Economic Implications of the Canada-U.S. Border Bridges: Applying a Binational Local Economic Model for International Freight Movements *

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Abstract

This study provides an approach to measuring the local economic costs stemming from delays on bridges connecting the U.S. and Canada. We focused on two of the busiest bridges in the U.S. and Canada that connect the Buffalo-Niagara Metropolitan region and Ontario province, using an approach that combines spatial networks and local economic impact models to estimate the economic costs of border delays on the local economies of the border regions. We estimated that the local economic impacts of delays on the Canada-U.S. border bridges in the range of $36,000 to $110,000 per day in total, indicating that a 1 percent increase of delay cost can produce 1.33 percent economic costs in total at the bridge connecting Buffalo and Ontario. Furthermore, the binational economic model provides information on which industries are most impacted from shipping delays on the bridges via supply chain, based on various scenarios. Our modeling approach and scenario development process have important implications for border-traffic planning analysis and border-city economies because they allow numerous simulation tests with respect to changes of international freight transportation costs and patterns for key economic sectors.

JEL Classification: R11; R15; R41

Key words: Border bridges; congestion; freight transportation; economic costs

1. Introduction

Border crossings are critical to the economies of border regions, where trucking is a dominant mode of shipping. Once a bridge is closed or its capacity is diminished, freight shipping via other bridges in the transportation network could be seriously impacted. This could set off economic ripple effects via various inter-industrial linkages involved in the production process. Considering that Canada and the U.S. enjoy the biggest trade relationship in the world, significant disruption of these trade linkages could have tremendous consequences for global trade. This study focuses on a case study of Canada-US highway crossings.

Since the terrorist attacks of 9/11, concern about highway networks coming under a man-made attack on transportation infrastructure has increased due to the sizable economic impacts such an occurrence could have. Indeed, estimating freight movements and shipping costs in border regions when such an event occurs is essential for planning governmental investments in each country. A combined transportation system and economic model focused at a local level can analyze local impacts that are not otherwise easily simulated. Although cross-border trade has been formally treated and studied historically by focusing on trade magnitudes (McCallum, 1995; Anderson and Smith, 1999), there is a dearth of studies that measure how freight trade disruptions can simultaneously impact proximate local regions of both countries. Different economic sector systems of each country must be compatible and combined with the highway network systems connecting the two countries. Complex and disaggregated models can lead to a better understanding of how economic impacts resulting from traffic pattern changes on the border bridges affect local economies in both countries. While it is worthwhile to construct an advanced model involving all of the various U.S. regions and Canada, this study first develops a binational price-type local economic model connecting Ontario and New York State as a test case after converting ton values to the number of trucks.

We are particularly interested in the role of bridges limited to Ontario province and the Buffalo-Niagara (BN) metropolitan region to identify local-level economic effects. The BN model, which is spatially decomposed to the zip code level and then integrated to a one-region model, is proposed to be consistent with the Ontario model for this study.

This study will contribute to the literature on binational and regional economic modeling theory and transportation network analysis, especially elements focused on the economic role of border bridges. It expands the understanding of local-level economic implications of major Canada-U.S. border bridges by suggesting a local economic tool to measure the economic importance of those bridges, especially involving the BN region proximate to the Province of Ontario.

2. Background

Canada and the U.S. are the biggest bilateral trade partners in the world. Trade between the two countries reached $645.7 billion in 2010, representing $1.8 billion worth of goods and services crossing the border every day. About 13 percent of Canadian jobs and more than 8 million U.S. jobs depend on the bilateral trade (Canada's Economic Action Plan, 2012).

Separated by the Great Lakes and waterways, the Province of Ontario and the BN region have a significant portion of trade activities with the U.S. by way of freight transportation via the border bridges connecting the two countries. The BN area experiences more than 12 million vehicles traveling annually between the two countries through the Buffalo-Niagara Gateway (GBNRTC, 2010). In 2010, the total number of passengers, crew, and pedestrians entering the U.S. through the Gateway was about 13 million people, which took 21.63 percent of the total entry number of all the U.S.-Canadian borders. The top three major U.S. gateways (Buffalo-Niagara Falls; Detroit; and Blaine) had about 45 percent of total U.S.-Canada crossings.

Figure 1 shows a binational highway network connected by border bridges in the BN region and the Ontario Province: the Peace and Lewiston-Queenston Bridges. If these bridges work improperly, it can impact not only New York and Ontario that are directly connected by the bridges, but also other remote states due to the interconnection of freight-carrying highways and economic networks.

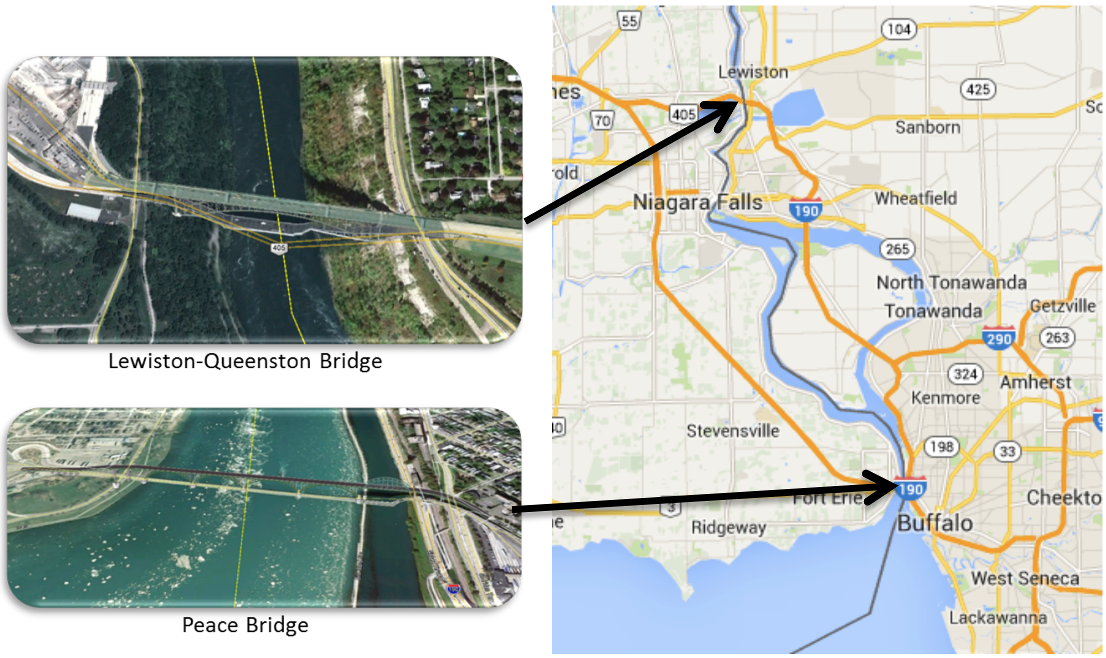

Figure 1. Highway Network between Buffalo-Niagara Falls and Ontario

[Source: Google Map]

As demonstrated in Figure 2, truck shipments are especially dominant in freight flows between Canada and the U.S. through the Buffalo-Niagara Falls Port of entry. Since the economic recession of 2004, the number of loaded truck containers declined until 2009 and have since increased. The most recent number of loaded containers is about 640,000.

