is evidence to suggest that commuters are resistant to changing the mode of transportation. See Mann, E. & Abraham, C. (2012). Identifying Beliefs and Cognitions Underpinning Commuters' Travel Mode Choices. Journal of Applied Social Psychology, 42 (11). pp 2730-2757. Retrieved June 2014.

[28] Truck traffic constitutes 5 per cent of AM peak period traffic travelling to Montréal and 14 per cent travelling away. While there is evidence to suggest that truck traffic toll elasticity is higher than that of regular traffic, the PBO assumed that trucks would divert in equal amount with cars. This assumption was based on the low overall elasticities estimated for the NBSL compared with the literature. See Standard & Poor's Traffic Forecasting Risk Study Update 2005: Through Ramp-Up and Beyond. Retrieved June 2014.

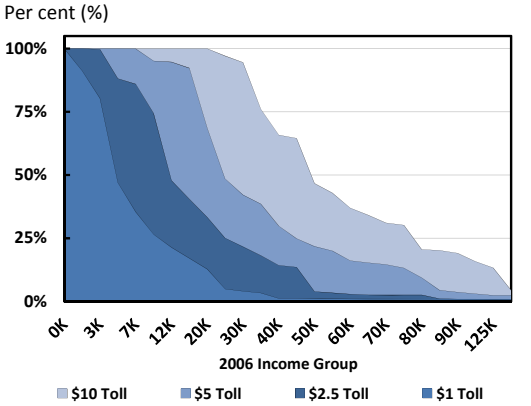
[29] During peak hours the toll is $2.50, while it is $1.88 during non-peak hours. See A25 Fee Schedule.

those at lower income levels will choose to divert first, as they have a lower willingness to pay.

While these commuters are not paying the toll directly, they effectively pay a portion of the toll in time by choosing to alter their trip to an alternative route.

Figure 7

Diversion by Income Group

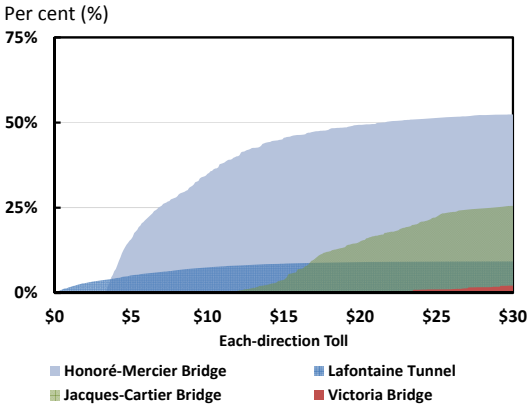


Source: Office of the Parliamentary Budget Officer.

Figure 8 illustrates the diversion to each alternate bridge as a share of new bridge commuters.

Figure 8

Net Diversion to Alternate Routes



Source: Office of the Parliamentary Budget Officer.

The Jacques Cartier and Victoria bridges are the two closest routes to the new bridge. However, both bridges are near enough to the Champlain Bridge that diverting commuters are quickly replaced. So these two bridges do not carry a large share of diverting traffic. It is the Honoré-Mercier Bridge that would take the largest net share of diverting traffic, though only at tolls higher than $3.30. On average, to divert to the Honoré-Mercier Bridge from the Champlain Bridge would add 8.3 kilometers to a commuter's distance.

Results: Toll revenue

To determine toll revenue, PBO applied the above diversion metrics to the 2011 traffic forecasts performed by Consortium BCDE for Jacques Cartier and Champlain Bridges Incorporated.[30] Table 9 provides the forecasted traffic flow in 2006 and 2026.

Consortium BCDE predicted a 4 per cent growth in Champlain Bridge traffic over the 20-year period. PBO applied an inferred overall annual average growth rate of 0.2 per cent, over the time frame of the operating period of the P3 contract to obtain anticipated traffic flows. The assumed operating period spanned 2021 to 2050.[31]

Table 9

Simulated Traffic Flows: 2006 to 2026[32]

Year	2006	2026	Variation
Night	12,028	12,009	-0.16%
AM peak	28,941	28,914	-0.09%
Day	60,053	65,986	9.88%
PM peak	31,129	31,317	0.60%
Evening	31,970	32,507	1.68%
Total	**164,119**	**170,733**	**4.03%**

Sources: JCCBI, Consortium BCDE Table 7.

Traffic and revenue estimates were obtained under different toll rates. Separate traffic diversion estimates were

[30] Consortium BCDE (2011). Pre-feasibility Study Concerning the Replacement of the Existing Champlain Bridge: Sectorial Report No2 – Transportation and Traffic Needs. Accessed June 2014.

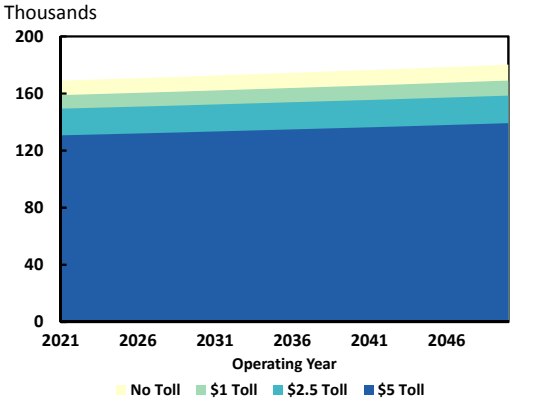
[31] While the new bridge will be in service in 2018, the substantial completion date for the bridge is 2020. See the NBSL Project Timelines. Accessed August, 2014.

[32] For the purposes of this analysis the periods cover time frames as follows: Night = midnight to 6 a.m., AM Peak = 6 a.m. to 9 a.m., Day = 9 a.m. to 3 p.m., PM peak = 3 p.m. to 6p.m., Evening = 6 p.m. to midnight.

applied to Montréal-bound and South Shore-bound traffic. The traffic diversion estimated during the morning peak period was applied to the duration of the day to obtain a total estimate.[33]

Figure 10

Average Daily Commuters

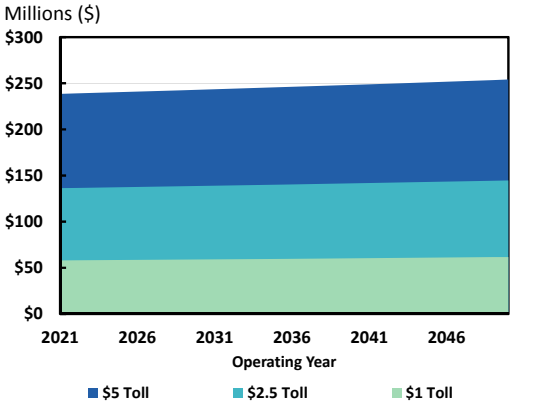


Source: Office of the Parliamentary Budget Officer.

