The Ties that Bind: Bi-national Trade Implications of the US and Canada Using Bi-national Freight Movement Network via Border Crossings[1]

Ha Hwang*
JiYoung Park**
Changhyun Kwon*
Kathryn Friedman*
Nathan Attard*
Shen Hao Chang*
Samuel Wells*

*University at Buffalo, The State University of New York
** Corresponding Author (jp292@buffalo.edu)
Department of Urban and Regional Planning
University at Buffalo, The State University of New York

1. We wish to thank the U.S. Department of Transportation (USDOT) through University Transportation Research Center, Region II, Research and Advanced Technology Initiative (RF #499974125) for sponsoring this research. This work could not have been possible without this support. However, any opinions, findings, conclusions, or recommendations in this article are those of the authors and do not necessarily reflect the view of USDOT. We also thank Lei Lin for providing us with a detailed border traffic dataset.

Highlights

- We developed a bi-national freight network model connecting freight flows of trucks via ports of entry between the US and Canada.
- We monitored and analyzed border wait times to determine the border crossing delay baseline values that are essential for the bi-national Transportation Combined National Interstate Economic Model to operate.
- Weighted Eigenvector Scores reveal that Detroit, Buffalo, Port Huron, Blaine-Pacific Highway, and Champlain are the five most important ports of entry for trucks in terms of their impact on bi-national trade.
- While freight flows via major ports of entry are dispersed to many US states, Canadian freight flows tend to stay within the province of their ports of entry.

Abstract

This study combines US-Canada bi-national highway network data with a freight flow dataset using ports of entry (POE) via highway border crossings. Through several sub-procedures, the US and Canada highway systems are integrated into a single network dataset. In addition, border wait time dataset was monitored and analyzed to set the border delay baseline. This dataset enables us to explore the freight traffic pattern between the US and Canada. Weighted Eigenvector Score is computed using a Social Network Analysis tool. The results demonstrate that major regional bodies are the primary users of major POE between the US and Canada. This study not only offers an improved understanding of the economic implications of US-Canada border crossings, but also contributes to developing a simulation tool, a bi-national Transportation-combined National Interstate Economic Model. Such a tool is expected to extend and apply to other contexts, such as transportation and national and bi-national security, among other applications. Additionally, this study suggests several important considerations for US and Canadian officials charged with devising policy to protect against security threats while facilitating legitimate flows of goods, services and people across the border.

Key words: Cross-border freight; trade network analysis; border wait time; Bi-national TransNIEMO

1. Introduction

Freight transportation involves moving diverse commodities to satisfy global supply and demand for goods and services. These commodity outputs, which are connected with many diverse inputs, are often imported or exported via ports of entry (POE), primarily by truck. In 2010, the daily value of all modes of goods exchanged between the US and Canada was nearly $1.8 billion, making US-Canada trade the largest bi-national trade relationship in the world (Park et al., 2014a). The supply chains of both countries are highly integrated, with the majority of this trade being intra-industry. With the final outputs of these tightly integrated bi-national industries exported worldwide, significant disruptions of the bi-national freight network could cause tremendous economic consequences not only for the US and Canada, but for global trade.

The US and Canada are linked by many modes of transport, including trucks, trains, ferries, pipelines, and airplanes. Efficient connections are essential to the economic productivity of both countries. In the past decade, this efficiency has been threatened by several significant disruptions caused by man-made or natural disasters. Many public and private stakeholders now are aware of the magnitude that transportation disruptions could have on national economic systems. Once a border crossing is closed or its capacity diminished, freight movement via other border crossings in the transportation network could be seriously impacted by freight diverted from the affected crossings. This has the potential to cause adverse economic ripple effects for the various suppliers involved in producing a product. These disruptions could affect supply chains that extend far beyond nearby regions.

A secondary issue affecting bi-national trade is the delay that results from border security measures and inspections. Even though interstate and interprovincial trade may have larger impacts on each national economy than US-Canada trade (Anderson, 2009; Hewings et al., 1998; Hitomi et al., 2000), border crossings and their highway network approaches are often subject to high levels of congestion due to such measures, and hence, need a distinctive examination. This is especially true in the Niagara Falls area, where the highway network connecting Toronto and Buffalo is congested almost every day by passenger and freight vehicles. It is valuable to measure how congestion cost externalities affect the US and Canadian economies, from local communities to each nation as a whole.

Separated from the US by the Great Lakes and the waterways that connect them, a significant amount of Canadian trade with the US is by way of freight transportation via border crossings. Cross-border studies, however, have focused on the magnitude of trade (McCallum, 1995; Anderson and Smith, 1999) instead of on freight disruptions. Filling this void, we seek to measure how these disruptions can simultaneously impact the proximate regions of both countries. To address this issue, it is necessary to develop complex economic impact models linking the two countries with the highway network. Complex and disaggregated models can lead to a better understanding of how economic impacts that result from traffic pattern changes on border crossings affect local economies.

As an essential element for building a bi-national Transportation-combined National Interstate Economic Model (TransNIEMO), this study aims to develop a novel bi-national highway network combined with freight trade information between the US and Canada via POE connected by highways, in order to provide a stronger foundation of understanding for the economic implications of border crossings. Using the bi-national freight network dataset, we explored binational trade patterns and analyzed the role of POE. A general framework of the US-version of TransNIEMO is suggested in Appendix 6 and the theoretical and empirical details can be found in Park et al. (2011), Park et al. (2014a), Park et al. (2014b) and Cho et al. (2015).

Border entries include facilities for entry and departure of people and goods, such as airports, seaports, railways, and border crossings. Since this study only focused on border crossings on highways and examined bi-national freight movements, we established each border crossing dataset. However, as Detroit and Buffalo ports each have two border crossings, we pooled these two border crossings for various analyses applied in this study and neat visualization of the analyzed results.

This article is organized into five subsequent sections. Section 2 provides background on this study. Sections 3 and 4 present an overview and analysis of border wait times and trade issues on US-Canada border crossings, respectively. Section 4 also includes the data processing method and structure of bi-national freight movement data. Section 5 combines origin and destination freight value and truck movement with descriptive statistics, and applies social network analysis (SNA) to understand central border crossings. The article concludes with a brief summary and future discussions to be investigated for border security and policy issues using the bi-national transportation network-combined economic model. We expect to examine the economic and freight transportation importance of border crossings on the US-Canada economies, with emphasis on the various US states proximate to the province of Ontario in ongoing research using bi-national TransNIEMO.

2. Background

2.1 A Bi-national Freight Network Model

TransNIEMO has three sub-models, a national highway network model, a transportation cost impact model, and NIEMO. A national highway network model refers to the baseline highway network combined with freight flow data. A user equilibrium (UE) model is applied to allocate freights volume on the highway network. A transportation cost impact model generates additional shipping costs for network disruption scenarios. NIEMO generates nation-wide ripple effects for each scenario (Park et al., 2011l; Cho et al., 2015)

To propose a novel bi-national TransNIEMO, an integrated understanding of both the transportation network and the economy of the US and Canada is crucial. POE via highway border crossings that connect the US and Canada tie industries and local economies of the two countries together. Freight arriving from all over the world converges and diverges at POE by truck. Given that neighboring regions of the US and Canada are connected with border crossings and trade dataset is aggregated at these points relative to origin/destination states or provinces per commodity type, it is important to take a closer look at border crossings in order to explore the patterns and magnitude of freight flow on the bi-national economy.

In order to investigate freight flow between the US and Canada through POE by truck, we require data on the import and export of goods between the US and Canada by commodity type for each POE. This dataset provides a comprehensive description of bi-national economic relationships at each border point, with specific states or provinces, or at a national scale, for either the US or Canada. This is only a snapshot of commodity flow at border crossings, however. Since the ultimate goal of linking the economies of the two countries at border crossings is to develop a TransNIEMO-type bi-national model, our interest is in building a complex dataset that includes not only the total amount of goods traded between both countries, but also their regional origins and destinations.

