Welfare Costs of Border Delays: Numerical Calculations from a Canadian Regional Trade Model*

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Canada's biggest trading partner is the neighbouring United States which traditionally accounts for over three quarters of its exports and half of its imports. With such an order of magnitude, the Canada-US bilateral trade continues to rank high in both volumes (about a billion dollars per minute) and political context even in the presence of trade disputes and frictions over softwood lumber and various contestable agriculture products. Trade and security concerns dominate negotiation agendas between the two countries.

This paper provides a quantitative assessment of the welfare costs of border delays such as those that might occur as a result of post 9/11 security measures. Even though a number of measures have been taken since 2001 to mitigate the effects of increased security, indications are that, especially for Canada-US border

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crossings, the situation is still of significant concern.[1] Although bilateral trade with the United States still tops the priority list, we widen our scope to consider border delays in trade with the rest of the world. This is sensible since border security has more or less become a global issue. Outside the United States, a number of countries such as Britain, Spain, Turkey, and Indonesia have experienced terrorist attacks and as a result, many countries have tightened border security as a precautionary measure.

We investigate the regional and sectoral consequences of time delays arising from tightened security as well as congestion at inadequate border-crossing facilities (e.g., Windsor-Detroit bridge/tunnel). We also make some illustrative simulations related to border security measures and services trade including tourism and travel. Tourism has lately become an issue of interest as stringent travel document requirements recently passed by the US Congress raise fear of business downturns for border towns and travel industries on both sides of the border.

The focus of this paper is on the provincial and sectoral distribution of the welfare costs arising from border delays. We model these using a variant of BMRT (Basic Model of Regional Trade) – a computable general equilibrium (CGE) model of regional trade for Canada. We will crudely model both the private and public burdens of increased security. This incidence of burden of cost is similar to the distinction made by Brück (2005) between private costs associated with increased security (e.g., higher cost of passports or waiting time) and public costs of administering and enforcing the border (e.g., more guards, new scanning technology).

Our results, though still preliminary, indicate that the issue of border delays is extremely important to Canada, and worth further investigations. The modeling approach outlined in this paper suggests a venue to quantify the welfare costs of these border delays in a regional context. Despite that BMRT is essentially a Canadian model designed to address issues of interest to Canadians, we believe that our work can help serve as a starting point for further research on similar issues of welfare costs on the US side of the border.

The plan of the remaining of the paper is as follows. In the next section, we briefly survey the small but growing literature on border delays, and trade. Then, we provide a short summary of the CREAP (Canadian Regional Economic Analysis Project) benchmark-equilibrium data set and its companion numerical model BMRT. The following section describes how our regional model needs to be modified to include the added resource costs from border delays. This is followed by a discussion of some difficulties and challenges in data collection and adaptation. Then, we provide some preliminary simulation results. The paper ends with a summary and conclusions. The Appendix contains a brief description of the analytical structure of the model.

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1. The Globe and Mail, a Canadian newspaper ran a series about border delay and security issues in April-May of 2008. The conclusion was that delays had returned to levels broadly similar to those in late 2001. See Manley (2008) and McKenna (2008) for examples.

Literature Review

The early literature on border delays and trade liberalization (Cudmore and Whalley 2005) focuses on issues faced by developing and transition countries in a pre-9/11 context such as excessive delays in customs clearance for bureaucratic and bribe-seeking purposes. These issues are however quite different from recent experiences of security-driven delays occurred at the Canada-US border as documented by various government and private agencies such as Ontario Chamber of Commerce (2004, 2005, 2006), Canada Border Services Agency (2009), Canada-US-Ontario-Michigan Border Transportation Partnership (2004), Canadian Manufacturers and Exporters (2005), and Canadian Centre for Pollution Prevention (2005). These documents provide useful background information to our study.

In a recent study based on the Québec provincial input-output model and extraneous trucking cost data, Martin et al (2005, 2006a,b) estimate that border delays could cost truckers, on average, about 32 minutes per shipment which translates into about C$290 million per year for Canadian exporters. Since these cost estimates apply to truckers only, they can be best viewed as a lower bound for the actual costs of border delays. Other potential economic costs on business travels and tourism remain to be investigated.

Looking at the situation from a global point of view, Bergeijk (2006) reviews recent theoretical and empirical studies on the impact of transnational terrorism on trade for a number of countries, and suggests that more attention be given to the interdependence of trade and security in both theory and policy.