Figures 10 and 11 illustrate the number of daily commuters and the total annual revenue over the operating period of the P3 contract for the new bridge under three separate one-way toll rates, respectively.[34]

Figure 11

Estimated Total Annual Revenue



Source: Office of the Parliamentary Budget Officer.

[33] Diversion estimates for Montréal–bound traffic were applied to the AM peak period as well to traffic leaving Montréal during the PM peak period. Diversion estimates for traffic leaving Montréal during the AM peak period were applied to all other periods, as the traffic levels in this direction were the most similar to traffic observed outside of peak periods.

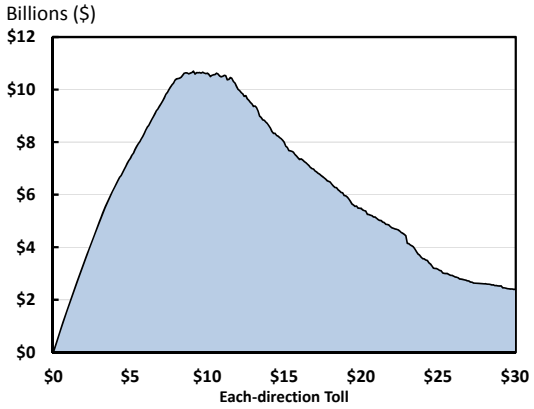
[34] All prices are in 2013 constant dollars.

Results: Revenue maximizing solution

With estimates of the diversion resulting from a toll rate, the revenue-maximizing toll could be determined. Figure 12 depicts the estimated revenue collected by toll rate in 2013 constant dollars.

Figure 12

Total Revenue – P3 Operating Period



Source: Office of the Parliamentary Budget Officer.

Note: The operating period of the P3 contract was assumed to be from 2021 to 2050.

The revenue-maximizing solution occurs at a toll of $9.10 in each direction.[35] At that price, total annual revenues would be approximately $356 million over the P3 operating period, with average daily traffic of 107 thousand vehicles equivalent to a diversion of 38 per cent of drivers (See Table 13 for a summary). Larger tolls would reduce the revenue generated.

It is unlikely that this revenue-maximizing toll would be implemented, as Government is not uniquely profit seeking. Other than covering an expected profit for the P3 consortium, it would aim to set the toll at a level that at most would cover costs. Such a toll would minimize diversion and maximize the benefit of the new bridge.

[35] Prices are in 2013 constant dollars. The PBO assumed that with electronic tolling it would not be difficult for tolls to increase annually with inflation, or at least increase sporadically to achieve the same effect.

Table 13

Simulated Traffic Flows at Revenue Maximizing Toll

Period	Montréal-bound	South shore-bound	Total
Night	4,700	2,700	7,400
AM peak	11,300	6,400	17,700
Day	21,900	20,700	42,600
PM peak	7,500	11,800	19,300
Evening	8,100	12,100	20,200
Total	**53,700**	**53,700**	**107,400**

Source: Parliamentary Budget Office calculations.

Results: Toll covers costs

Annex A provides a detailed breakdown of the operating and maintenance costs considered here. Costs in the first year of operation are estimated at $9.3 million with an additional variable component.

If the toll were set to cover only operating and maintenance costs, the toll required would be about $0.80. This price would cover annual operating and maintenance costs for the bridge during each year of the operating period. At this toll, the diversion from the new bridge would be approximately 1.35 per cent.

Table 14

Cost Recovery Toll Rates

Scenario	Toll	Total Revenue (Billions)	Traffic Diversion (%)
O&M only	$0.80	$1.5	1.4%
Construction, O&M	$1.40	$2.5	2.3%
$3B project cost, O&M	$2.60	$4.4	3.4%
$5B project cost, O&M	$3.90	$6.2	10.6%
Revenue-maximizing	$9.10	$10.7	37.9%

Source: Parliamentary Budget Office.

Note: Values in 2013 constant dollars.

The toll required to cover both the construction costs and operating and maintenance for a $1 billion bridge would be $1.40, and would cause a diversion of 2.3 per cent of total traffic. This cost estimate covers only the estimated direct costs and does not include indirect costs such as financing expenses and taxes, which can potentially be significant.

Any procurement method used to obtain the bridge is likely to include financing costs. This toll can be considered as a theoretical minimum, assuming that the toll price is set to cover the cost of the bridge. This toll would generate revenue equal to the direct cost of building and operating the bridge.

The Government has provided a design and construction cost estimate for the project of between $3 billion and $5 billion. This estimate included the design and construction of the bridge replacement as well as the approaches.[36] Including PBO's estimates of operations and maintenance, the cost recovery tolls based on the Government's broad estimates of $3 billion to $5 billion would be $2.60 to $3.90.[37] Table 14 provides additional details regarding diversion.

Figure 15 depicts the plausible range of tolls with an effective maximum and minimum represented by the revenue maximizing and the construction and operating and maintenance cost recovery tolls, respectively.

The cost recovery toll rates presented here are based on broad estimates of costs. There are currently a number of unknown variables, such as the financing costs faced by the P3 consortium.[38] Because of these

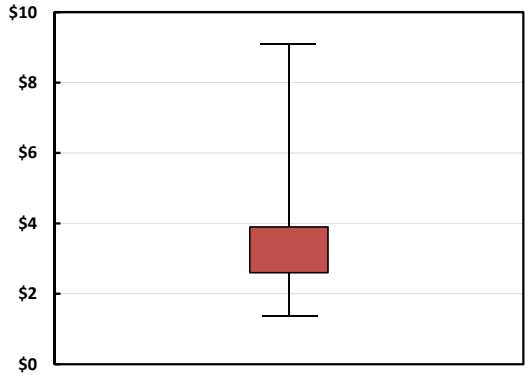
[36] This design and construction cost estimate is taken from the NBSL Business Case. The components of the estimate have been clarified through discussion with representatives at Transport Canada. This cost estimate was based on the pre-feasibility study conducted by the BCDE consortium. Retrieved September 2014.

[37] PBO also examined the tolls required to cover the Government's estimated total project cost under the assumption that there was no traffic diversion. Under this assumption the tolls required to cover the cost of the project ranged from $2.30 to $3.30 to cover a $3 to $5 billion project.

[38] The Conference Board of Canada notes that there are additional upfront costs to P3 procurement when compared with traditional procurement, including higher financing costs and higher transaction costs. However, these actual

Figure 15

Range of Cost Covering Tolls



Source: Office of the Parliamentary Budget Officer.