To obtain this dataset, we required crossing-specific trade data in terms of import and export value of goods by respective origins and destinations, and also by commodity type. After much investigation, we concluded that there is no comprehensive data that records both origin and destination information from regions in the US to Canada or vice versa through specific POE. Instead, there are several freight-related data sources related to specific POE, which have regional origin or destination information available. By connecting the two countries with POE in our network model, we could collect geographically combined freight origin and destination data.

2.2 Social Network Analysis and its Applications in Various Domains

The concept of Social Network Analysis (SNA) has been discussed among sociologists since the early 19th century. Sociologists regarded societies as networks of reciprocal influence. Due to computational complexities and difficult data collection procedures, however, sociological researchers were challenged in utilizing SNA.

With recent developments in computational technology, many fields, including sociology, have been utilizing SNA due to the theoretical flexibility of its applications. De Montis (2005) employed a weighted network approach to examine inter-municipal commuting network at the inter-city level and its relation with the topological structure. Municipalities and flow of commuters are regarded as nodes and links, respectively, in this study. Shih (2006) applies network analysis to tourism in Taiwan. This study used survey data collected from 21,412 respondents asking about up to sixteen destinations visited, and the sequence in which these destinations were visited. The destinations are treated as nodes and the tourists' routes among destinations are treated as a series of links in the tourism network. Cantner & Graf (2006) applied SNA methods to describe the evolution of the network of innovation in Jena, Germany. The study constructed two different networks, the "inventor overlap" network, and the "technology overlap" network. The inventor overlap network treats innovators (corporations) as nodes, while a link is created when they share an inventor. The number of inventors that two innovators share becomes the weight of a link. A link is created when two innovators produce the same type of commodity in the technology overlap network, with nodes defined the same way as in the inventor overlap network. Fagiolo, Reyes & Schiavo (2010) constructed World Trade Web (WTW) to explore the regularities of global trade relationships and its evolution over time using international trade data for 159 countries between 1981 and 2000. Countries and trade flow (US dollar) are defined as nodes and links, respectively. This paper explores WTW with many SNA approaches from simple global network properties to vertex specific properties such as connectivity, assortativity, and cluster coefficient analysis for each country.

In network analysis, centrality generally measures the relative density of arcs for each node. Centrality is used to identify the most important actors in a network (Wasserman, 1994). Centrality, popular in social science, was applied in this study to identify the magnitude of key border crossings on the bi-national freight movement of trucks in relation to regional origins and destinations (ODs) in both the US and Canada. Since our bi-national network consists of two different types of nodes, regional origins/destinations and border crossings, it is basically a 'multimodal network.' Edges are formed only between different types of nodes. Web blogs with a user network are common examples of multimodal networks. Users connect to one or multiple web blogs to view and comment, and interact only via web blogs, whereas there is no direct connection of blog to blog or user to user. In the current bi-national freight network, users and web blogs are replaced with regional origins/destinations of both countries and border crossings, respectively. Freight flows from regional origin/destination nodes to POE nodes (and vice versa) serve as edges, while corresponding twenty-foot equivalent unit (TEU) values (see Section 4.4 for the details) are denoted as weights for edges.

There are five kinds of centrality concepts which are commonly employed in Social Network research: Degree Centrality, Closeness Centrality, Betweenness Centrality, Eigenvector Centrality, and Clustering Centrality. Degree Centrality is the simple count of edges for each node. It can be divided into 'in-degree' and 'out-degree' when the defined relationship of a network has direction (e.g., like or hate, flow of money, etc.) and direction is meaningful. In the bi-national freight network, weighted degree centrality is the summation of TUEs for each node when the volume of TEU is applied as the edge weight. It has no more meaning than simple statistics in this study. Closeness Centrality is the summation of reverse-coded distance scores from one node to all other nodes. Betweenness Centrality denotes how often a person lies on the shortest path between pairs of vertices. While these two centrality concepts are indispensable to explore general types of networks (e.g., social networks), they do not prove useful in understanding the bi-national freight network. This network has direct origins and destinations, so an understanding beyond one degree is not considered, whereas Closeness Centrality and Betweenness Centrality consider whole networks to generate scores for each node. Clustering Centrality examines egocentric networks to consider how neighbors of one node are interconnected. While there is value in understanding regional or bi-national trade clusters, we will employ this concept of Clustering Centrality in future research.

Among the centrality concepts described above, we chose Eigenvector Centrality. Eigenvector Centrality indicates the influence of nodes within a network. In a Twitter network, for example, when a person is connected with a very famous person who has an enormous number of followers, this person might have a higher Eigenvector Centrality score than others who are not connected with famous people. However, Eigenvector Centrality not only considers the degree centrality of connected neighbors, but also the number of neighbors. It is theoretically possible one node that is connected to hundreds of other nodes with small degree centrality scores has a higher Eigenvector Centrality score than another node that is only connected to one other node with a large degree centrality score, or vice versa. This is because Eigenvector Centrality combines both the number of neighbors and their degree centrality. In the current study, Eigenvector Centrality scores for border crossings represent a combination of the number of connected states and provinces and their connected border crossings as degree centrality scores. We also apply the volume of freight as the edge weight.

3. Border Wait Times

3.1. Border Wait Times between the US and Canada

An understanding of border wait time is crucial when measuring the bi-national economic effects caused by interruptions at border crossings. Border wait time is defined as the time that elapses between a car joining an inspection queue line and leaving an inspection booth. Because the length of an inspection queue line is incessantly changing based on circumstances (e.g., volume of traffic, staffing capacity, intensity of inspection level, and so on), inductive loop-detectors, ranging radar detectors, and video-imaging processing techniques have been developing to identify the beginning point of a queue line (Savean and Jones, 2008). Border security enhancements or other border-related transportation disruptions can result in increased border wait times, increased travel time, or increased travel distance for trucks. In freight transportation, time and distance generally contribute to the generalized cost of travel. An increased travel cost will adversely affect bi-national supply chains. In addition, border wait times can differ at different border crossings due to infrastructure (for example, the number of dedicated commercial inspection lanes) and border agency staffing levels. Therefore, it is important to better understand trends and characteristics of border wait time at different border crossings.

The US Customs and Border Protection (CBP), an agency of the US Department of Homeland Security, maintains a list of current border wait times and open inspection lanes (refer to http://bwt.cbp.gov/). This dataset is also available in the form of a live RSS (Rich Site Summary or Really Simple Syndication) feed. An RSS feed is a format that can provide users with frequently updated information. The CBP's RSS feed updates approximately every hour with this information. We monitored the CBP's RSS feed over the period of one week from 16 to 22 September 2014 in order to gain information on border wait times.

The CBP's RSS feed monitors 29 different border crossings. We excluded 5 crossings that are closed to commercial traffic. Table 1 shows the average number of open commercial vehicle lanes and the average delay time at 24 border crossings between the US and Canada. Interestingly, the longest average wait time was at noon, suggesting that truck drivers converge at border crossings at off-peak hours in order to avoid passenger vehicle commuters (Park et al., 2011).

Table 1. Commercial Vehicle Lanes and Delay Time During Four Different Time Periods at Border Crossing Bridges between the US and Canada

	AM Peak	Noon	PM Peak	Midnight	Average
Average Commercial Vehicle Lanes Open	1.49	1.89	1.81	1.24	1.61
Average Delay Time (minutes)	0.99	2.29	1.83	0.70	1.45

Source: The US Customs and Border Protection Agency, tabulated by authors

Note: AM Peak recorded the closest available update to 7:00 AM local time, Noon closest to noon, PM Peak closest to 5:00 PM, and midnight closest to midnight.