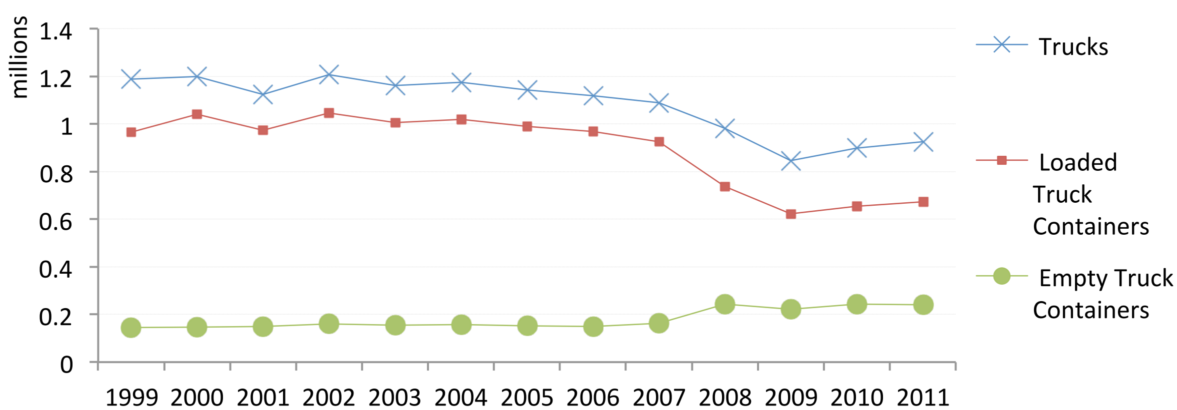

Figure 2. Border Crossing/Entry Data of Buffalo-Niagara Falls Port, NY from 1999 to 2011

[SOURCE: U.S. Department of Transportation, Research and Innovative Technology Administration, Bureau of Transportation Statistics, based on data from the Department of Homeland Security, U.S. Customs and Border Protection, Office of Field Operations. available at http://www.bts.gov/programs/international/ as of January 2013.]

It is not common to find a study of border delay effects on both economies before the 9/11 event. Since that event, border delay impacts seemed to focus on intensified border inspection for national security. Studies have started with the costs related to transportation time (Texas Transportation Institute and Battelle Memorial Institute, 2002; Windsor Chamber of Commerce, 2002; KPMG, 2002; Roberts et al., 2013) and expanded to measure how the time delayed at borders affects a national economy.

For example, Taylor et al. (2003) estimated the costs of border management and trade policies on both the U.S. and Canadian economies to be US$7.52 to US$13.20 billion annually. Walkenhorst and Dihel (2006) applied economic data to the measurement of economic impacts of border delays. Applying the Global Trade Analysis Project (GTAP) tool, a multi-national computable general equilibrium (CGE) model, they simulated border delay impacts: border delays could raise the cost of trade by between 0.5 percent and 1.6 percent, resulting in a reduction of global trade of about 1 percent per a 1 percent increase in trade cost. More recently, Nguyen and Wigle (2011) considered inter-industrial and inter-regional relations for the analysis of border delays, constructing a Canadian CGE model. They estimated that a 1 percent border delay cost on the industry of merchandise and services would induce a 1 percent GDP loss and a 3.6 percent international trade loss for Canada. Overall in these studies, the delay impacts at the U.S. and Canadian borders could cost C$15~$30 billion every year for Canada (MIRS, 2011). A more recent study by Roberts et al. (2013) reported the estimated impacts on the U.S. economy associated with waiting time change at major ports of entry, which stems from the staff change of the Customs and Border Protection, using U.S. GDP, value of time, and employment on the passenger and freight sides. Applying the GTAP tool, this study also measured the U.S. trade impacts on other countries including the economies of Canada and Mexico. However, all of these studies lack an assessment of the economic costs of border-crossing delays on the local areas of both Canada and the U.S.

A few studies measuring local economic impacts associated with the Canada-U.S. border delay are concentrated on Canada impacts. The Ontario Chamber of Commerce Borders and Trade Development Committee (2004) indicated that the Ontario economy may experience annual economic costs in the range of C$5.25 billion to C$6.85 billion from delays at the Ambassador Bridge, which is one of the busiest border crossings and can affect the neighboring U.S. states. For the Quebec economy, border delays stemming from new customs and border security systems could cost as much as C$350 million a year (Martin et al, 2005). Nguyen and Wigle (2011) also found that Ontario may experience a 1.3 percent GDP loss and a 5.1 percent of international trade loss. However, they did not specify the economic impacts on neighboring local areas in the U.S.

Inter-and multi-regional input-output (IO) structures were first suggested theoretically more than fifty years ago to capture the increased interregional trade patterns in a country. More recently, transportation delivery costs have been significantly decreased. Fuel efficiency has been substantially increased mainly by using lighter, high-performance plastics and energy-conserving adhesives to reduce vehicle weights. Indeed, the innovations significantly contributed to increasing interregional transactions. Therefore, spatial modeling needs to clearly understand the interregional trade patterns.

However, it has been difficult to find efforts that integrate two important branches of spatial modeling: transportation network and spatial economic impact models. In the U.S., there were are studies that combine commodity flows and regional IO models at the urban and regional levels (Gordon et al., 1998, Ham et al., 2005; Kim et al, 2002; Cho et al., 2001). While Okuyama et al. (1999) and Kim et al. (2002) empirically applied a mid-west regional economic model, they failed to capture the full, nation-wide spillover economic impacts that are transferred from inter-regional freight movements.

A recent study by Park et al. (2011) presented the framework of TransNIEMO (Transportation Network Combined National Interstate Economic Model) to address this omission, studying California and Arizona. Gordon et al. (2010) elaborated TransNIEMO by adding the nation's highway network. After separating truck movements from the intra- and inter-industry trade flows that the National Interstate Economic Model (NIEMO), an MRIO-type model for the U.S., estimated using the modal coefficients available from the Freight Analysis Framework version 3 (FAF3) data, they loaded the NIEMO trade flows onto the U.S. highway network. In spite of the national expansion of the application framework, what still remains unanswered is how major transportation infrastructure, such as air and water ports, highway and rail networks, bridges and so forth, play a role in the interregional trade framework.