Note: Dollar amounts are in 2013 constant dollars. This chart does not show quartile values as in a usual box-and-whisker chart, rather it depicts a likely range of tolls, represented by the shaded box, as well as the effective maximum and minimum potential tolls, represented by the whiskers.

unknown values, the above tolls should be considered approximate.

With more details of the project's financing structure and the exact cost of construction, it is possible that a more accurate estimate of the toll could be generated.

Summary

As a source of revenue for the Government, tolls on the Champlain Bridge replacement have the potential to cover construction and operating and maintenance costs. There are a large number of potential tolling schedules, of which PBO examined only one, a flat toll.

Under this schedule, a flat toll of $1.40 (in 2013 dollars) would cover all direct costs related to the bridge only, with a minimum diversion of 2.3 per cent of total traffic.

Other tolling schedules could be created to minimize congestion, for example increased tolls during peak periods. Such schedules were not examined here.[39]

This analysis also determined a revenue maximizing toll of $9.10. This would result in significant adverse effects on traffic patterns, and would generate more revenue than required to meet project costs.

costs are offset by risk transfers from Government to the contractor. See Dispelling the Myths: A Pan-Canadian Assessment of Public-Private Partnerships for Infrastructure Investments. Retrieved June 2014.

[39] An example of perk period tolls are those implemented by the Port Authority of NY & NJ for the bridges between the states of New York and New Jersey.

Annex A
Detailed Methodology

Methodology: Data inputs

When considering traffic diversion, PBO assumed that the main consideration facing drivers was the added time of taking another route. This incorporated commuters' value of time and allowed for an objective measure of the difference between trips.

Data on trip time were obtained from the Google Maps Traffic application (Figure 1), providing data on trip length and distance under various historic traffic conditions.[40,41] PBO examined data for trips between 6 a.m. and 9 a.m. This time represented the average weekday morning commute for most drivers.

Trip times were obtained for trips across the St. Lawrence based on origins and destinations corresponding to the 2008 Origin-Destination Survey conducted by Agence métropolitaine de transport (AMT).[42,43] AMT origins and destinations were matched to either census subdivisions, as determined by the 2006 Census, or by City of Montréal arrondissement boundaries.[44,45]

Points of origin were taken as the latitude and longitude associated with the representative point (for census subdivisions) or shape centroid (for Montréal arrondissements) linked with each origin area.[46] In total 36 South Shore and 41 Montréal Island origin areas were considered.

Resulting times and distances were calculated for each possible bridge crossing. Those trips for which the existing Champlain Bridge was the optimal route were considered as base traffic for the replacement bridge. The difference in time and distance relative to alternate routes was compared.

The alternate routes considered were the Jacques Cartier Bridge, the Victoria Bridge, the Honoré-Mercier Bridge, or the Louis Hippolyte Lafontaine Tunnel.[47]

Methodology: Willingness to pay

To compare the incremental time difference of diverting to a toll, an estimate of the value that drivers place on their time was used. This was obtained from the concept of willingness to pay and through estimating commuters' reservation price, the maximum price that a given driver would be willing to pay to cross the bridge.[48] A driver's willingness to pay depends on the value that the driver places on the time saved by using the bridge,

[40] Google Blog: The bright side of sitting in traffic: Crowdsourcing road congestion data. Accessed June 2014.
[41] Google Maps Application
[42] AMT 2008 O-D Survey. Accessed June 2014.
[43] The trips examined consisted of origins and destinations between the South Shore and Montréal Island.
[44] Statistics Canada GeoSuite 2006, CSD Table. Retrieved June 2014.
[45] Arrondissements de la Ville de Montréal shape files retrieved June 2014. Arrondissement centriods were obtained from Google Earth and Earth Point
[46] For census subdivisions representative points and centroids are similar as they both indicate the geographic centre of a polygon. Representative points differ slightly in when the census subdivision area includes water.
[47] During the AM peak period the Victoria Bridge lane leaving Montréal Island reverses direction. Due to the configuration of the road network this results in two separate routes across the Victoria Bridge. For the purposes of this analysis the non-peak period route to Montréal Island was examined, and those routes leaving Montréal Island via the Victoria Bridge were excluded from the list of viable options.
[48] Breidert, C. (2006). Estimation of Willingness-To-Pay: Theory, Measurement, Application. Deutscher Universitats-Verlag.

which is dependent on the individual's value of time.[49]

Value of time in theory depends on a number of factors, primarily wealth, income, purpose of the trip and mode of transportation.[50] For the purpose of this analysis, PBO examined trips taken during the morning peak period, which is primarily composed of commutes to work, and correspondingly the value of time was taken as equal to an individual's total income.[51,52] Together with the actual cost of the trip, measured as cost of gas over the given distance, individual travel cost for each route was obtained with the following formula:

$$X_{i,j,k,m,r} = d_{i,j,m} \cdot p + t_{i,j,m,r} \cdot v_k$$

Where d is distance, p is price of gas, t is time duration of the trip, and v is the individual's value of time. The subscripts i, j, k, m and r correspond to the origin, destination, income group, route choice and toll rate, respectively (Figure 2).[53,54]

Total income distribution data were obtained from the 2006 Census, split by census subdivision.[55,56,57] Under the assumption that incomes were evenly distributed across Champlain Bridge commuters, the number of bridge commuters by income group and origin was obtained. Commuters were divided into 26 separate income groups.

The time duration variable, $t_{i,j,m,r}$, was determined by a combination of the trip time between an origin-destination pairing and the added congestion as a result of the toll. To account for this the number of drivers that divert for a slightly lower toll was used to calculate the congestion, using:

$$t_{i,j,m,r} = G_{i,j,m} + \mu_{i,j,m,r-1} \cdot C_{i,j,m}$$

Where G is the base trip time determined by Google Maps, μ is the number of commuters that divert to another route at a given toll, and C is the congestion factor for the given route.