The average delay time for all of these crossings is 1.45 minutes, with Blaine – Pacific Highway, Buffalo/Niagara Falls – Peace Bridge, Detroit – Ambassador Bridge, Detroit – Windsor Tunnel, and Sumas as the only ports with delay times above 3 minutes (see Figure 1). The majority of border crossings have delay times of one minute or less. Comparing the average delay time and dedicated commercial vehicle lanes open, there seems to be a moderate linear relation, with an R^2 equaling 0.6441. This linearity between the average delay time and the number of commercial vehicle lanes open can be understood as the implication of border crossing infrastructure investment policies. For example, the Detroit-Ambassador Bridge and Buffalo-Peace Bridge have the highest number of commercial lanes open relative to the value of commodities crossing, while they still report the longest commercial wait time of all the border crossings. This suggests the need for more investment in commercial inspection lanes at these crossings to handle regular commercial traffic. Given that the current infrastructure does not adequately accommodate current commercial traffic under normal border crossing conditions, these bridges would be challenged to accommodate commercial traffic diverted to these crossings in case of a disruption at another link in the bi-national highway network.

It should be noted that this is an hourly average for a specific week; there are seasonal increases and decreases in traffic, and other high peak points within each hour and between the four points in time where we recorded wait time and open commercial inspection lanes. To obtain a better understanding of these variations, we looked at hourly trends over a longer period of time at two bridges; the Peace Bridge and Lewiston-Queenston Bridge, the two commercial crossings between metropolitan Buffalo, New York and the Niagara Region of Ontario. This analysis follows this section in Section 3.2 and examines how delay varies hourly by week and by month.

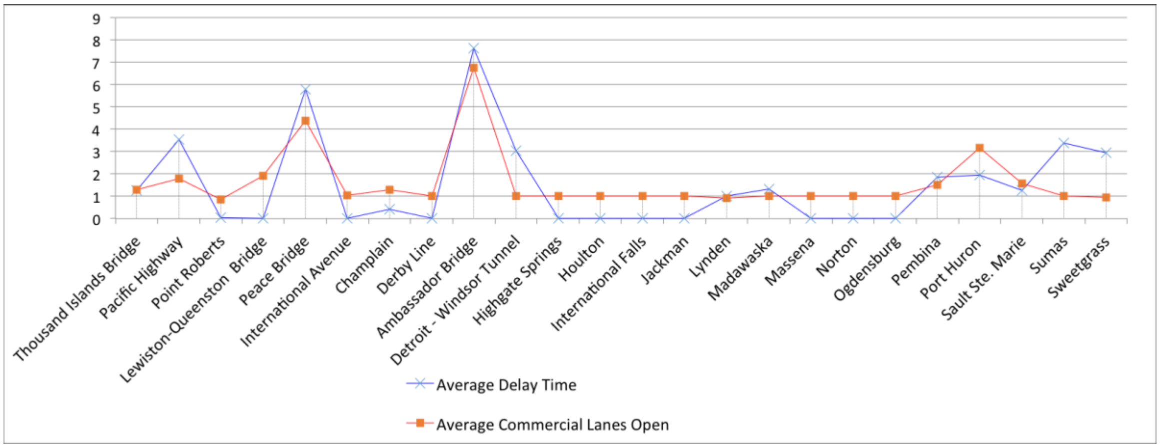


Figure 1. Average Delay Time and Commercial Vehicle Lanes Open at 24 Border Crossings

Source: The US Customs and Border Protection Agency, generated by authors

3.2 Border Wait Time in Ontario and New York

We collected wait time data for commercial vehicles at the US-Canada border crossings near Buffalo, NY, namely, the Peace Bridge (PB) and the Lewiston-Queenston Bridge (LQ), from April to August 2014. The wait time data was recorded each hour, and 17,251 observations were recorded. To collect the data, an automated program was developed. We discarded 665 records, mainly due to data unavailability for at least one bridge as a result of an Internet connection error. We considered both directions on both bridges to create four cases: To US via PB, To US via LQ, To Canada via PB, and To Canada via LQ. Table 2 summarizes the average wait time. We found that the average wait time varied from 1.35 minutes to 8.77 minutes when we considered all 24 hours, and varied from 16.88 minutes to 27.24 minutes when we omit time periods with zero wait time. This difference is attributed to low traffic volume during the overnight hours. In the case of 'To Canada via LQ', there was no delay 92.0% of the total time, while 'To US via PB' there was no delay 67.8% of the time.

Hourly variation in border wait time is significant, as presented in Figure 2. It is interesting to note that peak and non-peak patterns among the four cases are quite different. While there are two peak wait times to enter Canada on both bridges, one around 10am and the other around 7pm, wait times to enter the US via LQ continuously increases until 3pm before subsequently decreasing. Wait times to enter the US via PB also show a similar pattern as 'To US via LQ', but with delay decreasing after 3pm. This suggests that the US border agency increases staffing levels around 3pm to avoid long wait times. However, we cannot confirm this as we do not have access to data regarding hourly staffing levels. It may also be true that the Canadian border agency increases staffing levels at both the PB and LQ before 3pm.

Figure 3 exhibits hourly wait times each weekday. In the middle of a typical week, from Tuesdays to Thursdays, there are peaks early in the morning around 7am, indicating high volume of freight transshipment during weekdays. We also note that wait time subsides earlier on Friday afternoon than on all other weekdays. There is a longer wait time to enter Canada via LQ relative to other cases on Wednesday at 11pm.

There is also significant variation in wait time by month, as shown in Figure 4. The low peak is in June and the high peak is in August. Wait times more than double in August compared to June. The two bridges, PB and LQ, are close to Niagara Falls, a tourist destination that attracts many travelers from both countries. High volumes of tourists traveling in passenger vehicles may affect staffing available for commercial vehicle inspections.

Table 2. Summary of Wait Time for Commercial Vehicles at the Peace Bridge (PB) and Lewiston-Queenston Bridge (LQ)

Truck Class	No delay percentage	Overall truck average wait time (min)	Overall truck average positive wait time (min)
To US via PB	67.8%	8.77	27.24
To US via LQ	83.6%	3.64	22.30
To Canada via PB	89.0%	1.82	16.62
To Canada via LQ	92.0%	1.35	16.88

Notes: 1. 'No delay percentage' is the percentage of time periods with zero wait time; 'Overall truck average wait time' is the average wait time of all time periods; and 'Overall truck average positive wait time' is the average wait time excluding time periods with zero wait time.

Source: The US Customs and Border Protection Agency, tabulated by authors.

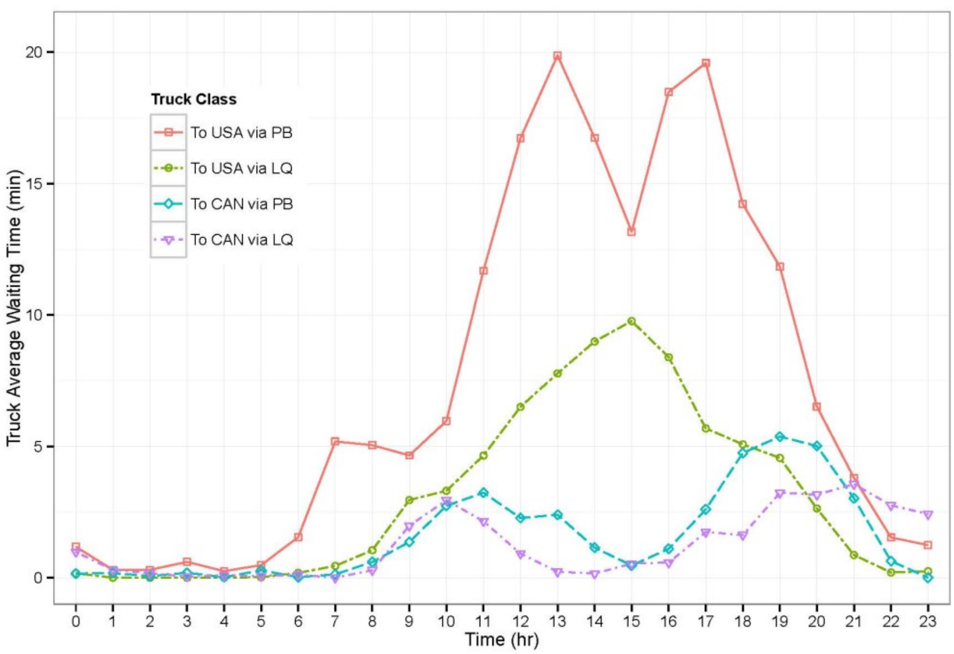


Figure 2. Hourly Wait Time of Commercial Vehicles on the Border Crossings

Note: CAN = Canada; PB= Peace Bridge; LQ = Lewiston-Queenston Bridge
Source: The US Customs and Border Protection Agency, generated by authors.