A TransNIEMO type model useful for measuring the economic impacts stemming from highway network disruptions had been developed in Europe since the early 1990s: the Strategic Model for Integrated Logistics and Evaluations for Netherlands (Tavasszy et al, 1998); the Italian national model (Cascetta et al., 2008); a model for Belgium (Geerts and Jourguin, 2001); the REGARD model for Norway (Expedite Consortium, 2000); the STREAMS model (Leitham et al., 1999); and the SCENES European model (Scenes Consortium, 2001). A Spatial CGE based transportation networks model was also applied for the freight network analysis and economic effect estimation: for example, the CGEurope model (Bröcker, 1998; 2003), the Dutch SCGE model of RAEM (Elhorst and Oosterhaven, 2006), the Swedish SCGE model (Sundberg, 2009), the Italian SCGE model (Roson, 1995) and so forth.

International and domestic freight movements provide fundamental information on economic structure and relationships among economic and geographic entities in each country and to all other countries that are involved in international trades. Because network and other economic activities are integrated, they cannot be studied in isolation. While most analysts have been trying to integrate and study them all together, the challenge has been on how to assemble the necessary information to facilitate integrated, international modeling efforts. These transportation network-combined economic models deliver a tool to simultaneously address the economic relations between transportation network and economic implications in a country or internationally. However, a binational TransNIEMO type model that connects the U.S. and Canada and simultaneously delivers local impacts of both countries has not yet been reported. This study was limited to model a binational TransNIEMO model, while the empirical applications were simplified to be applied for local areas in both countries.

3. Methodology and Data

3.1. A Binational Price-type Economic Model

While an integrated transportation-economic model involves several sub-procedures to be developed, in this study we attempted to create a consistent economic sector system for two countries and developed a scenario based transportation simulation model combining a cost analysis model that captures border delay effects. For the Canadian model, we applied an Ontario Province input-output account for the year 2008 which is available from Statistics Canada; however, it requires constructing a symmetric industry-by-industry IO account due to different sector codes between commodity and industry. Also, additional adjustments were needed to be consistent to the U.S. industrial sector system because both sector codes are not detailed and cannot match one-to-one. For the BN metropolitan model, we developed a zip-code level MRIO model for 2008 while we only applied the one-region BN metropolitan model in this study, which includes 20 industry sectors consistent to two digits of NAICS sector and one industry sector undefined. We simplified the network analysis by adding U.S. and Canada simulation scenarios to measure the economic impacts associated with border delays on local regions.

Both the BN and Ontario economic models were integrated to one system. However, we could not add trade flows between the two regions due to the lack of trade flows that only cover both regions. To measure the cost-effects, we transformed the integrated BN-Ontario economic model to be a price-type economic model. Because total transportation costs cannot be normalized with total outputs (X) in the IO account, developing a traditional Leontief price model is not appropriate. Alternatively, a Goshian quantity type of price effect model was developed as suggested in equation (1) (Miller and Blair, 2009, p543-555; Ghosh, 1958; Rose and Allison, 1989; Park, 2008). Apart from the theoretical debate on supply-driven model, it is empirically important to address that the Goshian approach is still useful unless external costs can be normalized with total outputs.

$$\Delta C = G\,\Delta T \qquad (1)$$

where

ΔC = a vector of total cost change;
$G = (I - B^T)^{-1}$;
I = identity matrix;
B^T = a transposed matrix of $\hat{X}Z$;
$\hat{X}$ = the diagonal matrix of X;
Z = an interindustrial flow matrix;
ΔT = a vector of transportation cost change.

This binational price-type economic model was applied to measuring cost changes from the baseline, based on the destination country. For example, if a truck arrives from Toronto to the BN region through the BN bridges, the BN price changes were only measured.

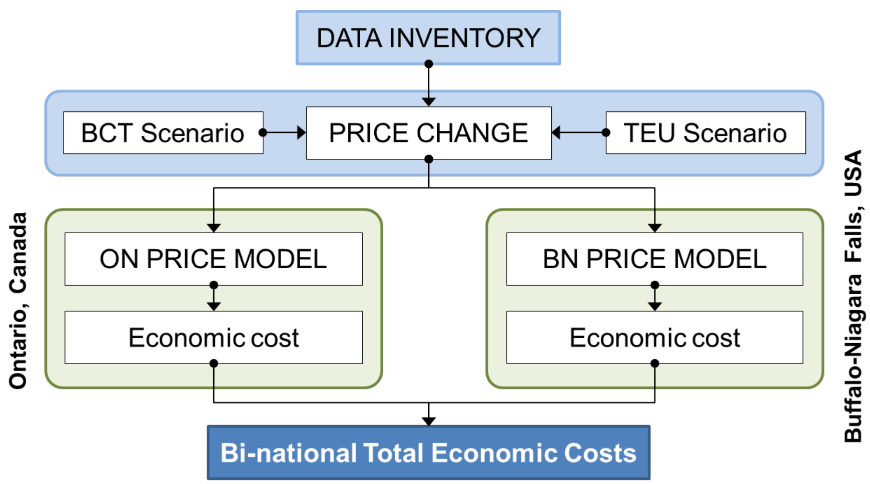

Figure 3. Constructing 2008 Buffalo-Niagara zip-code level economic model

Notes: 1. BCT= Border Crossing Time
2. TEU = Twenty-foot equivalent unit in a truck capacity type

As demonstrated in Figure 3, based on Border Crossing Time (BCT) scenarios and twenty-foot equivalent unit (TEU) assumptions to convert ton values to the number of trucks, each country's price model measures economic costs stemming from the delays of truck movements on the BN bridges. Total binational economic costs will be the sum of the economic costs of each economic model.

3.2 Transportation Cost Analysis Model

When commodity flows between freight origin-destination (OD) pairs are given, freight assignment becomes the major task for uploading to highway networks in order to measure trucking costs. The highway network model estimates freight trip-makers' routing choices between all available zone pairs. The assignment of freight trips to the regional highway network is a network loading procedure that determines traffic volume in each road link by allocating freight trips between OD pairs to the links on the network in response to the link travel times (Xu et al. 1999; Friesz et al. 2011). We simplified the different highway network complexities with the following assumptions: trip durations are related to truckers' labor costs; distance is associated with the other variable costs besides labor; and trade coefficients are insensitive to changes. This is because neighboring areas will not have diverse detouring routes but accept delays on the network. Our approach is more useful to this type of border delay study; because of this we simplified the network connections. This truck cost analysis approach will be used for developing a simulation based economic impact model.