The price of gas was taken as the April 2014 Montréal average price of gas. The fuel consumption of the 2006 Honda Civic was used to determine a willingness to pay of 11 cents per kilometer of distance saved by using the new bridge.[58,59,60,61]

On the basis of the above calculation the best alternative route was determined according to the incremental minimum cost:

$$X_{i,j,k} = Min(X_{i,j,k,1}, \dots, X_{i,j,k,4}) - X_{i,j,k,0}$$

Here, $X_{i,j,k,0}$ represents the cost of taking the Champlain Bridge. The result of these calculations is was a 786 X 26 matrix of reservation prices for each origin-destination pairing and income

[49] Crozet, Y. (2005) Time and Passenger Transport. OECD European Conference of Ministers of Transport, Round Table 127.
[50] ibid
[51] AM peak period refers to the three hour period from 6AM to 9AM corresponding to many commuters' trip to work.
[52] The measure of income used in this analysis is before tax income.
[53] Crozet, Y. (2005) Time and Passenger Transport. OECD European Conference of Ministers of Transport, Round Table 127.
[54] Incremental cost of vehicle maintenance was excluded.
[55] Statistics Canada, 2006 Census of Population, Statistics Canada catalogue no. 94-581-XCB2006001. Retrieved June 2014.
[56] Income data was inflated to 2013 dollars using Table 380-0072 Current and capital accounts - Primary household income. Retrieved June 2014.
[57] Incomes were further divided within income groups by applying the income distribution for Montréal found in Statistics Canada Table 202-0402.
[58] Kent Marketing Services. Retrieved May 2014.
[59] 2006 Honda Civic fuel consumption. Retrieved June 2014.
[60] The Honda Civic was the best-selling car for the past 16 years.
[61] Based on the terminated Canadian vehicle survey the average age of a car up to 2009 was 8 years. See CANSIM Table 405-0045. Accessed June 2014.

group. The diversion from the Champlain Bridge for a given toll was calculated using the Hadamard product of the above matrix and the binary matrix defined by the below piecewise function:

$$D_{i,j,k}^{T} = \begin{cases} 0, & if\ T < X_{i,j,k} \\ 1, & if\ T \geq X_{i,j,k} \end{cases}$$

Where T is the toll rate, and D represents the decision to divert or to pay the toll, with 1 representing the choice to divert. The sum of the elements of the resulting matrix is the total diversion for a given toll.

Methodology: Increased alternative route congestion

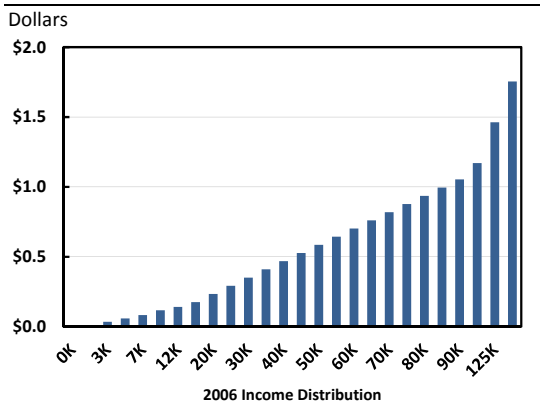
As mentioned above, using the AMT 2008 O-D survey, a reservation price was determined for all Champlain Bridge commuters by calculating the incremental time saved by using the Champlain Bridge when compared to the next best route.[62] Figure A1 shows the reservation price by income for commuting time savings of a minute.[63]

Tolls set above a commuter's reservation price will induce diversion. Any traffic diversion from the replacement bridge will increase congestion on alternative routes. As a result, some drivers who regularly take an alternate route will want to avoid this congestion and are willing to pay. Some of these drivers will then choose to divert to the new bridge provided that the toll is low and it is not too inconvenient a route.

This diversion and replacement can be expected to take place over time and then reach equilibrium. This PBO analysis examines the medium-term period, after this adjustment occurs.

Figure A1

Reservation Price by Income, per minute



Source: Office of the Parliamentary Budget Officer.

Further, PBO assumed that there was no excess capacity on any of the alternative routes and modelled each alternative route with traffic at full capacity.[64]

Utilizing a theoretical capacity flow of 2,000 vehicles per lane per hour and an inferred average speed based on trip duration, PBO estimated the incremental time delay for each additional vehicle above the capacity per origin-destination pairing.[65,66,67] Congestion was assumed to occur over the distance of the trip, rather than only over the constrained bridge portion.[68]

[62] The PBO assumed one passenger per vehicle.

[63] This figure ignores distance and congestion calculations, which vary by origin-destination pairing and route choice.

[64] In this model full capacity represents the threshold at which, beyond this point, traffic begins to slow considerably and exhibit stop-start patterns of movement. This model uses linear interpolation to approximate the difficult to model traffic that is beyond capacity. Traffic below capacity is considered in this model to exhibit no change in traffic speeds when compared to full capacity.

[65] McMaster Institute for Transportation & Logistics (2011). Champlain Bridge Montréal Impacts of Disruptions to Bridge Capacity. Retrieved June 2014.

[66] The theoretical free flow capacity spans 1,800 to 2,400 vehicles per lane per hour with 2,000 being a commonly used point estimate. See Traffic Flow Theory and Note 33. The PBO estimated, using linear interpolation, that as more vehicles divert to alternative routes there will be an incremental time delay per car due to the reduced speed when crossing the bridge.

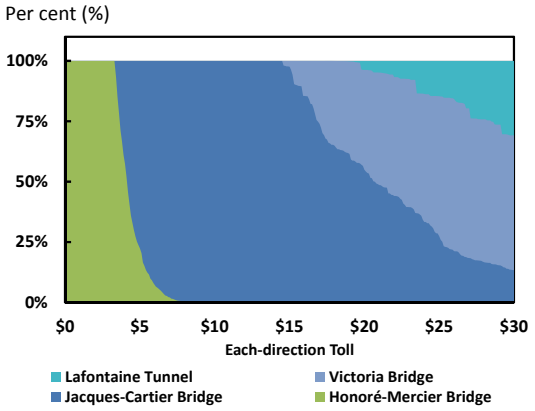
[67] Inferred average speeds were obtained from Google Maps data relaying time (in minutes) and distance (in kilometers) to travel from a specific origin to a specific destination.

[68] While this is an overly conservative assumption, as the congestion incurred by additional bridge commuters would only occur at constrained portions of a trip, it is difficult to

The added congestion as a result of diversion has the result of inducing some commuters to divert to the new bridge, according to their willingness to pay. Those commuters willing to divert from an un-tolled bridge to a tolled one represent high-income individuals who value reliable travel time and are willing to pay.[69]

Figure A2

Diversion Replacement – To Montréal



Source: Office of the Parliamentary Budget Officer.

PBO assumed that the total diversion to the new bridge would not be greater than the number who divert away from the bridge. The result is that, at low tolls, those leaving the new bridge will be replaced by those wishing to take it. Figures A2 and A3 depict the replacement of those unwilling to pay a given toll by those who are, by route.

For the majority of alternate routes, commuters are willing to replace those who divert from the new bridge, with the Honoré-Mercier Bridge being the exception. For many commuters, the Honoré-Mercier is the alternate route of choice. Beyond a toll of $3.30 when heading to Montréal Island, and a toll of $7.90 heading away, diversion to the Honoré-Mercier increases substantially.

determine exactly where this congestion will take place, as it can be different for each separate origin-destination pairing.