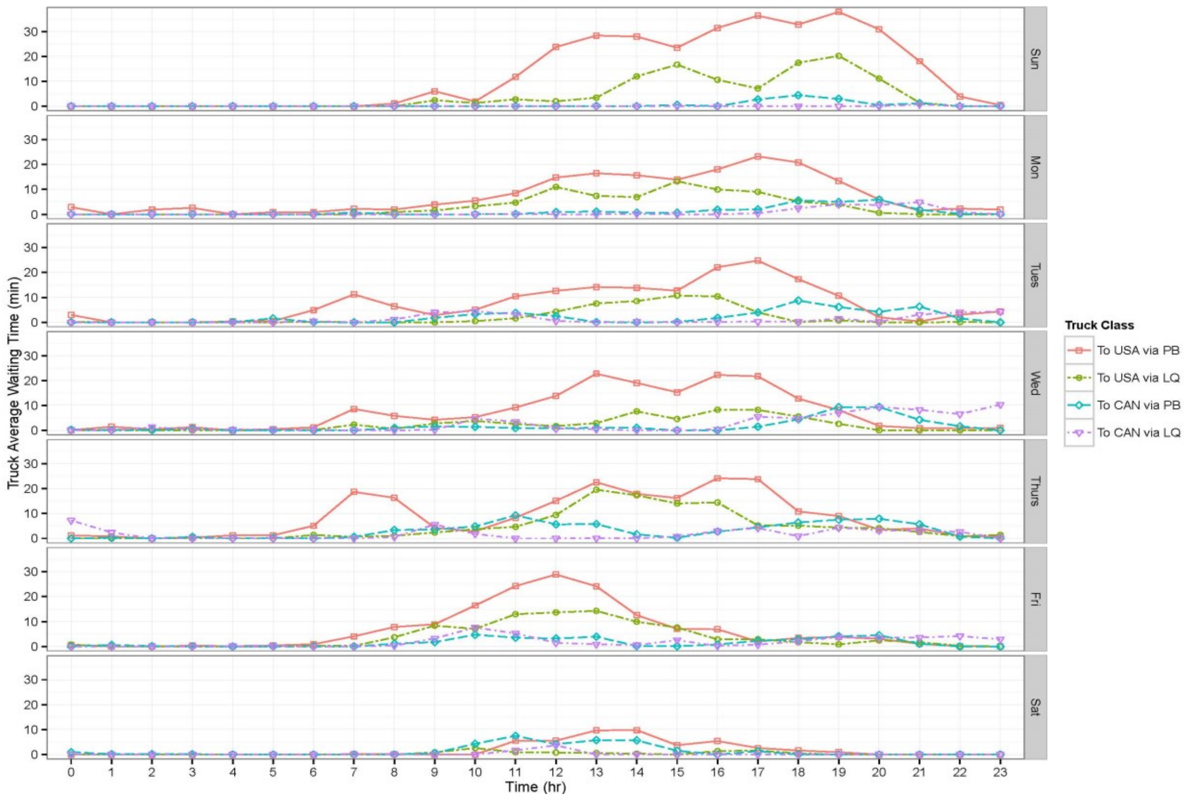


Figure 3. Hourly Wait Time of Commercial Vehicles on the Border Crossings on Each Weekday

Note: CAN = Canada; PB= Peace Bridge; LQ = Lewiston-Queenston Bridge
Source: The US Customs and Border Protection Agency, generated by authors.

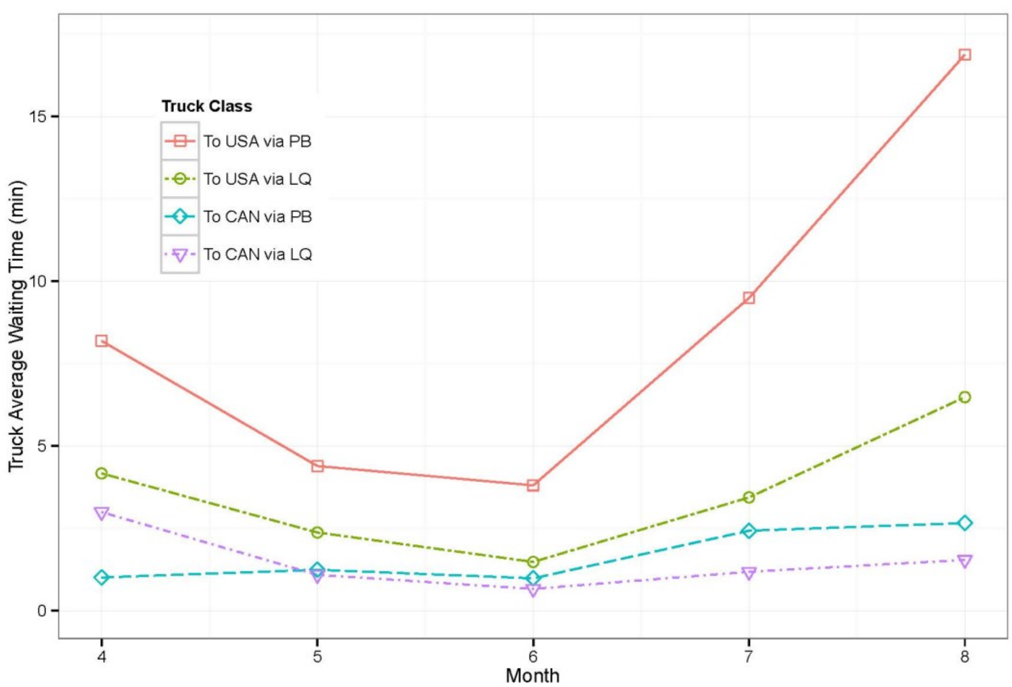


Figure 4. Monthly Variations in Wait Time of Commercial Vehicles on the Border Crossings

Note: CAN = Canada; PB= Peace Bridge; LQ = Lewiston-Queenston Bridge
Source: The US Customs and Border Protection Agency, generated by authors.

These results demonstrate that the average border wait time information presented in Section 3.1 does not adequately address the complexity of congestion at major border crossings. Therefore, it is necessary to further assess border crossings that record heavy delays using the method applied in Section 3.1 with the method applied in Section 3.2.

4. Border Trade

4.1 Trade between the US and Canada

The US and Canada enjoy immense economic benefits from the free flow of goods and services across their borders. Building upon the largest bilateral trading relationship in the world, leaders of both countries have agreed to a joint declaration, Beyond the Border: A Shared Vision for Perimeter Security and Economic Competitiveness (USDHS, 2011), a key tenet of which is to facilitate movement and trade across the border. This policy recognizes the importance of land border crossings and has targeted investment in these areas to further enhance trade.

US-Canada land border crossings play a significant role in facilitating bi-national trade. We collected border trade data from WISERTrade (www.WISERTrade.org). Table 3 illustrates that total bilateral truck trade between the two countries has grown steadily from 313.9 billion USD in 2011 to 335.9 billion USD in 2014. US imports grew at a rate of 8.30% during this period, outpacing the growth of imports (5.88%). Consistently ranked as the top 3 commodities over this four year period were vehicles and related components, industrial machinery and electrical machinery. Among the top 10 traded commodities, vehicles and related components have experienced a substantial growth rate of 37% while paper related products, the only commodity type that declined, dropped 11%. Hence, with the growing exchange of goods between the two countries, it is critical to investigate the freight flows of individual border crossings to further understand this bi-national trade relationship.