Table 1. Breakdown of operational costs of trucking

Vehicle-based Motor Carrier	**Cost per Mile (2011)**	**Driver-based Motor Carrier**	**Cost per Hour (2011)**
Fuel & Oil Costs	0.590	Driver Wages	18.39
Truck/Trailer Lease or Purchase Payments	0.189	Driver Benefits	6.05
Repair & Maintenance	0.152		
Truck Insurance Premiums	0.067		
Permits and Licenses	0.038		
Tires	0.042		
Tolls	0.017		
Total	**1.095**	**Total**	**24.44**

[Source: American Transportation Research Institute (2012)]

To estimate the transportation cost with a certain level of the border cross service rate, we applied the following equation:

$$(\text{Transportation Cost Per Trip}) = \text{VCPM}\times\text{TD} + \text{LCPH}\times(\text{TD}/\text{S} + \text{WT} + \text{BCT}) + \text{AIFC}\times\text{FCPG}\times\text{BCT} \quad (2)$$

where

VCPM = Vehicle Cost Per Mile = $1.095/mile
TD = Trip Distance = 102 miles
S = Speed = 65 mph
WT = Wait Time = 1 hour
LCPH = Labor Cost Per Hour = $24.44/hour
AIFC = Average Idling Fuel Consumption = 1 gallon/hour
FCPG = Average Fuel Cost Per Gallon (Diesel) = $3.84/gallon
BCT = Border-Crossing Time; Baseline BCT = 10 minutes= 10/60 hours

In the above, we assume that the transportation cost consists of three components: costs associated with travel distance, costs associated with travel time (see Table 1), and fuel consumption while waiting. The first distance component is represented by the Vehicle Cost per Mile (VCPM) and is estimated as $1.095/mile. The second time component is represented by the product of Labor Cost per Hour (LCPH) and the ratio of the total travel time to the travel distance. We used the average LCPH, $24.44/hour. When trucks are waiting on the border and the engines are idling, the average idling fuel consumption is approximately 1 gallon per hour (Illinois Environmental Protection Agency, 2008), and the average fuel cost in 2011 is estimated as $3.84/gallon (American Transportation Research Institute, 2012). While the national average truck speed is reported as 40 mph in ATRI (2012), it includes all operational conditions with standing time due to congested conditions, for example, in borders. Johnson and Murray (2010) report that average truck speed varies from 60.9 mph to 69.8 mph, and Berwick and Farooq (2003) and Gordon et al. (2010) used 65 mph for the average truck speed used for their truck costing models. Since standing and waiting time at the border bridges are separated from driving time and the 40 mph speed would be too conservative leading to much higher trucking costs, we applied the 65 mph speed for this study.

For the bridges between Ontario and Western New York, we considered two cities, Toronto and Buffalo. We regard Toronto as the economic centroid of Ontario, and Buffalo as the gateway to all destinations in New York. The travel distance between the centers of Toronto and Buffalo is measured as 99 to 105 miles, depending on which bridge is used. It is 99 miles, 103 miles, or 105 miles when Peace Bridge, Rainbow Bridge, or Lewiston-Queenston Bridge is used, respectively. Since Rainbow Bridge prohibits the passing of commercial trucks, we only consider the Peace Bridge and Lewiston-Queenston Bridge in the context of freight transportation. The trip distance we used in the computation is 102 miles, which is the average of 99 miles and 103 miles. The two paths are presented in Figure 4.

The waiting time, denoted by WT, represents the average time that is required for loading and unloading at the origin and destination locations, while BCT refers to the non-driving time required to cross the border that includes waiting time due to congestion on the bridge and custom check time by the border agencies. According to the Canada Border Services Agency (2013), the current standard waiting time on Monday through Thursday is 10 minutes, and on Friday thru Sunday and holidays is 20 minutes. At the current average border service rate, we assumed the waiting time is 10 minutes. However, if we were to consider increasing or decreasing the border service rate by changing the number of open lanes and/or the number of officers in on duty, the average waiting time at the border will change.

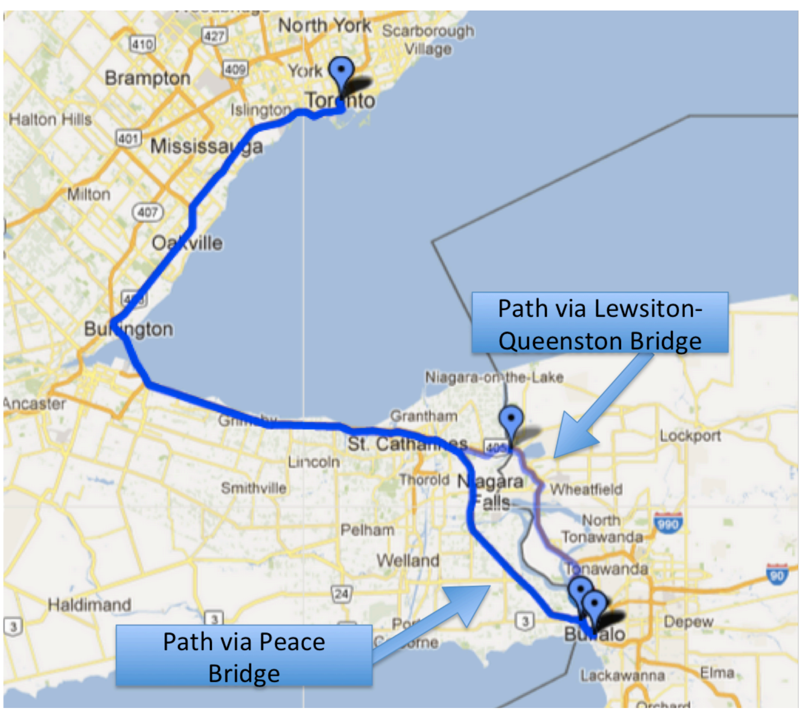

Figure 4. Two freight routes between Toronto and Buffalo.

3.3. Data

This project requires data on traffic volumes on highway and economic input-output data for each region. We collected data from Statistics Canada (http://www.statcan.gc.ca) which provided province-level input-output data for Canada including Ontario under the Economic Accounts. The IMPLAN data (http://www.implan.com) that are used for constructing the zip-code level input-output model and the BN regional model; and FAF3 data that were used for freight flow (http://ops.fhwa.dot.gov/freight/freight_analysis/faf).

First, we aggregated the 2008 Ontario use matrix as our baseline economic impact model. The raw Ontario use matrix is composed of 48 commodity sectors and 25 industry types. Because the 48x25 matrix structure is incompatible with the input price data, it was aggregated to a 22 x 22 input-output (I-O) economic structure. Most of the sectors are convertible to two-digit North American Industry Classification System (NAICS) sectors except for some service sectors, which are consistent to the U.S. industrial classification system (See Appendix B). Note that service sectors are not included in freight flows[1].