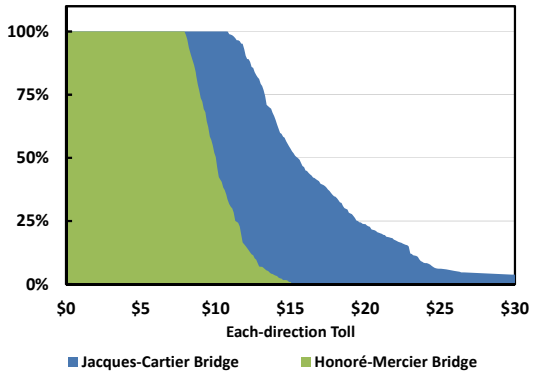
[69] As this model examines a period after adjustments have settled, this model assumed that no more commuters will divert to the NBSL than the number diverting away.

Methodology: Approximate cost of bridge

The toll revenue will at least partly serve to cover some of the cost of the new bridge.[70] To obtain an estimate of the portion of the cost likely to be covered by the toll, PBO estimated the operating and maintenance (O&M) costs of the new bridge. For the purpose of this analysis, PBO accepted Consortium BCDE`s bridge construction cost estimate of $1.12 billion.[71]

Figure A3

Diversion Replacement – From Montréal



Source: Office of the Parliamentary Budget Officer.

Further, the Government has broadly estimated that the project design and construction will cost in total $3 billion to $5 billion.[72] These two total cost scenarios were also investigated.

PBO investigated the required tolls for three scenarios:

- Toll must cover annual O&M costs
- Toll must cover annual O&M costs and Consortium BCDE's construction costs

[70] Stephen Harper on the Champlain Bridge, April 29, 2014.

[71] The total construction cost of the new bridge was estimated to be $1.28 billion (2010 dollars) by the Consortium BCDE in the Pre-feasibility Study Concerning the Replacement of the Existing Champlain Bridge. Their cost estimate involved both preparatory and post-construction work that was eventually left out of the P3 project scope. The remaining in-scope work amounted to $1.06 billion, which was inflated at two per cent to $1.12 billion in 2013 dollars.

[72] Infrastructure Canada's broad estimate of NBSL project cost. Retrieved June 2014.

- Toll must cover annual O&M and the Government's project design and construction costs.

In estimating O&M costs, PBO relied on historical Jacques Cartier and Champlain Bridges Inc. (JCCBI) data, as well as estimates related to similar projects in the Tappan Zee Bridge (TZB) in New York State and the Golden Ears Bridge in British Columbia (See Box A1).

O&M was divided into four categories:

- Regular maintenance
- Repair
- Regular operations
- Tolling operations

Regular maintenance and regular operation costs were estimated from financial information obtained from JCCBI. Regular operations costs were assumed to not increase over time and PBO calculated the 10-year average operation costs for JCCBI as approximately $1.5 million.[73]

Historic regular maintenance costs for the existing Champlain Bridge were provided to PBO by JCCBI. PBO calculations estimated annual regular maintenance costs of $2 million, with an average annual real growth of 1.96 per cent.[74]

Tolling operations data were obtained from financial documents for the Golden Ears Bridge.[75] Annual tolling costs were taken as a $2.8 million fixed cost and a 50 cent variable fee per vehicle.

Box A1

Similar Bridges

The Tappan Zee Bridge (TZB) crosses the Hudson River in New York State and suffers peak period congestion pressures, as well as an increasing repair bill. As a component of the I-287 highway, the TZB is a part of the network that serves New York City (NYC) and New Jersey. The two nearest alternative routes across the Hudson are the George Washington Bridge in NYC, and the Bear Mountain Bridge further upstream. All are toll bridges.

The Golden Ears Bridge (GEB) is a toll bridge in British Columbia completed in 2009 connecting Surrey and Langley to Maple Ridge. Early traffic has been less than forecasted, but the addition of a toll to the nearby Port Mann Bridge has created a more constrained traffic system. As a result, GEB traffic has been increasing.

Sources: Governor's I-287 Task Force. (2000). Long Terms Needs Assessment and Alternatives Assessment: I-287/ Tappan Zee Bridge Corridor.
Translink. (2011). Statutory Annual Report.
Translink. (2013). Statutory Annual Report.

Repair cost estimates were determined based on observations for the TZB that repair costs doubled in nominal terms every 10 years. This corresponded to a real annual average growth rate of 4.1 per cent. Base level annual repairs costs were taken as equal to the annual regular maintenance of approximately $2 million.

[73] Financial data obtained from JCCBI as well as corporate annual reports. Regular maintenance costs were subtracted from O&M expenses and an assumed 70 per cent of remaining costs were attributed to the Champlain Bridge. The average over from 2002 to 2012 resulted in an average operating cost of $1,465,920. JCCBI Corporate reports retrieved June 2014.

[74] Costs were deflated using CANSIM Table 327-0043: Price indexes of non-residential building construction in Montréal Quebec.

[75] South Coast British Columbia Transportation Authority 2013 Statutory Annual Report Accessed June 2014.

Annex B
Results Comparisons and Sensitivity Results

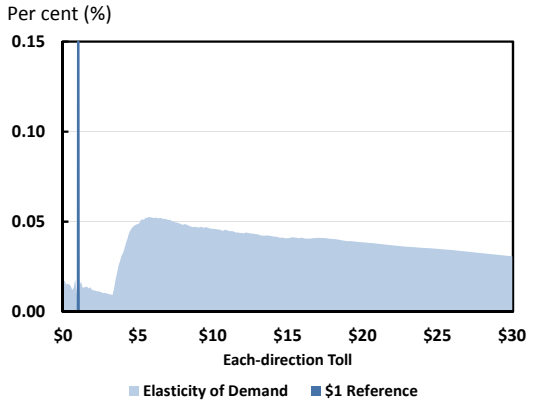
Result comparison: Elasticity

The calculation of traffic diversion allowed for the computation of demand elasticities at different toll rates. Using a reference toll of one dollar, Figure B1 depicts the price elasticity of demand.

The derived price elasticities range from 0.01 to 0.02 for tolls below $3 and between 0.03 and 0.05 for tolls above $5. See Box B1 for a discussion of price elasticity of demand.

Figure B1

NBSL Elasticity of Demand



Source: Office of the Parliamentary Budget Officer.