Table 3. Freight Imports and Exports by trucks in USD between the US and Canada

	2011	**2012**	**2013**	**2014**
Imports*	149,684	152,815	152,684	162,113
Exports*	164,170	172,218	172,732	173,819
Total**	313,855	325,033	325,416	335,933

Note: *Imports (Exports) denote freight flow from (to) Canada to (from) the US. ** Number is rounded to unit.
Unit: $ millions.
Source: WISERTrade (www.WISERTrade.org), tabulated by authors.

4.2 Data Processing for Freight Imports and Exports

Using publicly available data sources, we obtained origin and destination information for US and Canada imports and exports to and from POE, even though we ultimately will not know direct regional origins and destinations through specific border crossings. There are two key sources available for this information, Freight Analysis Framework version 3 (FAF[3], http://ops.fhwa.dot.gov/freight/freight_analysis/faf) and WISERTrade (http://www.wisertrade.org). We chose to mine WISERTrade data since it covers both the US and Canada and is actual recorded data, as FAF only covers the US with estimates. The WISERTrade POE data shows the flow of freight between each border crossings and each country's regional origins and destinations by commodity type in US dollars, along with some tonnage values. We created a complex dataset using these values, where we characterized exports with an origin state or province and port identification code value, and imports with a port identification code and destination state or province.

Bi-national freight flow at POE can be expressed by the following equations (1-1 through 1-4).

$$US\ Exports\ to\ Canada = \sum_b \sum_i \sum_{k_{O_i}} O_{ib} \cdot V_{k_{O_i}} \quad (1\text{-}1)$$
$$US\ Imports\ from\ Canada = \sum_b \sum_i \sum_{k_{D_i}} D_{ib} \cdot V_{k_{D_i}} \quad (1\text{-}2)$$
$$Canadian\ Exports\ to\ the\ US = \sum_b \sum_j \sum_{k_{O_j}} O_{jb} \cdot V_{k_{O_j}} \quad (1\text{-}3)$$
$$Canadian\ Imports\ from\ the\ US = \sum_b \sum_j \sum_{k_{D_j}} D_{jb} \cdot V_{k_{D_j}} \quad (1\text{-}4)$$

Then, we assumed the relationship between the US and Canada trade flow (2-1 and 2-2),

$$US\ Exports\ to\ Canada = Canadian\ Import\ from\ US \quad (2\text{-}1)$$
$$US\ Imports\ from\ Canada = Canadian\ Export\ to\ US \quad (2\text{-}2)$$

where

$b = border\ bridges\ between\ US\ and\ Canada$

$i = US\ states$

$j = Canadian\ provinces$

$k = 2digit\ harmonized\ system\ (HS)\ codes = \{1 \ldots 99\}$

$O = Origin\ of\ freight\ flow$

$D = Destination\ of\ freight\ flow$

$m = US\ states\ i\ or\ Canadian\ provinces\ j$

$k_{O_m} = Group\ of\ HS\ commodity\ codes\ for\ i\ or\ j\ as\ origin, \forall k_{O_m} \subset k$

$k_{D_m} = Group\ of\ HS\ commodity\ codes\ for\ i\ or\ j\ as\ destination, \forall k_{O_m} \subset k$

$V_{k_{O_m}} = Value\ of\ HS\ commonidy\ k\ in\ state\ i\ or\ province\ j\ as\ origin$

$V_{k_{D_m}} = Value\ of\ HS\ commonidy\ k\ in\ state\ i\ or\ province\ j\ as\ destination$

4.3 The Edge List of US and Canada POE

Identifying and connecting US and Canadian border crossings through highways is another important task for building a bi-national freight flow dataset. We obtained 138 border crossings (69 border crossings for each country) by comparing GIS data obtained from the Canada-United States Transportation Border Working Group (TBWG), and port import and export data from WISERTrade. Since highway network datasets of both countries are not neatly connected on border crossings, we manually connected them using ArcGIS 10.1, and integrated these into a bi-national highway network (see Figure 5). Using this completely integrated bi-national highway network, we built the bi-national highway network dataset, which generates arcs and nodes.

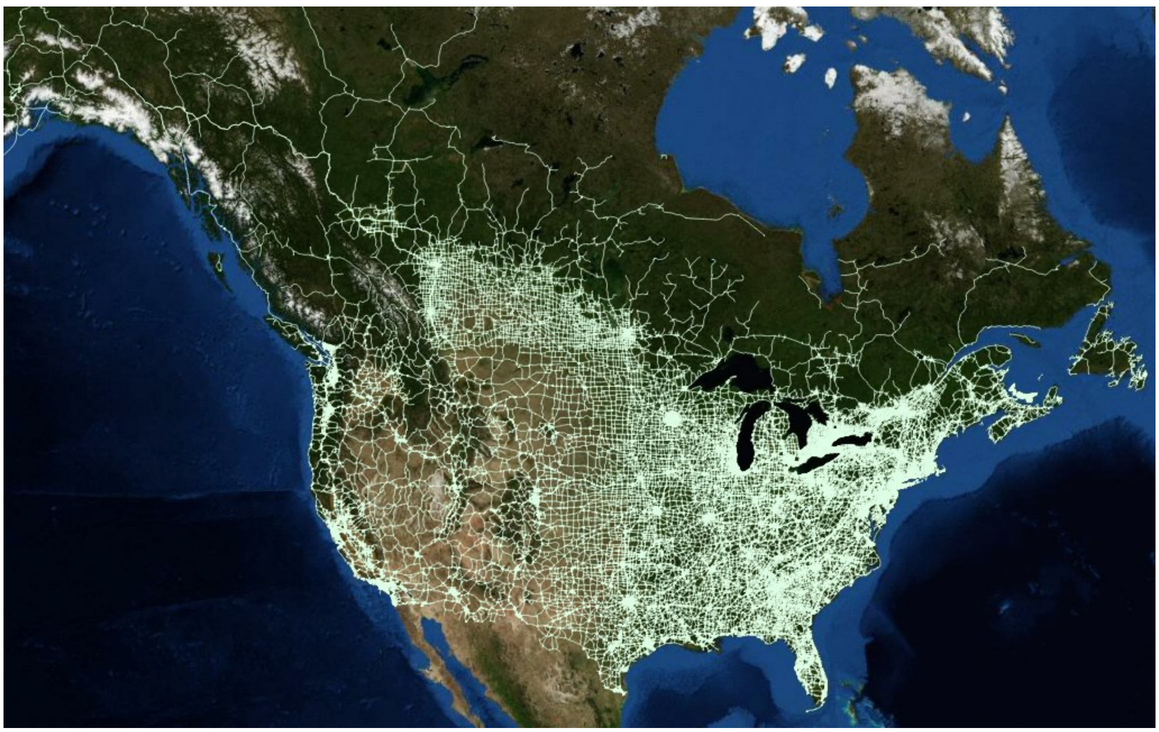


Figure 5. Bi-national Highway Network of the US and Canada

Note: The map visualization is generated by ArcMap 10.1.
Source: Highway shapefiles are collected from GeoGratis and FHWA for Canada and US, respectively.

This process generated the edge list including border crossings connecting the US and Canada. This edge list is the key component required in connecting bi-national freight flow, since all the commodity data on freight origins and destinations are connected to one node of the edge list in either the US or Canada. As illustrated in Figure 6, while the ideal bi-national freight network would have direct origin and destination information between the US and Canada, we proposed a data-driven bi-national freight network linked at border crossings. Appendix 1 presents the example of the bi-national freight network dataset, which shows the data structure. This dataset has a single array form, which is the most efficient data structure for representing networks (Ahuja et al., 1993). This edge list stores link ID, from-node ID, to-node ID, HS2 commodity type, value of freight in US dollars, TEU, and other link attributes. The names of the ports that are paired by border crossings between the US and Canada are available in Appendix 2.