On a worldwide basis, Walkenhorst and Dihel (2006) cite earlier studies which estimate that while the pre-9/11 frictional costs (e.g., paperwork, time and other compliance costs) normally associated with border crossing amount to 5-13 % of the value of traded goods, the additional post-9/11 frictional and security costs could raise an extra amount of 1-3 % of the value of goods. In their simulation based on the GTAP global trade model (Hertel 1997), they consider the following counter-factual scenarios for ten regions and ten sectors:[2]

- Transportation costs of all goods are uniformly increased by 1 % of the original value of traded goods,
- Transportation costs of all goods are uniformly increased by 2.5 % of the original value of traded goods,
- Other runs where the rates applied still average 1 %, but the relative height of costs depends on the mode of travel and the regions in question.

2. The ten regions include Western Europe, Eastern Europe, North Africa and Middle East, Sub-Saharan Africa, Oceania, North Asia, South Asia, North America, Latin America, and Rest of the World. The ten sectors include agriculture, mining, food, textiles and leather, wood and paper, chemicals, non-metallic minerals, basic metals, machinery, and other manufacturing and services.

Their results show that under scenario (i), the welfare cost of worldwide heightened border security, calculated in terms of Hicksian equivalent variations, could be about US$75 billion per year – about 0.7 % of the world gross national product.

In an analytical vein, Huang and Whalley (2008) suggest that the adverse effects of border delays could be more than just the time delay costs which are usually calculated. Using the inventory-theoretic approach to the theory of demand for money (in which consumers balance money holdings against frequent trips to banks), they argue that, in the presence of costly border delays, importers tend to hold larger inventories to guard against the risk of being out of stock. In the simple case with certainty in border delays, the social cost of border delays are twice the time delay costs, i.e., the additional inventory costs equal the time delay costs. In case of uncertainty in border delays, for a given average delay, the added inventory costs tend to increase with the variance of the delays.

Basic Framework

This section gives a short summary of the basic framework of the CREAP benchmark data set and its companion BMRT numerical model (see Nguyen et al (2007a, b) for details). This package provides a starting point for our modeling work on border delays from a Canadian perspective.

CREAP Data

The CREAP data set used here is based on the 1998 S-level provincial input-output (IO) table compiled by the IO Division of Statistics Canada. These raw data from Statistics Canada contain missing values in suppressed cells and need to be balanced to produce a benchmark micro-consistent data set satisfying the usual zero profit and market equilibrium conditions. In particular, the IO matrix is rectangular which means that each sector can produce a vector of outputs (multi-product) instead of the usual single-product case as in most CGE models with squared data.

The data set provides a numerical snapshot of Canada as a small open regional economy with 10 provinces, 25 sectors, and 56 aggregate commodities. In addition, there are sufficient details on emission, energy, taxes, and trade to explore various policy issues on the environment, public finance, agriculture, and trade.

BMRT Model

The BMRT model is a static provincial CGE model of Canada. All productive sectors have nested CES/CET[3] production functions with intermediate goods and constant returns to scale. The model features perfect competition in all markets and multi-product technology in all sectors. Produced outputs are differentiated between those destined for the own province and those destined for other markets. There is interprovincial trade as well as international trade. Domestic and imported products are considered to be imperfect substitutes (i.e., Armington goods (1969)). Each province has a representative household which receives all income and tax revenues (local, provincial and federal) collected in the province. Households can choose between labour and leisure based on incomes, the cost of goods and the price of leisure, which is dependent on, among other things, direct taxation of labour income.

The model includes exports and imports to and from the rest of world. The export activities use 'inputs' of provincial exports and produce 'outputs' of foreign exchange. Similarly, the import activities take 'inputs' of foreign exchange and produce 'outputs' of the rest-of-world goods destined for the provinces. To implement the experiments considered here, we assume that additional inputs are required to complete the import and export transactions.[4] A key consideration for the pattern of regional and sectoral effects is the input profile assumed.

Experiment Designs

To focus on issues of trade and border delays, we need to make some modifications to both the original CREAP data and BMRT model outlined in the previous section. We aggregate the ten Canadian provinces into five regions, namely, Québec (QC), Ontario (ON), British Columbia (BC), Atlantic Canada (AC), and Prairie Provinces (PP).[5] In addition, there are 12 sectors (Table 1) and 23 commodities (Table 2) instead of 25 sectors and 56 commodities in the original S-level data set.