For comparison, there is evidence of price elasticity to toll changes in New York City for passenger cars in the range of 0.03 to 0.50.[76] In general, there is evidence to suggest that toll bridge price elasticities range between 0.15 and 0.310.[77]

A similarly constrained bridge is the Tappan Zee Bridge in New York State. Like the Champlain Bridge, the TZB is scheduled for replacement.[78] Many drivers use either the TZB or the George Washington Bridge as part of their daily commute.

Box B1

Price Elasticity of Demand

Price elasticity of demand (PED) measures the percentage change in the quantity demand of a good or service in response to a percentage increase in price. For example, a PED with respect to a bridge toll of 0.02 means that a 100 per cent increase in the toll corresponds to a 2 per cent decrease in bridge transit demanded. PED is determined by:

$$PED = \frac{-\Delta T/T}{\Delta P/P}$$

Where,

T= travel demanded;
ΔT= change in travel demanded resulting from a price change;
P= price of travel;
ΔP= change in price of travel.

Characterization of PED is as follows:

Characterization	PED
Perfectly inelastic	0
Inelastic	0<PED<1
Unit elasticity	1
Elastic	PED>1

Source: Office of the Parliamentary Budget Officer, Litman, T. (2013) Understanding Transport Demands and Elasticities: How Prices and Other Factors Affect Travel Behaviour, Victoria Transport Policy Institute. Retrieved June 2014.

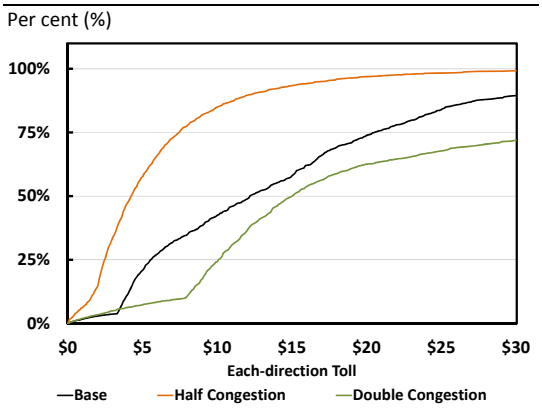
[76] Hirschman, I., McKnight, C., Pucher, J., Paaswell, R., Berechman, J. (1995). Bridge and tunnel toll elasticities in New York: Some recent evidence. Transportation (22). pp. 97-113. Relevant table retrieved June 2014.

[77] Burris, M. W. (2003). The toll-price component of travel demand elasticity. International Journal of Transport Economics. 30 (1), pp. 45-59. Retrieved June 2014.

[78] The New NY Bridge. Accessed June 2014.

Figure B2

AM Peak Diversion – Varying Congestion

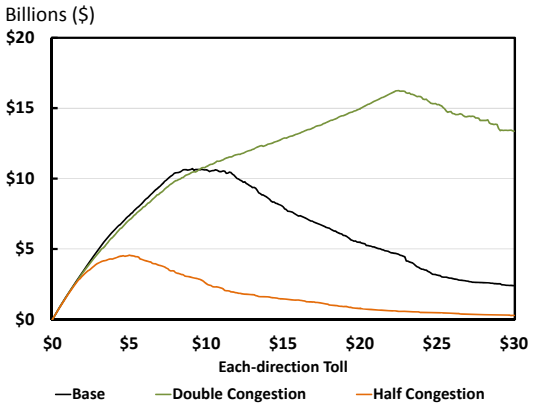


Source: Office of the Parliamentary Budget Officer.

According to traffic diversion documents published as a part of the new bridge planning process the expected elasticity of traffic on the TZB replacement is approximately 0.04.[79] This result is in rough agreement with the elasticities for the Champlain Bridge replacement obtained with the PBO model.

Figure B3

Total Revenue – Varying Congestion



Source: Office of the Parliamentary Budget Officer.

Note: The operation period of the P3 contract was assumed to be from 2021 to 2050.

Determinants of elasticity vary by individual and can include trip purpose, income, number and type of alternatives, and destinations.[80] To be conservative, PBO examined a period where the majority of road travelers are commuting for work. Work-related trips tend to have lower elasticity than those trips taken for other purposes.[81]

As the distribution of work-related trips is concentrated in on-peak time periods, there is a possibility that traffic diversion during off-peak travel times could be greater than that assumed in this report.

Model validation: Congestion sensitivity

The above model is reliant on an estimate of incremental congestion incurred by vehicles diverting from the Champlain Bridge replacement to an alternate route. To determine the effects of a change to this congestion assumption, PBO examined models of congestion that are double and one-half the congestion assumed above. The results are presented below.

At double congestion, the number of vehicles willing to divert from the new bridge decreases, owing to the decreased willingness to incur additional congestion. At this congestion, increased diversion from the new bridge during the morning peak period would begin at a toll of $8.00, compared with $3.40 in the base case, and $0.10 in the half congestion scenario (see Figure B2).

The resulting revenue from these varying assumptions is shown in Figure B3. Revenue maximization in the double-congestion scenario occurs at a toll of $22.50

[79] The NY Bridge Toll Diversion Analysis. Accessed June 2014. The PBO assumed a $15 PANYNJ bridge toll in 2017.

[80] Litman, T. (2013) Understanding Transport Demands and Elasticities: How Prices and Other Factors Affect Travel Behaviour. Victoria Transport Policy Institute. Retrieved June 2014.

[81] Gunn, H.F., Tuinenga, J.G., Allouche, J.F. and Debrincat, L. (1998). ANTONIN: A forecasting model for travel demand in the Ile de France. Transport Planning Methods, Volume II, European Transport Conference, Proceedings of Seminar E, P424. pp. 99-121. Relevant table retrieved June 2014.

compared with a base-scenario toll of $9.10. The revenue-maximizing scenario for half congestion is $5.00.

To cover the cost of a $3-billion bridge as well as operations and maintenance over the operating period, the double-congestion case would again require a toll of $2.60. However the estimated diversion increases from 3.4 per cent to 4.3 per cent when compared with the base case. In the half-congestion case, a $3.1 toll would be required, resulting in a diversion of 34.8 per cent of total traffic.

When covering the cost of a $5-billion bridge, the base case and double-congestion case remain similar with tolls of $3.90 and $4.20 respectively. However, with the half-congestion case, the revenue maximizing toll of $5.00 is insufficient to cover the cost of the project.

Table B4

Revenue Maximizing Toll Rates

Congestion Scenario	Toll	Total Revenue (Billions)	Traffic Diversion (%)
Half	$5.00	$4.6	57.6%
Base	$9.10	$10.7	38.9%
Double	$22.50	$16.2	64.9%

Source: Parliamentary Budget Office.

Note: Values in 2013 constant dollars.