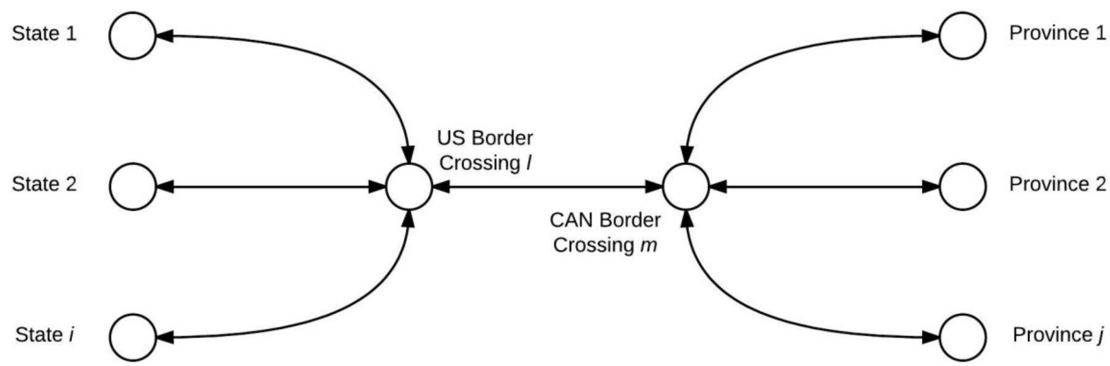


Figure 6. The Bi-national Freight Network on Border Crossings

Note: CAN = Canada

4.4 Converting Dollar Value to TEU

From WISERTrade, we could only obtain freight flow value by border crossings and by origin and destination in US dollars. However, in order to connect border freight flow into the bi-national highway network dataset, value in US dollars had to be converted into a unit of weight. In freight analysis, this value is generally calculated in the form of TEU. The TEU is a standard unit of measurement based on the size of the standard shipping container used on container ships. These shipping containers, upon reaching a container port, are transferred onto trucks or trains.

Using WISERTrade data, however, proved to be an issue because freight information was not directly available using this unit of measure. WISERTrade provides only air and vessel data in terms of both weight and dollar value. We could, however, convert dollar value into TEU by considering the characteristics of commodities, as containerized cargo, transported by vessels (generally more similar in characteristics to those transported by truck than those transported by air). Therefore, for the purpose of this analysis, we assumed that the commodity types traded between the US and all other countries by vessel would have similar characteristics to the commodities traded between the US and Canada by truck. Note that perishable goods which are defined in Harmonized System (HS) 2-digit codes 7 and 8 may be different. However, total freight of perishable goods only accounts for 1.29% and 2.23% for import and export of US side, respectively. Therefore, the differences seem trivial and are not considered in this study.

To conduct the conversion, we downloaded vessel data from WISERTrade and calculated "ton/dollar" for each commodity, which is a number of tons per one US dollar. To finally convert ton value to the standardized freight volume, we adopted the concept of the TEU as representing 18 tons (Park et al., 2014a). This is in order to accommodate for the fact that freight containers often contain some form of packaging to protect the products being delivered from damage. A unique "TEU/dollar" value was applied for each commodity type. For the purpose of commodity type, 2-digit HS codes are used to differentiate commodities. The HS system is a unified global tariff nomenclature that classifies commodities. This classification system is maintained by the World Customs Organization. We multiplied the "TEU/dollar" ratios with the dollar value of each commodity at each border crossings and by origin/destination and obtained TEU values. See Appendix 4 for more details on generating "TEU/dollar," and Appendix 3 for a list of 2-digit HS codes and descriptions.

5. Analysis

5.1 Descriptive Statistics

Since the US and Canada have the largest bi-national trade relationship in the world, a primary interest of our study was to determine what type of commodities are currently trading between the two countries. We first aggregated the total value of goods traded by truck via all border crossings. Table 4 shows top imports and exports between the US and Canada in terms of both monetary values and TEU. Overall, manufactured instruments and machinery with complex systems of internal components such as vehicles, computers and industrial machinery are ranked highest, similar to the findings in Park et al. (2014a). The lowest ranked commodity types are agricultural products. These commodities have a higher TEU in proportion to monetary value.

After getting a snapshot of aggregate trade, we then looked at regional origins and destinations for commodities to and from the US and Canada via border crossings. Table 5 explains top provinces and states in terms of exports and imports in both US dollars and TEU. For Canada, an overwhelming proportion of freight originates from and is destined to Ontario. For the US, freight is more evenly distributed across the 48 contiguous states, though Michigan ranks highest in imports and exports when looking at both dollar value and TEU. Another notable observation is that Michigan and Ontario, the top ranked state and province, respectively, are directly connected. This makes evident the fact that the economies of Michigan and Ontario are tightly linked.

Table 4. Top Commodities Exchanged Between the US and Canada by Total TEU

HS Code*	**Export**				**Import**				**Total**	
	Canada		US		Canada		US		Canada	
	Value**	TEU***	Value	TEU	Value	TEU	Value	TEU	Value	TEU
44	3,204	590,687	1,362	251,197	1,518	279,812	1,869	344,568	7,952	1,466,263
72	3,464	369,019	3,720	396,318	3,703	394,526	2,456	261,608	13,343	1,421,470
27	2,585	298,990	1,885	218,058	1,914	221,411	1,609	186,171	7,993	924,630
48	4,483	274,129	3,343	204,428	3,351	204,890	2,296	140,369	13,473	823,816
87	28,027	152,261	32,288	175,412	32,450	176,291	21,364	116,062	114,129	620,025
39	6,814	165,521	7,271	176,610	7,249	176,087	4,142	100,604	25,476	618,822
7	1,545	107,241	1,721	119,413	1,702	118,080	1,074	74,492	6,042	419,225
23	702	81,628	954	110,827	953	110,756	464	53,951	3,073	357,161
28	1,335	130,841	605	59,270	666	65,219	724	70,964	3,330	326,294
84	19,942	72,626	24,966	90,920	24,887	90,632	15,051	54,815	84,846	308,993
10	521	91,984	318	56,158	319	56,231	449	79,260	1,608	283,634
12	686	70,440	397	40,791	399	40,952	828	85,065	2,309	237,249
25	275	65,211	250	59,205	251	59,450	131	30,966	907	214,832
76	3,307	69,119	2,447	51,154	2,450	51,210	1,756	36,705	9,960	208,188
19	2,514	65,236	1,998	51,843	1,956	50,739	1,427	37,019	7,895	204,836
31	552	76,826	267	37,173	267	37,224	372	51,738	1,458	202,961
2	2,011	50,703	1,902	47,948	1,902	47,945	1,454	36,657	7,269	183,253
73	3,334	37,814	4,793	54,369	4,790	54,331	2,310	26,204	15,226	172,718
20	906	38,032	1,162	48,797	1,153	48,429	561	23,533	3,782	158,791
40	2,597	36,066	2,342	32,528	2,347	32,594	2,072	28,767	9,358	129,955
38	1,481	22,333	2,568	38,739	2,578	38,889	1,035	15,605	7,662	115,565
47	275	46,466	98	16,614	97	16,309	189	31,901	659	111,290
3	1,980	40,463	564	11,531	591	12,066	2,262	46,211	5,397	110,271
22	726	26,913	822	30,464	820	30,421	400	14,846	2,768	102,644
29	366	12,654	1,086	37,494	1,092	37,695	268	9,266	2,812	97,109

Notes: *Harmonized System Code. Refer Appendix 3 to the HS code sector definition. **Value in US Dollars (millions). ***Twenty-foot equivalent unit.
Source: WISERTrade (www.WISERTrade.org), tabulated by authors.