We consider the following four illustrative experiments to look at border delays and related costs:

- *Transport Costs Increase 1% on Merchandise Trade (Exp 1)*: We simulate an across-the-board increase of transportation costs associated with imports and exports of all merchandise trade. In this experiment, the transport costs will rise by 1 % of the initial cost of the imports or exports. Exp 1 is thus similar

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3. CES (constant elasticity of substitution) and CET (constant elasticity of transformation) refer to a class of well-behaved functional forms often used in CGE models.
4. See more details in the next section.
5. Atlantic Canada consists of four smaller provinces on the East Coast, namely, Newfoundland, Prince Edward Island, New Brunswick, and Nova Scotia while the Prairie includes Alberta, Saskatchewan, and Manitoba.

TABLE 1 List of Sectors

	Sector	Description
1	UTL	Utilities
2	FIR	Finance, insurance, real estate
3	BSV	Business and computer services
4	AGR	Primary agriculture
5	MIN	Mining
6	CON	Construction
7	WRT	Wholesale and retail
8	SGS	Social and government services
9	OPR	Other primary (agriculture, fisheries, forestry)
10	MFG	Manufacturing
11	TRN	Transportation
12	AFE	Accommodations, food and entertainment

TABLE 2 List of Commodities

	Commodity	Description	Experiments
1	LUM	Lumber	merchandise
2	PRP	Printing and publishing	merchandise
3	MET	Primary metals and metal products	merchandise
4	OMP	Other manufactured products	merchandise
5	MEQ	Machinery and equipment	merchandise
6	MVP	Motor vehicles and parts	merchandise
7	TRS	Transportation and storage	services
8	UTL	Utilities (including communication services)	services
9	FIR	Finance, insurance, and real estate services	services
10	BSV	Business and computer services	services
11	ELY	Electricity	n/a
12	AGR	Agricultural goods	merchandise
13	FFT	Forestry products, fish and fur	merchandise
14	MIN	Ores and minerals	merchandise
15	PFD	Processed food	merchandise
16	TCL	Textiles and clothing	merchandise
17	FAF	Furniture and fixtures	merchandise
18	PPP	Pulp and paper	merchandise
19	CON	Construction	services
20	WRT	Wholesale and retail	services
21	SGS	Social and government services	services
22	AMS	Accommodations, meals and entertainment	services
23	FUE	Fuels	merchandise

to the 1 % experiment in Walkenhorst and Dihel (2006).

- *Transport Costs Increase 2% on Merchandise Trade (Exp 2)*: Same as Exp 1 except that the cost increase is doubled to 2 % of the initial value of trade. Exp 2 thus loosely corresponds to the 'high-cost' case in Walkenhorst and Dihel (2006) as well as the initial case in Huang and Whalley (2008) where costs are multiplied by two to reflect inventory costs.
- *Transport Costs Increase 5% on Services Trade (Exp 3):* We simulate an increase in the cost of selected services trade, notably, accommodation services and meals (AMS), business and computer services (BSV), and transportation and storage (TRS). Tourism is inextricably linked to border crossings, and selected business services are commonly associated with border crossings; in this case, the cost increase is 5 % of the initial trade volume.
- *Exp 2 and Exp 3 Combined (Exp 4)*: This is the most severe case with cost increases of 2% on merchandise trade and 5% on service trade.

As mentioned above (footnote 4), we assume that border delays require additional inputs to complete the import and export transactions. In the case of merchandise trade, the added 'delay' costs are inputs of domestically-produced 'transportation and warehousing' (TRS). That is, for the 1% cost increase in Exp 1, after the border delays, an amount of C$10,000 in inputs of TRS would be required to import an additional C$1 million in imports. Similarly, for the 2% cost increase in Exp 2, this number is doubled. Note again that transportation services (delays) and storage (warehousing) are the same commodity (TRS) in our model. In the case of services trade, we assume that border delays mean that firms are required to use more domestically-produced business services (BSV) to complete all imports or exports.

Our intention would be to model a given average increase in trade-related costs, but differentiate the costs by province and good as well as by imports and exports. The model is capable of doing so once data are available. At this point we have not modeled the direct public cost to Canadians of providing further border security. Undoubtedly this is an area that needs further work as there will be important policy implications for the years to come.

Data Challenges

Border crossing is a complex phenomenon that goes beyond country boundaries as well as the usual paradigms of rational behavior and government policy. As a result, attempts to investigate the extent of border delays will face serious challenges both at conceptual and practical levels. This section discusses some of these data issues encountered in our modeling effort.

Transport Mode

To make the experiment more realistic, it would be useful to find out what mode of transport is used by different export and import flows. For example, trucking is the most popular transport mode in merchandise trade across the Canada-US border (e.g., Windsor–Detroit bridge/tunnel) while business travelers would prefer air travel. We are unaware of any source for the transport modes associated with trade flows distinguished by source province and commodity. Walkenhorst and Dihel (2006) argued that air travel was the highest risk and would therefore have the highest increase in costs.