Second, we collected freight flow movements between Canada and the U.S. through Buffalo from FAF3 data. The summary of the freight movements by the Standard Classification of Transported Goods Sector System (SCTG) is suggested in Table 2. The total freight amount from the U.S. to Canada is 12.5 million tons, while that from Canada to the U.S. is 10.8 million tons. In both trades, the Base Metals sector outputs accounted for the greatest ton-value.

Third, we converted the SCTG-based sector values to the NAICS-based ton values. Refer to the conversion table as suggested in Appendix A that bridges the SCTG sector system to the NAICS sector system adopting the approach of Park et al. (2009). The NAICS-based ton values are suggested in Table 3, where only five NAICS sectors include non-zero ton-values. Manufacturing is the greatest industry sector in direct trade flows between Canada and the U.S., presenting 83 percent of the total ton value. In addition,

[1] The aggregated economic flows and technical I-O coefficients will be provided upon request.

Total Farm (Agriculture industry), Natural Resources and Mining, and Information that includes newspaper and paper products are major industry sectors in the Canada-U.S. trade flows via Buffalo bridges.

Table 2. Trade Flows between Canada and the U.S. via Buffalo Niagara Metropolitan Areas by the Standard Classification of Transported Goods Sector System

SCTG codes	Sector Description	Trade Flows from the U.S. to Canada through Buffalo	Trade Flows from Canada to the U.S. through Buffalo
1	Live animals/fish	18.90	38.54
2	Cereal grains	11.57	61.39
3	Other ag prods.	445.10	407.13
4	Animal feed	180.42	317.11
5	Meat/seafood	39.12	156.33
6	Milled grain prods.	153.68	402.66
7	Other foodstuffs	495.26	505.66
8	Alcoholic beverages	189.24	291.52
9	Tobacco prods.	1.76	5.27
13	Nonmetallic minerals	263.84	226.79
14	Metallic ores	75.38	27.60
15	Coal-n.e.c.	226.57	735.53
20	Basic chemicals	566.86	200.13
21	Pharmaceuticals	17.72	27.54
22	Fertilizers	27.57	28.33
23	Chemical prods.	1,110.70	397.09
24	Plastics/rubber	1,048.71	811.00
26	Wood prods.	653.91	604.36
27	Newsprint/paper	345.52	97.16
28	Paper articles	944.31	1,012.42
29	Printed prods.	370.31	104.81
30	Textiles/leather	201.60	62.73
31	Nonmetal min. prods.	597.13	447.81
32	Base metals	1,625.17	1,661.56
33	Articles-base metal	381.87	405.31
34	Machinery	647.55	326.63
35	Electronics	169.74	114.94
36	Motorized vehicles	1,348.66	760.18
37	Transport equip.	41.36	15.49
38	Precision instruments	33.60	6.86
39	Furniture	99.99	265.40
40	Misc. mfg. prods.	38.75	27.42
43	Mixed freight	88.05	248.16
		12,459.94	10,800.85

Units: 1000 tons
Base year: 2007

Mode: Truck only
[Source: Freight Analysis Framework version 3]

Table 3. Trade Flows between Canada and the U.S. via Buffalo Niagara Metropolitan Areas by the North American Industry Classification System Sector System

2digit NAICS codes	Sector Description	U.S. to Canada through Buffalo	Canada to U.S. through Buffalo	Total	
				1000ton	%
11	Total Farm	774	962	1,736	7.46
21	Natural Resources and Mining	564	989	1,553	6.68
31~33	Manufacturing	10,754	8,490	19,244	82.73
51	Information	280	111	391	1.68
93	Unspecified industry	88	248	336	1.44
Total		12,460	10,801	23,261	100.00

Units: 1000 tons

4. Scenarios

Using the model, we will examine three border-crossing time (BCT) scenarios, which are 10 minutes, 30 minutes, and 60 minutes. These increases of BCT may be because of increased congestion on border bridges, decreased border bridge capacities, border bridge closures for maintenances, or road network disruption near border bridges. We assume that the increased level of BCT remains throughout the year. Because the BCT scenarios are linear, any segmented BCT scenario can be applied to the final results.

For each scenario of increased BCT, we compute the total transportation cost per trip between Toronto and Buffalo as follows:

a. Scenario 1 (BCT = 10 minutes)
   - (Transportation Cost Per Trip) = \$1.095/mile × 102 miles + \$24.44/hour × (102miles/65mph + 1 hour + 10/60 hour) + (1gallon/hour × \$3.84/gallon × 10/60 hour) = \$179.195

b. Scenario 2 (BCT = 30 minutes)

- (Transportation Cost Per Trip) = \$1.095/mile × 102 miles + \$24.44/hour × (102miles/65mph + 1 hour + 30/60 hour) + (1gallon/hour × \$3.84/gallon × 30/60 hour) = \$188.622

c. Scenario 3 (BCT = 60 minutes)

- (Transportation Cost Per Trip) = \$1.095/mile × 102 miles + \$24.44/hour × (102miles/65mph + 1 hour + 60/60 hour) + (1gallon/hour × \$3.84/gallon × 60/60 hour) = \$202.762

We summarized the BCT scenarios, total transportation cost per trip, and percent change over baseline (that is BCT=10) in Table 4. We assumed all truck flows move with dry cargo container of twenty-foot equivalent units (TEU), which is equivalent to maximum gross mass of 24,000 kg (WSSA, 2013). By subtracting the tare mass of the container, the freight trade amount was converted to containers using ratios of 18, 20 and 22 (Ton/TEU).

Table 4. Border-Crossing Time scenarios and percent change over baseline

	Scenario 1	Scenario 2	Scenario 3
Border-Crossing Time (Minutes)	10	30	60
Transportation Cost Per Mile (\$/mile)	1.76	1.89	1.99
Total Transportation Cost Per Trip (\$US)	179	189	203
Over baseline change (%)	0	5.26	13.15

The estimated loaded truck containers for the trips from the U.S. to Canada range between 560,000 and 700,000, while the number of containers from Canada to the U.S. is in the range between 490,000 and 600,000. Comparing our total loaded truck containers with the historical loaded truck containers (about 1,000,000 on average between 1999 and 2007) reported in Table 5, a proper scenario would be the 22 Ton/TEU ratio case.

Our economic centroid assumption is that all trucks move to/from Toronto for the Canada case and Buffalo for the U.S. case. This is because we cannot know where a truck departs and where it arrives. Therefore, we combined the increased truck delay cost per trip suggested in Table 4 with the estimated loaded-container trucks in Table 5 where only those sectors that have container flows are presented. We redefine the trade flows of 'Canada to/from the U.S.' as 'Toronto to/from Buffalo'.