Table 5. Top Exports and Imports of Provinces and States by TEU

Province /State	Export		Import		Total	
	Value*	TEU**	Value	TEU	Value	TEU
Canada	143,933	3,428,082	145,509	2,875,653	289,442	6,303,735
ON	91,652	1,592,749	96,757	1,788,221	188,408	3,380,970
QC	27,943	881,869	8,399	171,876	36,341	1,053,745
BC	6,636	335,925	12,374	424,388	19,009	760,313
AB	6,366	228,551	6,394	112,247	12,761	340,798
MB	5,189	131,786	11,234	198,840	16,422	330,625
US	144,104	2,822,975	93,496	2,204,359	237,600	5,027,334
MI	18,053	277,977	22,580	370,407	40,633	648,384
OH	14,241	269,356	5,394	137,049	19,635	406,404
WA	4,760	211,620	3,577	124,828	8,337	336,448
IL	10,065	157,107	6,296	175,656	16,361	332,762
CA	7,771	192,254	6,203	125,998	13,974	318,252
IN	8,480	129,151	5,730	112,520	14,210	241,670
TX	7,304	98,696	6,398	89,848	13,701	188,544
NY	4,630	107,366	1,720	80,937	6,349	188,303
ND	1,420	76,657	1,749	111,311	3,169	187,969
WI	5,597	105,182	2,411	78,178	8,008	183,360
PA	6,021	152,835	944	30,399	6,965	183,234
MN	4,126	84,927	2,117	80,654	6,243	165,581
OR	2,106	78,005	870	40,377	2,976	118,382
KY	4,707	72,737	2,211	35,251	6,918	107,988
MA	1,837	29,764	2,161	64,866	3,999	94,630

Notes: *Value in US Dollars (millions). **Twenty-foot equivalent unit.
Source: WISERTrade (www.WISERTrade.org), tabulated by authors.

With aggregate and regional trade analyzed for the POE, the key links in bi-national supply chains and key nodes in a bi-national combined economic model were subsequently observed. Figure 7 visualizes the size of freight flow in dollar value for each border crossing. The general trend is that the ports with the greatest freight flow are located along major transportation corridors and have a physical highway connection and link major metropolitan areas. This is particularly evident in Ontario; it contains the highest amount of freight flow and features extensive highway connections to major metropolitan centers in the Midwest and the Northeast regions of the US.

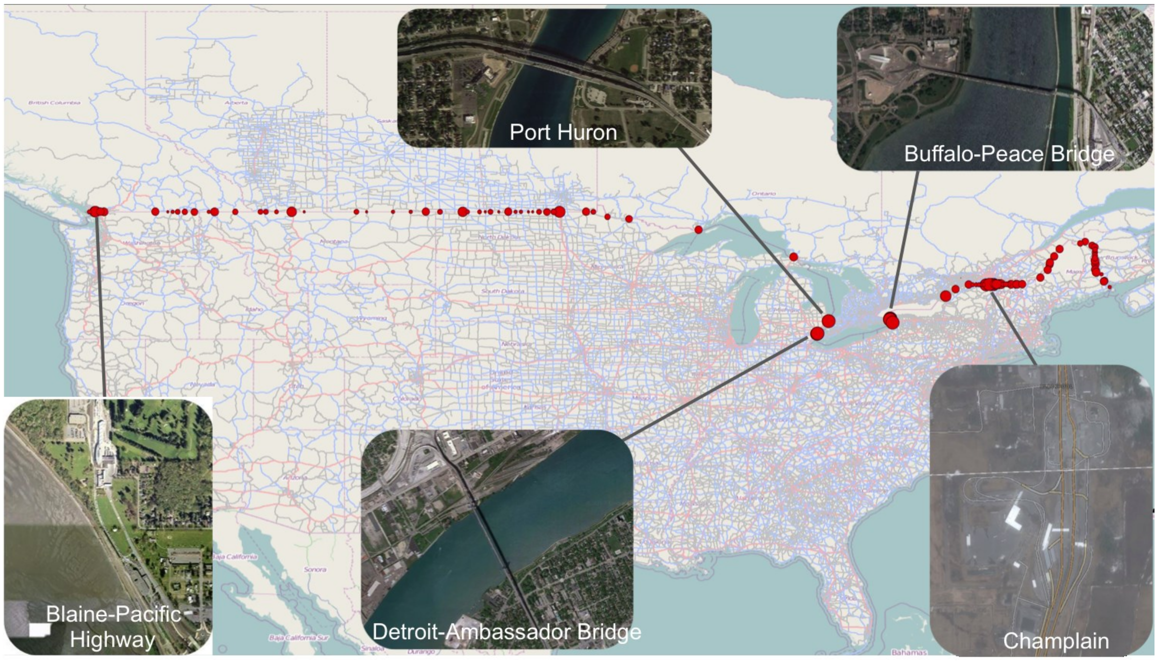


Figure 7. Visualization of Freight Value on Border Crossings between the US and Canada

Note: Red circles represent the magnitude of trade flow in US Dollars; larger circles indicate greater magnitudes.
Source: Tiger Products and GeoGratis (Highway Networks), Google Maps (Border Crossings), and WISERTrade (Freight value points), generated by authors using ArcGIS 10.2 and PowerPoint 2013.

Given the concentration of US-Canada trade on only a few POE, we chose the top five POE for closer analysis. Table 6 summarizes dollar value and TEU volume of the top five border crossings. Rank is sorted by total TEU, which does not have a proportional relationship with total monetary value. As indicated by monetary value and TEU volume, for example, a large proportion of the freight crossing at Blaine-Pacific Highway involves agriculture-related goods while Champlain has a high proportion of manufactured goods in their trade flow.

Table 6. Top 5 Border Crossings by Monetary Value and TEU

POE name	Export		Import		Total	
	Value *	TEU **	Value	TEU	Value	TEU
Detroit	45,007	740,833	52,021	833,644	97,028	1,574,476
Buffalo	27,674	552,757	15,097	330,264	42,771	883,021
Port Huron	19,552	426,804	22,482	437,654	42,034	864,458
Blaine-Pacific Highway	5,732	181,312	8,395	267,437	14,127	448,749
Champlain	11,213	251,494	5,915	101,662	17,128	353,156

Notes: *Value in US Dollars (millions). **Twenty-foot equivalent unit.
Source: WISERTrade (www.WISERTrade.org), tabulated by authors.

One feature in common among the top five POE is the presence of a multi-lane highway on either side of the crossing facility. We found there is a relationship between TEU and number of designated commercial inspection booths. This is, however, not the case for the number of designated commercial lanes. The number of Free and Secure Trade inspection booths, which provide commercial trucks fast-tracked border crossing travel, also does not correspond to TEU units passing through a border crossing.

5.2 Centrality and Network Scope

We calculated Weighted Eigenvector Score (WES) using TEU as a weight factor for all POE and regional ODs (Equation 3). WES is the Eigenvector Centrality score that applies edge weight as initial values, while normal Eigenvector Centrality score applies "1" as its initial values. By applying edge weights, TEU, WES for border crossings considers the number of edges to regional bodies, magnitude of neighbors (after applying edge weight, magnitude means combination of number of connecting border crossings and their volume of TEU to all border crossings), and the strength of ties connecting each regional body, namely TEU. This score shows that POE, with higher WES, link major import and export states/provinces with high freight volume, and which states/provinces use bustling POE with high freight volume. To be specific, when a border crossing has high WES value, it is the combined output of: 1) The magnitude of states/provinces that use this border crossing; 2) The count of states/provinces that use this border crossing; and 3) The volume of TEU from states/provinces. When a state/province has high WES value, it is the combined output of: 1) This state/province uses many border crossings (geographical scope of bi-national trade is wide); 2) This state/province uses bustling border crossings (border crossings with large magnitudes); and 3) The volume of TEU from border crossings is high. While the meaning of WES for border crossings is more significant, WES for states/provinces is still meaningful.

$$x_v = \frac{1}{\lambda}\sum_{t\in M(v)} x_t = \frac{1}{\lambda}\sum_{t\in G} a_{v,t}x_t \qquad (3)$$

$where$

$G = (V, E) is\ a\ graph\ with\ |V|\ which\ is\ number\ of\ nodes\ (state\ or\ province\ ODs)$

$and\ |E|\ which\ is\ number\ of\ arcs;$

$A = (a_{v,t}) is\ the\ adjacency\ matrix;$

$a_{v,t} = 1\ if\ node\ v\ is\ linked\ to\ node\ t, 0\ otherwise;$

$M(v)\ is\ a\ set\ of\ nodes\ connected\ to\ node\ v$

$\lambda\ is\ \ a\ constant\ to\ make\ the\ equation\ a\ nonzero\ solution.$

The WES approach generates the centrality of the top five POE on the freight flow network (see

Table 7). Interestingly, this ranking of POE on WES is the same as the rank of POE on total TEU. This denotes that the volume of TEU is a more important factor than the scope of network for border crossings because most border crossings have connections with most states/provinces. Detroit-Ambassador Bridge (NY) and Buffalo-Peace Bridge (NY) are the top two POE due to their proximity to Ontario, which generates two-thirds of total freight flow in Canada. Among regional ODs, Ontario got the maximum value of 1. This means Ontario is the most outstanding center of freight movement between the US and Canada. Considering the fact that the values of imports and exports between the two countries are similar, it is reasonable to understand that many Canadian provinces are ranked above American states because of the higher number of regional ODs in the US than Canada.