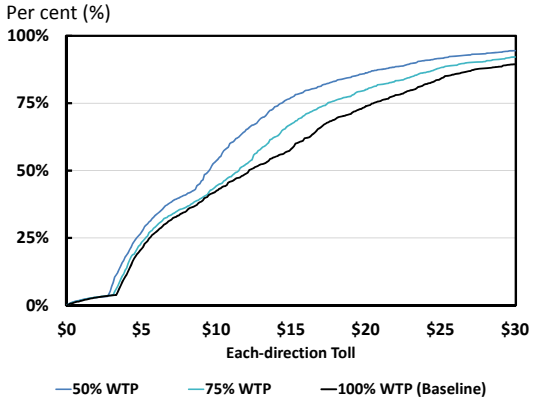
Table B4 provides added detail to the analysis. In higher levels of congestion, more revenue can be raised as drivers are unwilling to divert from the new bridge. At lower levels, the lack of congestion on alternative bridges is enough for commuters to divert. In both of the revenue maximizing scenarios examined, the diversion from the new bridge would more than half the total ridership of the bridge, leading to high levels of congestion on alternative routes.

Model validation: Value of time sensitivity

As noted in the methodology, an individual's value of time depends on a number of factors and can vary depending on trip purpose and mode of transportation. To determine the sensitivity of the model to various values of time, PBO adjusted the assumed willingness to pay (WTP) per minute of time saved. The report presented a WTP of 100 per cent of income. Scenarios of 50 per cent and 75 per cent are examined here.[82,83]

Figure B5

WTP Sensitivity – Total Diversion



Source: Office of the Parliamentary Budget Officer.

Reducing WTP in relation to income resulted in an increase of diversion away from the replacement bridge at low toll rates. However the low toll rates also induced replacement from other routes, with a net effect that did not differ much from the baseline scenario. As the toll increased, diversion also increased, inversely proportional to WTP (See Figure B5).

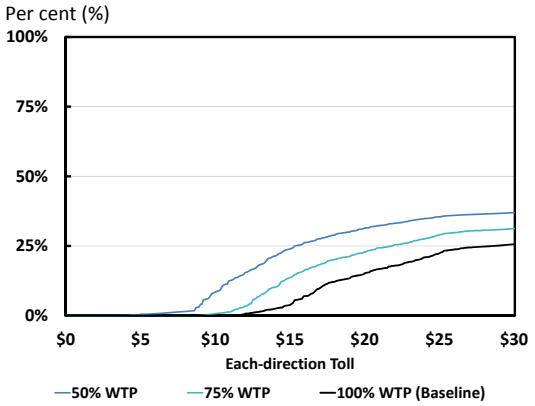
As shown in Figures B6 and B7, diversion was mostly directed to the Jacques Cartier

[82] Conventional estimates place an individual's value of between 50 and 100 per cent of income. See Crozet, Y. (2005) Time and Passenger Transport. OECD European Conference of Ministers of Transport, Round Table 127.
[83] Small, Winston, and Yan. (2005). Uncovering the Distribution of Motorists' Preferences for Travel Time Reliability. Econometrica, 2005 (12).

Bridge, with the other alternate routes exhibiting less change.

Figure B6

WTP – Diversion to Jacques Cartier

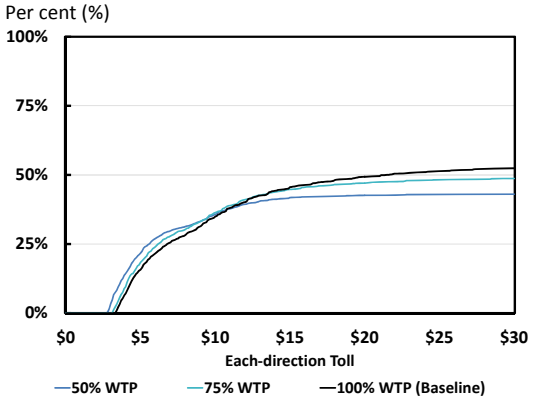


Source: Office of the Parliamentary Budget Officer.

The impact of different WTP ratios on overall revenue is presented in Figure B8. As net diversion is similar at low toll rates for all three scenarios, there is little difference in total revenues. At higher tolls there are greater variances in revenue forecasts. However, in general these tolls are more than the revenue maximizing toll and PBO assumed that they are unlikely to be implemented.

Figure B7

WTP – Diversion to Honoré-Mercier



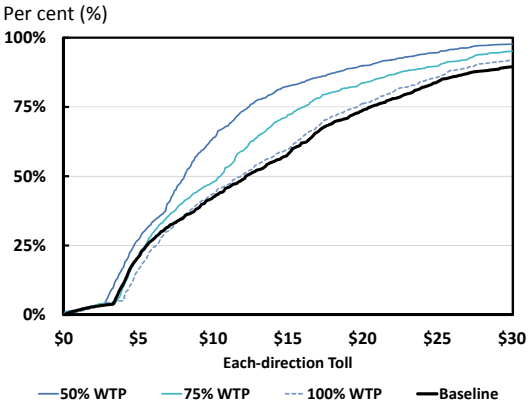
Source: Office of the Parliamentary Budget Officer.

Model validation: Income distribution sensitivity

PBO assumed that the income distribution of those crossing the new bridge would be similar to that of residents of the origin location. This is a simplifying assumption in the absence of more detailed information. It is possible that in general, those crossing the bridge are individuals who work on Montréal Island. To account for this, PBO re-examined the model and the WTP sensitivity analysis using only individuals earning more than $25,000.[84]

Figure B8

Income – Total Diversion



Source: Office of the Parliamentary Budget Officer.

Figure B9 depicts the total diversion from the new bridge compared with a baseline that includes all incomes. In comparing the two 100 per cent WTP scenarios (Baseline and 100% WTP), there is little difference in diversion. This is a result of diversion replacement from other bridges.

In the baseline scenario, those at low incomes are diverting at very low tolls, and are being replaced by those drivers from other routes willing to pay the toll on the new bridge. In the scenario with a truncated income distribution, very few drivers divert at low tolls and so are not replaced. As the toll increases, more drivers

[84] 2013 dollars.

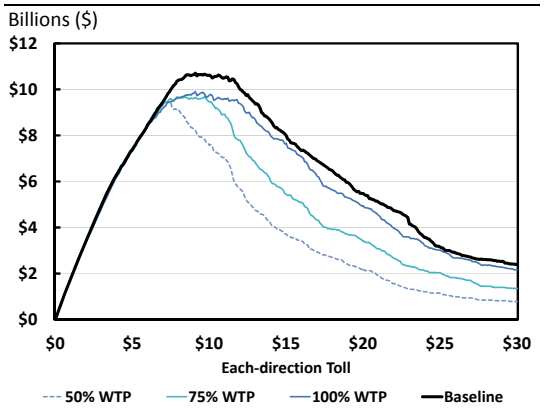
divert, but because of the higher toll, fewer are replaced.