Tourism

One of the most visible impacts immediately after 9/11 was the marked decline in non-business travel. Although there is a small growing literature on CGE modeling of the tourism sector (see Blake (2006), Blake and Sinclair (2002) for example), we are unaware of attempts to model this in a multisectoral context across the Canada-US border. It would seem that these impacts were mostly related to the sense of insecurity engendered by 9/11, and only slightly to delays and tightened security.

Business Services

It would be useful to know which business services rely most on temporary entry of business travelers to conduct their business, and furthermore, what amount of trans-border travel is associated with the trade flows we observe. Further, it would be interesting to know how essential the travel is to the completion of the transactions. We are not aware of any data that would illuminate the relevant empirical magnitudes.

Input Composition

So far we have made what strike us as reasonable assumptions in terms of interpreting what exactly constitutes the ‘costs’ associated with border delays. In our terminology, we would like to know the input composition of various elements of these costs. In addition to finding what these goods and services are, we would also like to know whether the flows require domestically-produced inputs, imported inputs, or an Armington composite of the goods in question.

TABLE 3 Summary of Results: Welfare Changes

	Welfare Changes (C$ million)					
Exp	QC	ON	BC	AC	PP	Canada
1	-1113.54	-2829.97	-508.74	-241.18	-735.73	-5429.17
2	-2203.62	-5582.41	-1003.78	-475.39	-1452.85	-10718.05
3	-432.48	-1132.45	-224.11	-95.96	-306.97	-2191.97
4	-2644.15	-6748.90	-1231.14	-572.43	-1763.85	-12960.46

	Welfare Changes (% GNP)					
Exp	QC	ON	BC	AC	PP	Canada
1	-0.56	-0.82	-0.40	-0.38	-0.44	-0.60
2	-1.12	-1.61	-0.80	-0.75	-0.86	-1.19
3	-0.22	-0.33	-0.18	-0.15	-0.18	-0.24
4	-1.34	-1.95	-0.98	-0.90	-1.04	-1.44

Input Incidence

There is an added modeling issue associated with exports. Currently, the added costs are associated with the act of exporting, when in fact it would be quite natural to think of them being associated with the domestic-imported transformation in the model.

Simulation Results

This section presents a summary of simulation results of the four experiments outlines in Section 4, namely, 1 % transport cost increase on merchandise trade (Exp 1), 2 % transport cost increase on merchandise trade (Exp 2), 5 % transport cost increase on services trade (Exp 3), and both Exp 2 and Exp 3 combined (Exp 4). In the first subsection, we discuss the welfare and sectoral impacts of these increases in border crossing costs. In the second subsection, we explore the general trade pattern impacts of some selected experiments.

Welfare Impacts

Table 3 shows that all regions in Canada incur significant welfare costs of border delays (measured in terms of Hicksian equivalent variations) ranging from C$5.4 billion for 1 % increase in transport costs on merchandise trade (Exp 1) to C$13 billion for increase in transport costs on both merchandise and services trade (Exp 4). For Canada as a whole, our welfare cost of 0.6 % of gross national product in Exp 1 is probably comparable with the global estimate of 0.7 % by Walkenhorst and Dihel (2006).

Among all regions of Canada, Ontario stands out as the biggest and the most

TABLE 4 Transportation Overview

	Change in Activity (%)				
Exp	QC	ON	BC	AC	PP
1	16.27	22.28	10.86	13.46	12.86
2	32.01	43.46	21.38	26.49	25.35
3	-0.55	-1.01	-0.50	-0.05	-0.04
4	31.43	42.40	20.84	26.46	25.32

extensive in trade linkage with the United States. As a result, it is probably not surprising that Ontario consistently has the highest welfare costs of border delays both in dollar terms and percent of gross national product. In fact, Ontario alone bears more than half of the national welfare costs (e.g., 52 % or C$6.7 billion for Ontario compared to C$13 billion for Canada in Exp 4). In all four experiments, it is the only region that stands above the national figures.