Table 5. The Estimation of Annual Number of Container Trucks

2 digit NAICS Codes	Containers (TEU) from Buffalo to Toronto			Containers (TEU) from Toronto to Buffalo		
	18 Ton/TEU	20 Ton/TEU	22 Ton/TEU	18 Ton/TEU	20 Ton/TEU	22 Ton/TEU
11	43,019	38,717	35,197	53,469	48,122	43,747
21	31,330	28,197	25,634	54,922	49,430	44,937
31~33	597,448	537,704	488,821	471,685	424,516	385,924
51	15,530	13,977	12,706	6,184	5,566	5,060
93	4,892	4,402	4,002	13,787	12,408	11,280
Total	692,219	622,997	566,361	600,047	540,042	490,948

Notes: 1. Units = number of trucks
2. The definition of 2 digit NAICS Sector codes is described in Table 3 and Appendix B.

This combination of BCT scenarios and TEU estimates produces various scenarios that are used for input values to the Ontario and Buffalo-Niagara economic models. The annual economic costs increased from the baseline border-crossing time (10 minutes) are suggested in Tables 6-1 and 6-2 for the 30-minute and 60-minute BCT scenarios, respectively. The input scenarios are developed for each container capacity scenario by 2-digit NAICS sector per freight travel. According to the 30-minute BCT scenario, the delayed costs for the case of 'Buffalo to Toronto' freight movements are in the range between $5.3 million and $6.5 million, while the costs on the 'Toronto to Buffalo' movements may reach up to $5.7 million for one year. Manufacturing is the most impacted industry sector in both cases. The 60-minute BCT scenario can increase delay costs up to $ 16.3 million for one year.

Table 6-1. Increased Direct Economic Costs from the Baseline Border-Crossing Time by Container Capacity and by 2 Digit NAICS Sector during One Year: 30-minute BCT Scenario

2 digit NAICS Codes	Buffalo to Toronto (B2T)			Toronto to Buffalo (T2B)		
	18 Ton/TEU	20 Ton/TEU	22 Ton/TEU	18 Ton/TEU	20 Ton/TEU	22 Ton/TEU
11	405,537	364,983	331,803	504,051	453,646	412,405
21	295,349	265,814	241,650	517,753	465,978	423,616
31~33	5,632,147	5,068,932	4,608,120	4,446,571	4,001,913	3,638,103
51	146,400	131,760	119,782	58,300	52,470	47,700
93	46,112	41,501	37,728	129,969	116,972	106,339
Total	6,525,545	5,872,991	5,339,082	5,656,644	5,090,980	4,628,163

Notes: 1. Units = $U.S.
2. The definition of 2 digit NAICS Sector codes is described in Appendix B.

Table 6-2. Increased Direct Economic Costs from the Baseline Border-Crossing Time by Container Capacity and by 2 Digit NAICS Sector during One Year: 60-minute BCT Scenario

2 digit NAICS Codes	Buffalo to Toronto (B2T)			Toronto to Buffalo (T2B)		
	18 Ton/TEU	20 Ton/TEU	22 Ton/TEU	18 Ton/TEU	20 Ton/TEU	22 Ton/TEU
11	1,013,821	912,439	829,490	1,260,100	1,134,090	1,030,991
21	738,358	664,522	604,111	1,294,356	1,164,920	1,059,019
31~33	14,080,068	12,672,061	11,520,055	11,116,191	10,004,571	9,095,065
51	365,992	329,393	299,448	145,746	131,172	119,247
93	115,278	103,751	94,319	324,916	292,425	265,841
Total	16,313,517	14,682,165	13,347,423	14,141,310	12,727,179	11,570,163

Notes: 1. Units = $U.S.
2. The definition of 2 digit NAICS Sector codes is described in Appendix B.

5. Results

We estimated the economic costs that stem from freight movement delays between Buffalo and Toronto. We applied an Ontario economic model for the 'Buffalo to Toronto' (B2T) case and a BN economic model for the 'Toronto to Buffalo' (T2B) case. Table 7 presents total economic costs resulting from the T2B freight movements delayed using a BN economic model with the 22 Ton/TEU scenario which is most proper as addressed in Section 4. With the 30-minute BCT scenario, the estimated economic costs are $5.85 million. The 60-minute scenario presents a $14.6 million economic cost, but increases up to a $17.87 million economic cost if applied with the 18 Ton/TEU scenario as expected and shown in Table 9. The total economic costs with the B2T scenarios are slightly greater than the costs of T2B cases. The economic cost reaches $14.62 million in the 60-minute BCT and 22-ton per TEU capacity case in total as suggested in Table 8.

As expected, Manufacturing (Sector 31) will be most impacted in terms of economic cost increase, experiencing about 76 percent of the total costs in both regions because both regions' direct input cost changes are very concentrated in the Manufacturing sector (79 percent for the BN region and 86 percent for Ontario). Both regions may experience high costs in the Agriculture sector from delays on the bridges.

Table 7. Total Economic Costs Stemming from Delayed Freight Movements from Toronto to Buffalo Using a Buffalo-Niagara Economic Model

2 digit Codes	Sector Description	30minute BCT and 22Ton/TEU			60minute BCT and 22Ton/TEU		
		Direct Impacts	Indirect Impacts	Total Impacts	Direct Impacts	Indirect Impacts	Total Impacts
11	Total Farm	412,405	8,993	421,398	1,030,991	22,483	1,053,474
21	Natural Resources and Mining	423,616	5,651	429,267	1,059,019	14,127	1,073,146
22	Utilities	0	144,589	144,589	0	361,465	361,465
23	Construction	0	45,283	45,283	0	113,206	113,206
31~33	Manufacturing	3,638,103	830,572	4,468,675	9,095,065	2,076,386	11,171,451
42	Wholesale Trade	0	21,742	21,742	0	54,355	54,355
44~45	Retail Trade	0	24,718	24,718	0	61,794	61,794
48~49	Transportation and Warehousing	0	14,337	14,337	0	35,842	35,842
51	Information	47,700	23,652	71,352	119,247	59,128	178,375
52	Finance and Insurance	0	13,308	13,308	0	33,270	33,270
53	Real Estate and Rental and Leasing	0	17,412	17,412	0	43,530	43,530
54	Professional, Scientific and Technical Services	0	24,102	24,102	0	60,254	60,254
55	Management of Companies and Enterprises	0	12,596	12,596	0	31,489	31,489
56	Administrative and Support and Waste Services	0	11,829	11,829	0	29,572	29,572
61	Educational Services	0	8,680	8,680	0	21,698	21,698
62	Health Care and Social Assistance	0	83,628	83,628	0	209,065	209,065
71	Arts, Entertainment, and Recreation	0	5,803	5,803	0	14,508	14,508
72	Accommodation and Food Service	0	36,176	36,176	0	90,439	90,439
81	Other Services	0	20,651	20,651	0	51,626	51,626
92	Public Administration	0	12,394	12,394	0	30,985	30,985
93	Unspecified industry	106,339	32,350	138,689	265,841	80,873	346,714
	Total	4,628,163	1,219,301	5,847,464	11,570,163	3,048,187	14,618,350

Notes: 1. Units = $U.S.
2. The definition of 2 digit NAICS Sector codes is described in Table 3 and Appendix B.