The 50 per cent and 75 per cent WTP scenarios are roughly equivalent to the 50 and 75 per cent WTP scenarios examined above.

Figure B9 depicts the total revenue projected under the truncated income distribution scenario. Again, at low tolls there is little difference between the various scenarios, and differences can be observed only at high toll rates.

Figure B9

Income – Total Revenue



Source: Office of the Parliamentary Budget Officer.

Annex C
Assumptions

1. **Those commuters surveyed in the AMT Origin-Destination survey exhibit the same traffic behaviour as those drivers who take the Champlain replacement bridge.**
   — This assumption is required for the use of the AMT O-D survey as a dataset.

2. **That truck drivers exhibit the same behaviour as car drivers.**
   — There is evidence that truck drivers have a higher price elasticity of demand in response to tolls than other drivers. Some trucking companies demand that truck drivers take routes that do not have tolls. However, based on the very low elasticity estimates for Montréal, indicating that the traffic system is very constrained, it was decided to model truck traffic the same as car traffic.

3. **That morning peak period traffic diversion in the last congested direction is similar to afternoon peak period traffic diversion in the opposite direction, and also similar to non-peak period diversion in either direction.**
   — This is a simplifying assumption. As the data collected only cover the peak morning period, estimates derived from this period were extrapolated to other periods for the purpose of obtaining revenue estimates. A more exhaustive study could overcome the requirement of this assumption.

4. **That the 2006 Census subdivision income distributions are the same as those commuters that take the new bridge.**
   — We examine the impact of changing this assumption in the sensitivity analysis and find that at plausible tolls, the impact of this assumption is negligible.

5. **That all incomes have grown proportionally equal since 2006. (That there has been no shift in income distribution).**
   — This analysis examined income data at the census subdivision (CSD) level. However, income data at this detailed level of examination were not available for all Montréal CSDs from the 2011 National Household Survey. Therefore, income data from the 2006 Census were used. This study assumes that the income distribution has remained constant.

6. **That commuters, before the implementation of a toll, will take the shortest route available to them, as determined by Google Maps data.**
   — We do not know what route an individual will actually take and so an assumption is required to determine which route they are likely to take.

7. **Commuters' willingness to pay is 100% of their income per minute.**
   — This assumption is examined in further detail in the sensitivity analysis.

8. **That Google Maps travel distances and times are a good measure of actual time and distance in Montréal.**
   — Google Map data are derived from actual trips as measured from mobile phones using satellites, likely making them an accurate measure of trip duration. The sensitivity to this assumption is tested in Annex B using willingness to pay as a proxy.

9. **That as the new bridge experiences diversion, traffic will head to the second best bridge for commuters as measured by a combination of distance and time. Also that the diversion from alternate routes will choose the new bridge as their second best bridge.**
   — Under the assumption that commuters select their preferred route using this same criteria, it is plausible that the next best route is also selected using this criteria. That commuters diverting from alternate routes would automatically choose the new bridge is plausible, as all alternative routes other than the new bridge would also be experiencing increased congestion as a result of traffic diverting from the new bridge.

10. **That the toll will be raised over time to maintain 2013 constant prices.**
   — Without added information on the intended structure of the toll, to make any other assumption would complicate the analysis unnecessarily. While constant real prices may not be observed exactly in practice, some form could be likely (e.g. intermittent price increases that achieve the same total revenue as annual increases).

11. **An added car to the bridge will incrementally add to the length of the entire trip for each commuter.**
   — This assumption was necessary to simplify the analysis. While Google Maps provides indirect information on the present state of congestion on the roads, that information could not be used to predict the incremental increase in congestion as a result of vehicles added to a specific route. While more advanced modelling software would be able to estimate these impacts, the current analysis could not. The source of the congestion is the bridges, and their approaches, which serve as bottlenecks to traffic flow. However, it was difficult to determine the point in a commuter's trip at which they begin to experience congestion, so a conservative and simplifying assumption is that they will experience congestion over the entire length of the trip.

12. **That at a base level, all the bridges are operating at free-flow capacity.**
   — There is anecdotal evidence to suggest that Montréal-bound peak morning traffic operates beyond free-flow capacity. This assumption again simplifies analysis.

13. **That at free-flow capacity, a reduction of cars on the bridge is still at free-flow. It is only beyond capacity that there is a reduction in speed.**
   — This is related to the assumption above. This analysis treats free flow as a constant state at which there is little change in travel duration. Traffic that is beyond free-flow, however, is not treated as constant, as it enters a stop-start pattern that adversely affects trip duration.

14. **That cars added to a bridge at free-flow capacity will slow the traffic on the bridge in a linear fashion. Beyond free-flow capacity, traffic exhibits stop/start chaos that is difficult to model.**
    — Traffic that is not in free flow is difficult to model as there is a stop-start pattern to traffic that is unpredictable with simple models. To simplify the analysis, we assume here that the increase in travel time with an increase in congestion is linearly related to the increase in cars on the road. While a linear relationship is unlikely to be observed, the direction of the relationship is correct and the linear relationship is easy to model.

15. **That the traffic forecasts created by Consortium BCDE for the new bridge are accurate.**
    — The traffic forecasts created by Consortium BCDE were created using traffic forecasts from before the financial crisis. Traffic from this period appears to represent the maximum capacity for the bridge. Recently there has been a downturn in traffic as a result of the financial crisis, but current levels of traffic should not be expected to persist for the next 30 years. In light of this, the Consortium BCDE's traffic forecasts appear to be at least credible.

16. **That commuters will decide to divert from the new bridge based only on willingness to pay, not on other behavioural habits or characteristics.**
    — This is another simplifying assumption. There are many characteristics and values that drive an individual's decision making other than simply money. Factors such as habit, safety concerns and pleasure of driving experience can also play a role. In this analysis we ignore such considerations and model individuals as dispassionate economic decision makers.

17. **That more people will divert from the new bridge than will divert to it as a result of added congestion.**
    — This analysis models diversion as a two-step process: 1) individuals choose whether to divert from the new bridge, and 2) as a result of this diversion other drivers choose whether to divert to the new bridge. A more complex model would involve recursive iterations until the system would reach equilibrium. To mimic this approach, the maximum number of diversions to the new bridge is limited by the number of diversions away. This approach approximates the medium-term solution where equilibrium is reached.