Table 4 summarizes the impacts of border delays on transportation and storage (TRS). In the experiments that involve merchandise trade (Exp 1, 2, 4), all regions experience large expansions of the transportation sector. While initially unexpected, it results from the equilibrium concept used in the paper and our representation of border delays. For merchandise trade, we represented border delays as added inputs of transportation and storage to complete a given amount of cross-border trade. Since we use a long run equilibrium concept, the findings can be interpreted as an increase in the amount shippers would be expected to pay for accomplishing cross-border trade. To state this another way, if significant border delays became routine, trucking companies would increase freight charges for deliveries from Toronto to Indianapolis or from Canton, Ohio to Kingston, Ontario to reflect their added costs. This is what our findings reflect. In the long run, the truckers would be paid to sit waiting in their trucks on highway 401.

After the sudden tightening of the Canada-US border in 2001, trucking firms experienced very real short-term hardship. For the most part, they had charged a pre-specified amount for deliveries across the border, but were suddenly facing higher fuel costs and, depending on the arrangements between 'owner' and 'driver,' either a higher salary bill or longer hours to complete a given shipment. We view this as an interesting, but separate question from the one we address here, which is the cost and incidence of longer-term tightening of the border.

The transportation and storage sector results are part and parcel of our large welfare losses. In short, fuel, labour and other inputs that were previously producing other goods and services are now devoted to achieving a given amount of trade.

Table 5 summarizes the impacts of border delays on business and computer services (BSV). In the experiments that involve services trade (Exp 3, 4), generally all regions experience small increases (less than 2 %) in business services activities. This again points back to issues of data challenges discussed in the Data section above.

TABLE 5 Business Services Overview

	Change in Activity (%)				
Exp	QC	ON	BC	AC	PP
1	-0.27	0.10	-0.21	-0.62	-0.40
2	-0.54	0.17	-0.43	-1.24	-0.80
3	1.32	1.67	1.05	1.08	1.04
4	0.77	1.82	0.62	-0.18	0.23

Trade Pattern Impacts

In this subsection. we briefly discuss the effects of three of the experiments on the pattern of international and interprovincial trade. Specifically, we focus on the impacts of 2 % transport cost increase on merchandise trade (Exp 2), 5 % transport cost increase on services trade (Exp 3), and both Exp 2 and Exp 3 combined (Exp 4).

Merchandise Trade (Exp 2)

This experiment causes a province's merchandise exports to rise in price relative to the world price and the price of merchandise imports to rise relative to domestic goods. As such, one might expect the volume of international merchandise trade (imports and exports) to fall. There is scope for services exports and imports to rise, and the value of the Canadian dollar falls as a result of the significant decline in merchandise exports. [6]

The mechanisms affecting international trade flows are summarized in Table 6. The direct effects of the policy are on merchandise trade flows as mentioned above. Transport and services exports are significant intermediate inputs into the transportation services sector, and imports of both are expected to increases somewhat as a direct result of the increased demand for domestic transportation services.

To maintain the original trade balance, the value of the Canadian dollar falls about 3%. This causes all imports to fall and all exports to rise. Finally, the decline of real income in Canada of about 1% in all regions would lead to a decline in imports of about the same amount. To the extent that reduced demand in Canada permits more exports, this could also cause exports to rise. The observed pattern of effects are generally in line with the expected outcome of these effects. One exception is PRP (printing and publishing) in which international imports increase in all regions although international exports still fall as expected.

With almost no exception, both interprovincial and international trade flows of merchandise fall. It is not clear *a priori* what would happen to interprovincial

6. The model assumes that Canada's trade balance (in terms of foreign exchange) does not change as a result of the increase in border costs. In the initial equilibrium, Canada has a trade surplus.

TABLE 6 Patterns of International Trade

Trade Patterns in Exp 2		Policy Effect	Exchange Rate	Income Effect	Observed Effect
Merchandise	Exports	always down	always up	usually up[a]	usually down
	Imports	always down	always down	always down	usually down
Transport	Exports		always up	usually up[a]	always up
	Imports	usually up[b]	always down	always down	usually up
Services	Exports		always up	usually up[a]	usually up
	Imports	usually up[c]	always down	always down	usually down

Notes: a. Indirect effect: as income falls, the demand for domestic goods falls which is likely to cause more merchandise goods to be exported.
b. Sign of effect if trade volume is unaffected.
c. Substitution effect as services get less expensive relative to merchandise.

trade flows. The goods produced in each Canadian region which were formerly destined abroad could be sold in Canadian markets, either in their “own” region or the rest of Canada.

Given that all other provinces experience a similar shock, it is also not *a priori* clear whether the relative price effect will be positive or negative. The decline in real income will tend to cause them to decline. As mentioned before, most interprovincial trade in merchandise also falls, suggesting that the goods that were previously exported are now displacing interprovincial imports. There are some departures from this general pattern such as rises in Ontario’s interprovincial exports of primary goods, namely, AGR (agriculture goods), FFT (forestry products, fish and fur), and MIN (ores and minerals).