The direct impacts associated with transportation cost increases only in the five sectors suggested in Tables 6-1 and 6-2 will affect other sectors because additional transportation costs associated with supply chain occur externally to intermediate inter-industrial transactions. The increased transportation costs need to be treated as one of important value added factors when moving from suppliers to customers. Therefore, transportation cost increases in supply side stemming from the border delays will have ripple impacts on the cost increases across all sectors.

According to both regional IO results, however, most indirectly impacted industry sectors are different. For example, except for Manufacturing, the Ontario economy presents that the Agriculture, Government, and Financial sectors are most indirectly impacted industry sectors, but the BN regional economy shows the sectors as Utilities, Health Care/Social Assistance, and Construction. These are highlighted in both Tables 7 and 8. The sectoral difference in indirect impacts stems from different economic structure between the two local regions. A decomposition method can be applied to pursue the economic structure analysis (Miller and Blair, 2009), which is out of scope of this study.

Table 8. Total Economic Costs Stemming from Delayed Freight Movements from Buffalo to Toronto Using an Ontario Economic Model

2-digit Codes	Sector Description	30minute BCT and 22Ton/TEU			60minute BCT and 22Ton/TEU		
		Direct Impacts	Indirect Impacts	Total Impacts	Direct Impacts	Indirect Impacts	Total Impacts
11	Total Farm	331,803	169,123	500,926	829,490	422,797	1,252,287
21	Natural Resources and Mining	241,650	6,497	248,147	604,111	16,243	620,354
22	Utilities	0	16,281	16,281	0	40,703	40,703
23	Construction	0	87,791	87,791	0	219,473	219,473
31	Manufacturing	4,608,120	962,611	5,570,731	11,520,055	2,406,477	13,926,533
42	Wholesale Trade	0	61,536	61,536	0	153,837	153,837
44	Retail Trade	0	34,686	34,686	0	86,714	86,714
48	Transportation and Warehousing	0	88,725	88,725	0	221,807	221,807
51	Information	119,782	42,400	162,182	299,448	105,998	405,446
52	Finance, Insurance, Real Estate and Rental and Leasing	0	97,817	97,817	0	244,538	244,538
54	Professional, Scientific and Technical Services	0	59,191	59,191	0	147,975	147,975
56	Administrative and Support, Waste Management and Remediation Services	0	17,810	17,810	0	44,524	44,524
61	Educational Services	0	729	729	0	1,822	1,822
62	Health Care and Social Assistance	0	11,371	11,371	0	28,428	28,428

71	Arts, Entertainment and Recreation	0	9,207	9,207	0	23,017	23,017
72	Accommodation and Food Services	0	33,880	33,880	0	84,697	84,697
81	Other Services (Except Public Administration)	0	10,952	10,952	0	27,379	27,379
93	Unspecified	37,728	29,721	67,450	94,319	74,302	168,621
F2	Travel, Entertainment, Advertising and Promotion	0	78,348	78,348	0	195,865	195,865
F3	Transportation Margins	0	93,624	93,624	0	234,056	234,056
NP	Non-Profit Institutions Serving Households	0	7,120	7,120	0	17,800	17,800
GS	Government Sector	0	118,779	118,779	0	296,942	296,942
	Total	5,339,082	2,038,201	7,377,283	13,347,423	5,095,394	18,442,817

Notes: 1. Units = $U.S.
2. The definition of 2 digit NAICS Sector codes is described in Appendix B.

Table 9 summarizes the total binational economic cost increases and presents costs per day. The last column presents the per day costs by BCT type and by TEU capacity. While only BCT doubled (from 30 to 60 minutes), the corresponding total economic costs increased almost 2.5 times. The most negative scenario (60-minute BCT and 18-Ton TEU capacity) suggests the $110,700 economic cost per day in total if both bridges connecting the BN and Ontario regions experience one-year trade flow delays for 60 minutes.

Table 9. Summary of Economic Costs from Freight Movement Delays

		Toronto to Buffalo	Buffalo to Toronto	Total	Per day
BCT=30minutes	18 Ton/TEU	7,146,900	9,016,679	16,163,580	44,284
	20 Ton/TEU	6,432,210	8,115,011	14,547,222	39,855
	22 Ton/TEU	5,847,464	7,377,283	13,224,747	36,232
BCT=60minutes	18 Ton/TEU	17,866,872	22,541,220	40,408,092	110,707
	20 Ton/TEU	16,080,185	20,287,098	36,367,283	99,636
	22 Ton/TEU	14,618,350	18,442,817	33,061,166	90,579

Units: $U.S.

Finally, we calculated the total multiplier using total input and output cost changes. The input cost percentage over the baseline cost is in the range of 5.26 percent to 13.15 percent as suggested in Table 4. The output cost percentage over the baseline cost is calculated as total output cost change per truck on the basis of baseline total transportation cost per trip. For example, 6.98% = 100*{$16,163,580/(692,219+660,047)trucks}/$179,

where $16,163,580 = total output cost for the 30 minute BCT and 18 Ton/TEU case;

692,219 and 660,047 = total number of container trucks available from Table 5;

$179 = baseline total transportation cost per trip available from Table 4.

The output cost percentage is in the range of 7 percent to 17.5 percent. We measured an elasticity of border delay cost to total economic impact, using these two cost percentage changes. The elasticity of border delay cost to the total economic impact is estimated to 1.33 as summarized in Table 10. Therefore, a 1 percent increase in transportation cost could prompt a 1.33 percent total economic cost increases from freight movement delays at the bridges connecting Buffalo and Ontario.

Table 10. Elasticity of Delay Cost to Total Economic Impact: Total Multiplier

	BCT=30minutes	BCT=60minutes
Over baseline cost change in input (%)	5.26	13.15
Over baseline cost change in output (%)	6.98	17.45
Elasticity of Delay Cost to Total Economic Impact	1.33	

6. Conclusions and Discussion

In the aftermath of September 11, 2001, border security rose to prominence in discussions related to Canada-U.S. trade. Policy instruments that best capture attempts to mitigate tradeoffs between security and economy include the Beyond the Border Accord executed by the President and Prime Minister in 2011. Following the announcement of this Accord, there has been increased emphasis on the measurement of various phenomena associated with the Canada-U.S. border, but little progress is seen in this regard. Therefore, this study can be expanded to assess border and security policies and management, for example, significant increases of security on border bridges, increases or decreases of border bridge capacities, border bridge closures, and road network disruption near border bridges.