Services Trade (Exp 3)

The experiment here is to increase the cost of trading services (excluding electricity) across the border. The added trade costs are composed of business services inputs. The overall effect of this experiment on trade is much smaller, and the exchange rate is almost unchanged as a result. We would expect the volume of international trade in affected services (all but electricity) to fall, as is generally the case. International merchandise trade tends to rise, partly as a result of the small decline in exchange rate.

International trade in business services has two ‘direct’ effects. This is because they are the input into the added trade costs, which could cause imports and exports to rise (somewhat like transportation earlier). We would expect the trade volumes to decline because of the added trade costs. We observe international trade in business services declining in all regions.

Both Merchandise Trade and Services Trade

When both experiments on merchandise trade (Exp 2) and services trade (Exp 3) are combined, international imports of most goods and services tend to fall with the exception of transportation. Almost all international export flows of merchandise fall. International exports of other services tend to rise.

Summary and Conclusion

This paper investigates the welfare impacts of border delays arising from post-9/11 security concerns using a regional CGE model of Canada. The simulation results presented here should be taken as illustrative. Several elements of our experiments are uncertain. Nonetheless, we believe that a few broad lessons emerge:

- If the order of magnitude of costs suggested by Walkenhorst and Dihel (2006) as well as our results are to be believed, and further if even these can be argued to under-represent the 'true' burden, our first cut at modeling suggests that the issue of border delays is extremely important to Canada.
- The regional variation of impacts is also considerable, and reflects, to a large extent, the importance of trade to each region. Ontario stands out with the highest cost burden in the country, with Québec falling somewhat behind.
- For some sectors (e.g., transportation in merchandise trade and business services in services trade), the results go against intuition and expectation. That is, one would expect these sectors to struggle rather than thrive as a result of tighter border security. We argue that these unexpected results are indeed central to our findings. If border delays are permanently lengthy, more resources would have to go into the provision of a given volume of trade.

The welfare costs of even relatively modest border delays are quite high. This raises the possibility that the damage resulting from even more widespread border delays could be quite extensive in a trade-dependent country like Canada.

Possible Extensions

The paper can be further extended and refined in a number of directions as follows: In the absence of other data, we have restricted ourselves to across-the-board trade costs for merchandise trade. These costs are more likely to be differentiated by provinces and commodities resulting even higher overall welfare costs and more concentrated welfare burdens.

The BMRT model essentially assumes a small open economy taking world prices for exports and imports as exogenously given. This means that Canada would have to bear the brunt of the costs of delays and increased security. This is probably not unreasonable for a first approximation. However, it would be more realistic to think of Canada as facing a relatively elastic demand for her exports (instead of an infinitely elastic demand). Likewise, it is likely that the elasticity of supply of Canada's imports is quite high (but not infinite). It would be useful to incorporate these features into the modeling.

Because the model is perfectly competitive, we also abstract from one of the serious difficulties that arise with unanticipated or unpredictable delays. This is the existence of pre-existing contracts which bind firms to prices (of transportation services in particular) which in the short run do not reflect the costs associated with providing the service. We see this as a separate question worthy of consideration. In our calculations, border delay costs are formulated as added margins in exactly the same manner for both freight and passengers. While added margins appear reasonable for freight, it would be preferable to calculate delays for passengers in terms of added time costs at border-crossing points. Provided data are available, the model can be modified to handle passenger added time costs as have been done by transportation engineers, e.g., Ueda et al (2005).

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Appendix Model Description

This section describes the analytical structure of the BMRT model used in the paper. In this multi-regional framework, Canada consists of several provinces producing goods and engaging in trade with each other as well as with the rest of the world (ROW). Each province has one representative agent denoted by $h = 1, \ldots H$. Goods are denoted by $i = 1, \ldots, I$ and sectors denoted by $j = 1, \ldots, J$. Primary factors include capital (K) and labour (L). In particular, labour can be used either for leisure to increase utility or for work to earn income. Factors are mobile within any given province but immobile across provincial boundaries.

Demands

Each representative agent h has a two-level nesting utility structure with the first level being a constant elasticity of substitution (CES) aggregator of demands for leisure Λ_h and composite good C_h

$$U_h = CES(\Lambda_h, C_h) \qquad \text{(A1)}$$

At the second level, the composite good C_h is defined by a Cobb-Douglas (CD) aggregator of demands for all final goods C_{hi}

$$C_h = CD(C_{h1}, \ldots, C_{hI}) \qquad \text{(A2)}$$

Consumer demands are derived from maximizing utility subject to the budget constraint $E_h \leq I_h$, namely, the expenditure E_h must not exceed the endowment income I_h. On the expenditure side, consumers take goods prices p_{hi} plus sales taxes tc_{hi} as given

$$E_h = \sum_i p_{hi}(1 + tc_{hi})C_{hi} \qquad \text{(A3)}$$

while on the income side, they receive incomes from fixed endowments K_h of capital and L_h of labour (net of demands for leisure Λ_h). In addition, they receive government tax transfers R_h and foreign exchange transfers FX_h (denominated in domestic currency). Factor prices (r_h, w_h) minus direct factor taxes (tk_h, tl_h) are taken as given.

$$I_h = r_h(1 - tk_h)K_h + w_h(1 - tl_h)(L_h - \Lambda_h) + FX_h + R_h \qquad \text{(A4)}$$

Production

Each sector *j* in province *h* is denoted by the double index *hj* and its outputs *i* are denoted by the triple index *hji*. Each sector *hj* has a multi-product activity described by a constant elasticity of transformation (CET) aggregator Γ_{hj} of several outputs on the left-hand side and a two-level nesting structure of inputs on the right-hand side

$$\Gamma_{hj}(Y_{hj1}, \ldots, Y_{hjI}) = F_{hj}(IG_{hj}, VA_{hj}) \qquad \text{(A5)}$$

On the input side, the top level F_{hj} is a Leontief fixed-coefficient (FC) aggregator of intermediate goods IG_{hj} and value-added VA_{hj} which are in turns constructed as FC aggregators of intermediate inputs I_{hji} and as CES aggregators of factor inputs K_{hj} and L_{hj}, respectively

$$IG_{hj} = FC(I_{hj1},\ldots,I_{hjI}) \tag{A6}$$

$$VA_{hj} = CES(K_{hj}, L_{hj}) \tag{A7}$$

On the output side, sectoral output Y_{hji} is further fed into an additional CET aggregator and split into domestic goods Q_{hji} and exports X_{hji}

$$Y_{hji} = CET(Q_{hji}, X_{hji}) \tag{A8}$$

This domestic-export transformation thus divides sectoral outputs Y_{hji} into two components, namely, Q_{hji} destined for domestic uses and X_{hji} for exports.
Firms take output prices p_{hi} and factor prices r_h, w_h as given which include applicable taxes to_{hji} on outputs, ti_{hji} on intermediate inputs, and tk_{hj} , tl_{hj} on primary factors. Under perfect competition and constant returns to scale, zero profit conditions require that each sector *hj* must balance its total revenue R_{hj} with total cost C_{hj}

$$R_{hj} = \sum_i p_{hi}(1 - to_{hji})Y_{hji} \tag{A9}$$

$$C_{hj} = \sum_i p_{hi}(1 + ti_{hji})I_{hji} \\ r_h(1 + tk_{hj})K_{hj} + w_h(1 + tl_{hj})L_{hj} \tag{A10}$$

Provincial aggregates are obtained by summing the supplies of domestic goods Q_{hji} and exports X_{hji} over all sectors

$$Q_{hi} = \sum_j Q_{hji} \tag{A11}$$

$$X_{hi} = \sum_j X_{hji} \tag{A12}$$

Trade

On the import side, domestic goods and imports are combined into Armington composite goods A_{hi} according to the following two-level nesting structure

$$A_{hi} = CES(M_{hi,ROW}, D_{hi}) \tag{A13}$$

$$D_{hi} = CES(Q_{hi}, M_{hi1}, \ldots, M_{hi,H}) \tag{A14}$$

The first level is a CES aggregator of world imports $M_{hi,ROW}$ from ROW and

$$X_{hi} = \sum_{s} X_{hi,s} + X_{hi,ROW} \qquad \text{(A15)}$$

domestic composites D_{hi}. The second level defines the domestic composites D_{hi} as another CES aggregator of domestic goods Q_{hi} and inter-provincial imports $M_{hi,s}$ (i.e., goods *hi* imported from other source provinces $s = 1, \ldots, H$). Note that $M_{hi,h} = 0$ which means that a province does not import from itself (i.e., no imports from own sources).

On the export side, the supplies of provincial export goods X_{hi} produced must add up to the total amounts of inter-provincial exports $X_{hi,s}$ (i.e., goods *hi* exported to other destination provinces $s = 1, \ldots, H$) plus world exports $X_{hi,ROW}$ to ROW

Again, note that $X_{hi,h} = 0$ which means that a province does not export to itself (i.e., no exports to own destinations).