Also, we understand that international freight movements affect the urban economic structures near border bridges. However, an in-depth analysis on the economic impacts of border bridges across metropolitan areas still remains limited. Our tool for modeling and international freight flows surrounding border bridges can be applied for understanding the nature of international goods movement supply chain which is still poorly understood; we delivered implications of the supply chain logic for border cities. Based on a quantity-type of price economic model developed for this study, we found that the economic implications of the Canada-U.S. border bridges are in the range of $36,000 to $110,000 per day in total, indicating that a 1 percent increase of delay cost can produce 1.33 percent total economic cost at the bridges connecting Buffalo and Ontario. Furthermore, this study that measured the economic costs of delays on the bridges connecting the Buffalo-Niagara Metropolitan region and the Ontario province can be extended, for example, with the application of a decomposition method to the economic structural changes of these border cities.

For future work, we need to develop a queuing model that better describes the change of border-crossing time depending on the service rates, the arrival rates of freight trucks, and the closure of a border bridge. An M/M/c queue model may be appropriate for such modeling work, with arrivals governed by a Poison process and job service times exponentially distributed with border-crossing servers. Unfortunately, the modeling work requires an accurate estimation of the arrival and the service rates. At the current time, those values are unknown, except for the average border-crossing time which is given as 10 minutes. Since an M/M/c queue is highly sensitive to the service and arrival rates, we need to accurately measure the rates with the help of actual observation of the traffic patterns and the varying service rates. While dynamic traffic patterns may be indirectly observable through the waiting time reported on the websites of border agencies, time-varying service rates are generally unobservable without actually being measured on the border. Also, we noted that the waiting time in an M/M/c queuing system increases exponentially with a decrease of service rate; hence the scenarios considered in this project, with the BCT increases of 30 minutes and 60 minutes, could be conservative in the case of a bridge closure. In the extreme case, the queue length becomes infinite, yielding an infinite border-crossing time. It should also be noted that this study omitted aspects of resilience in dealing with delays which allows truckers using GPS and social media devices to find congested areas and to pursue alternative routes as appropriate on a real-time basis.

This study inherits a traditional limitation of input-output modeling: the fixed technical coefficient issue. In addition, hierarchical extensions of a one-region input-output model to multi-regional models are challenging, because trade flows and economic structures should be concisely considered for the upper and lower levels. It is important to note that full binational economic and transportation network connections require diverse data sources available in both countries. Furthermore, this study did not include other states and provinces neighboring the U.S. and Canada, and hence, neglected the re-routing of freight flows on the highway network. This study needs to incorporate other modes of transportation, especially the rail network. We plan to develop a modeling approach that combines the rail network with the highway network in order to build up a binationally integrated freight transportation network and a multi-modal freight model. This elaborate development will allow various scenarios to be studies that estimate the change of freight flows on the entire U.S.-Canada border bridges.

However, this study measured empirical evidence of freight sensitivity to congestion costs (Winston and Langer, 2006) using border crossing time scenarios of local areas in both Canada and the U.S. More importantly, this study has pointed to the various complexities in the construction of an operational binational model. We have described the many steps involved in assembling all the data and scenarios required and testing the model.

Certainly from a border policy perspective, a single unexpected delay requires minor adjustments. However, the additional time costs could be substantial if that delay continues for six months to a one year involving rerouting, especially for trucks already en route. However, this has not yet been clearly identified, and this study estimated the per-day economic costs stemming from the freight movement delays on the bridge that we may experience during one year. This will help to understand how scarce fiscal resources can be effectively used to reduce freight delays. In the future, a fully operational binational TransNIEMO can more fully estimate plausible economic costs in the U.S. and Canada.

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Appendix A. Conversion Table from SCTG to NAICS

SCTG Sector	NAICS Sector	Portion	SCTG Sector	NAICS Sector	Portion
1	11	1	**24**	31	0.015386
2	11	1	**24**	32	0.95895
3	11	0.914567	**24**	33	0.025664
3	31	0.085433	**25**	11	1
4	11	0.840811	**26**	11	0.020784
4	31	0.159189	**26**	32	0.979216
5	11	0.492889	**27**	32	1
5	31	0.507111	**28**	32	1
6	31	1	**29**	32	0.501719
7	11	0.383303	**29**	51	0.498281
7	31	0.616697	**30**	11	0.057428
8	31	0.743341	**30**	31	0.803957
8	32	0.256659	**30**	32	0.071898
9	11	0.415617	**30**	33	0.066717
9	31	0.584383	**31**	32	0.964643
10	21	1	**31**	33	0.035357
11	21	1	**32**	33	1
12	21	1	**33**	33	1
13	21	0.971784	**34**	32	0.043502
13	32	0.028216	**34**	33	0.956498
14	21	0.959096	**35**	32	0.001966
14	32	0.040904	**35**	33	0.71617
15	21	1	**35**	51	0.281864
16	21	1	**36**	32	0.044737
17	32	1	**36**	33	0.955263
18	32	1	**37**	33	1
19	32	1	**38**	33	1
20	32	1	**39**	33	1
21	32	0.825476	**40**	11	0.101181
21	33	0.174524	**40**	31	0.030584
22	32	1	**40**	32	0.015688
23	31	0.015531	**40**	33	0.852546
23	32	0.984469	**43**	93	1

Note: SCTG and NAICS 2 digit sector systems are suggested in Tables 2 and Appendix B respectively.

Appendix B. The U.S. 2-digit NAICS Sector Code System and Canadian Industry Code System

Sector Description	2-digit NAICS Sector Codes	2-digit Canadian Industry Codes
Total Farm	11	11
Natural Resources and Mining	21	21
Utilities	22	22
Construction	23	23
Manufacturing	31~33	31
Wholesale Trade	42	42
Retail Trade	44~45	44
Transportation and Warehousing	48~49	48
Information	51	51
Finance and Insurance	52	52 (5A)
Real Estate and Rental and Leasing	53	52 (5A)
Professional, Scientific and Technical Services	54	54
Management of Companies and Enterprises	55	52 (5A)
Administrative and Support and Waste Services	56	56
Educational Services	61	61
Health Care and Social Assistance	62	62
Arts, Entertainment, and Recreation	71	71
Accommodation and Food Service	72	72
Other Services	81	81
Unspecified industry	93	F1
Travel, Entertainment, Advertising and Promotion	-	F2
Transportation Margins	-	F3
Non-Profit Institutions Serving Households	-	NP
Public Administration	92	GS