Balance of Payments

The link between world prices $\pi_{i,ROW}$ (in foreign currency) and domestic prices $p_{i,ROW}$ (in domestic currency) is defined by the price relationship

$$p_{i,ROW} = \varepsilon \, \pi_{i,ROW} \qquad \text{(A16)}$$

where ε denotes the real foreign exchange rate (e.g., relative price of the Canadian dollar against the American dollar).
At the provincial level, trade imbalances between world imports $M_{hi,ROW}$ from ROW and world exports $X_{hi,ROW}$ to ROW can lead to the following provincial excess demands (or excess supplies) BP_h of foreign exchange

$$BP_h = \sum_i \pi_{i,ROW}(M_{hi,ROW} - X_{hi,ROW} \geq 0 \; (or \leq 0) \qquad \text{(A17)}$$

These excess demands are linked to consumer incomes I_h by an equivalent amount of foreign exchange transfers FX_h (denominated in domestic currency)

$$FX_h = -\varepsilon \, BP_h \leq 0 \quad (or \geq 0) \qquad \text{(A18)}$$

That is, provinces with an excess demand for foreign exchange ($BP_h > 0$) must offset it with a negative foreign exchange transfer to consumers ($FX_h < 0$), and vice versa. Each province thus must achieve an “extended” foreign exchange market equilibrium by

$$BP_h + \frac{FX_h}{\varepsilon} = 0 \qquad \text{(A19)}$$

At the national level, the excess demands for foreign exchange BP_i for goods *i* are derived by aggregating the values of imports and exports over all provinces *h*

$$BP_i = \pi_{i,ROW} \sum_h (M_{hi,ROW} - X_{hi,ROW}) \tag{A20}$$

Summing over all goods *i*, we have the balance of payments at the national level

$$\begin{aligned} \sum_i BP_i &= \sum_i \pi_{i,ROW} \sum_h (M_{hi,ROW} - X_{hi,ROW}) \\ &= \sum_h \sum_i \pi_{i,ROW} (M_{hi,ROW} - X_{hi,ROW}) \\ &= \sum_h BP_h \end{aligned} \tag{A21}$$

Since provinces offset their foreign exchange deficits/surpluses by equivalent amounts of transfers FX_h to their consumers, we can also write to the national balance of payments as follows:

$$\sum_i BP_i = \sum_h BP_h = -\frac{1}{\varepsilon} \sum_h FX_h \tag{A22}$$

Therefore, the condition for a national balance of payments equilibrium becomes

$$\varepsilon \sum_i BP_i + \sum_h FX_h = 0 \tag{A23}$$

which can be used to solve for the equilibrium foreign exchange rate ε.

Government Revenues

Government revenues T_h are defined by

$$T_h = Tc_h + Tp_h \tag{A24}$$

where Tc_h denotes revenues from sales taxes on consumer final demands for goods and direct taxes on factor endowment incomes (net of leisure)

$$\begin{aligned} Tc_h = &\sum_i tc_{hi} p_{hi} C_{hi} + tk_h r_h K_h \\ &+ tl_h w_h (L_h - \Lambda_h) \end{aligned} \tag{A25}$$

and Tp_h denotes revenues from producer taxes on primary factors, intermediate inputs, and outputs

$$Tp_h = \sum_j tk_{hj} r_h K_{hj} + \sum_j tl_{hj} w_h L_{hj} + \sum_j \sum_i ti_{hji} p_{hi} I_{hji} + \sum_j \sum_i to_{hji} p_{hi} Y_{hji} \tag{A26}$$

Market Clearings

A general equilibrium solution for the Canadian regional trade model can then be found by numerically solving for the extended price vector (r_h, w_h, p_{hi}, T_h, ε) which satisfies the following simultaneous system of equations of market clearing conditions:

- capital markets equilibrium for all provinces *h*

$$\sum_j K_{hj} = K_h \tag{A27}$$

- labour market equilibrium for all provinces *h*

$$\sum_j L_{hj} = L_h - \Lambda_h \tag{A28}$$

- Armington goods markets in equilibrium for all goods *i* in all provinces *h*

$$\sum_j I_{hji} + C_{hi} = A_{hi} \tag{A29}$$

- balanced budgets for all provinces *h*

$$R_h = T_h \tag{A30}$$

- foreign exchange market in equilibrium

$$\varepsilon \sum_i BP_i + \sum_h FX_h = 0 \tag{A31}$$