Based on the descriptive analysis result of regional origins and destinations, Ontario and Quebec in the East and British Columbia in the West dominate border trade among Canadian provinces, and Michigan, Ohio, Washington, and Illinois are the most important US states. Using WES provides different results. While Michigan is still the most dominant state, it is followed by California, Illinois, Texas, Ohio, and Washington. This indicates that large US states have wider networks than Canadian provinces. Additionally, US states on the Canadian border have a greater total volume of trade than some large US states, but this trade is with a small number of Canadian provinces, minimizing the border states' WES.

Table 7. Weighted Eigenvector Score of Top 20 POE (left) and US States and Canadian Provinces (right)

Rank	POE	WES	Rank	State/ Province	WES
1	Detroit (MI)*	7.69E-01**	1	ON (CAN)***	1.00E+00
2	Buffalo (NY)	7.23E-01	2	QC (CAN)	9.01E-02
3	Port Huron (MI)	3.64E-01	3	BC (CAN)	3.19E-03
4	Blaine-Pacific Highway (WA)	3.56E-01	4	MB (CAN)	1.72E-03
5	Champlain (NY)	2.65E-01	5	AB (CAN)	1.25E-03
6	Alexandria Bay (NY)	2.84E-02	6	SK (CAN)	4.99E-04
7	Ogdensburg (NY)	1.43E-02	7	NB (CAN)	1.08E-05
8	Sweetgrass (MT)	1.10E-02	8	MI (US)	2.61E-16
9	Pembina (ND)	1.02E-02	9	CA (US)	9.78E-17
10	Highgate Springs (VT)	8.95E-03	10	IL (US)	9.78E-17
11	Sault Ste. Marie (MI)	4.84E-03	11	TX (US)	9.78E-17
12	Portal (ND)	3.94E-03	12	OH (US)	6.52E-17
13	Derby Line Rt. 91 (VT)	3.03E-03	13	WA (US)	6.52E-17
14	Sumas (WA)	1.39E-03	14	IN (US)	4.35E-17
15	Massena (NY)	1.00E-03	15	TN (US)	3.80E-17
16	Calais (ME)	9.20E-04	16	GA (US)	2.72E-17
17	Eastport (ID)	8.10E-04	17	MO (US)	2.72E-17
18	Jackman (ME)	6.32E-04	18	KS (US)	2.45E-17
19	Norton (VT)	6.11E-04	19	KY (US)	2.45E-17
20	Grand Portage (MN)	5.24E-04	20	OK (US)	1.90E-17

Notes: *This refers to the relevant state or province where the border crossing bridge is located. For the abbreviations of US states and Canadian provinces, see Appendix 2.
**7.69E-01, and subsequent numbers in this form, are condensed using scientific notation, and should be understood as 7.69×10^{-1}, or .769.
***This refers to the relevant countries. CAN stands for Canada.
Source: Based on WISERTrade (www.WISERTrade.org), authors generated WES using R 3.1.1.

In terms of the geographical scope of the top POE, the US and Canada differ. Table 8 displays regional origins and destinations to and from the top five POE. In terms of exports, all top five POE have origins (US States to Canada or Canadian Provinces to the US) in most of the states and provinces of the US and Canada, respectively. While the top five POE are connected to most Canadian provinces where top exports originate, the proportion of TEU is highly concentrated to a province, especially Ontario. It shows a distinctive contrast to the export proportion of American states that are more evenly distributed. Figure 8 demonstrates that the top five provinces of Canada represent almost 100% of Canadian exports, while the top five American states represent 60 to 80% of total exports to Canada via the top five POE. It could be partly due to the different concentration of economic activities in US states versus Canadian provinces. Regardless of this difference, the proportion of the top five states or provinces for exporting TEU shows the diversity of regional originations for the US, while one province dominates the use of the top four POE in Canada. In terms of imports, Canadian POE are dominated by almost one province, where the POE are located (Figure 9). This denotes that Canadian import goods from the US are mostly consumed within the province of their POE, while American import goods from Canada are distributed and consumed nationwide. This is mainly due to a deepening economic division between the East and the rest, whereas the US has many developed metropolitan regions in diverse geographical locations. This result corresponds to the earlier prediction of McCallum (1995) on the Canada-US regional trade pattern. In his study, using the gravity model, Canadian shipment of goods to other provinces was predicted as only 4% while the predicted shipment to the US was 43%.

Table 8. Geographical Scopes and Freight Amount of the Top 5 POE

Top 5 Ports		US States	CAN Provinces
Detroit	US to CAN***	47 States MI* (0.21)**, OH (0.16), IN (0.08), IL (0.07), KY (0.06)	1 Province ON (1.00)
	CAN to US	48 States MI (0.30), OH (0.11), IL (0.10), IN (0.09), TX (0.05)	11 Provinces ON (0.77), QC (0.19), AB (0.01), NS (0.01), NB (0.01)
Buffalo	US to CAN	48 States PA (0.23), OH (0.21), NY (0.11), NC (0.06), NJ (0.05)	1 Province ON (1.00)
	CAN to US	48 States PA (0.24), OH (0.20), NY (0.09), NC (0.07), NJ (0.05)	13 Provinces ON (0.88), QC (0.05), BC (0.04), AB (0.02), MB (0.01)
Port Huron	US to CAN	49 States MI (0.19), IL (0.12), IN (0.10), CA (0.09), WI (0.08)	1 Province ON (1.00)
	CAN to US	48 States	11 Provinces

		MI (0.36), IL (0.15), IN (0.09), WI (0.06), OH (0.06)	ON (0.77), QC (0.20), NS (0.10), NB (0.10), SK (0.00)
Blaine-Pacific Highway	US to CAN	49 States WA (0.48), CA (0.18), OR (0.11), TX (0.02),	1 Province BC (1.00)
	CAN to US	48 States WA (0.44), CA (0.22), OR (0.14), TX (0.03), NV (0.01)	12 Provinces BC (0.87), ON (0.07), AB (0.03), MB (0.01), QC (0.01)
Champlain	US to CAN	46 States NY (0.21), NJ (0.14), PA (0.13), FL (0.08), NC (0.06)	1 Province QC (1.00)
	CAN to US	45 States NY (0.23), PA (0.14), NJ (0.13), FL (0.07), NC (0.06)	11 Provinces QC (0.89), ON (0.08), NB (0.01), AB (0.00), BC (0.00)

Notes: * This is the abbreviation of US states and Canadian provinces, which are top 5 TEU origins and destinations, in order. For the abbreviations of US states and Canadian provinces, see Appendix 2.
**Numbers inside of parentheses explain proportions of TEU; for example, in the Detroit row, the 0.21 next to MI under exports indicates that exports from Michigan via the Detroit-Ambassador Bridge account for 21% of total exports that cross the bridge from the US.
***CAN = Canada

Source: WISERTrade (www.WISERTrade.org), tabulated by authors.

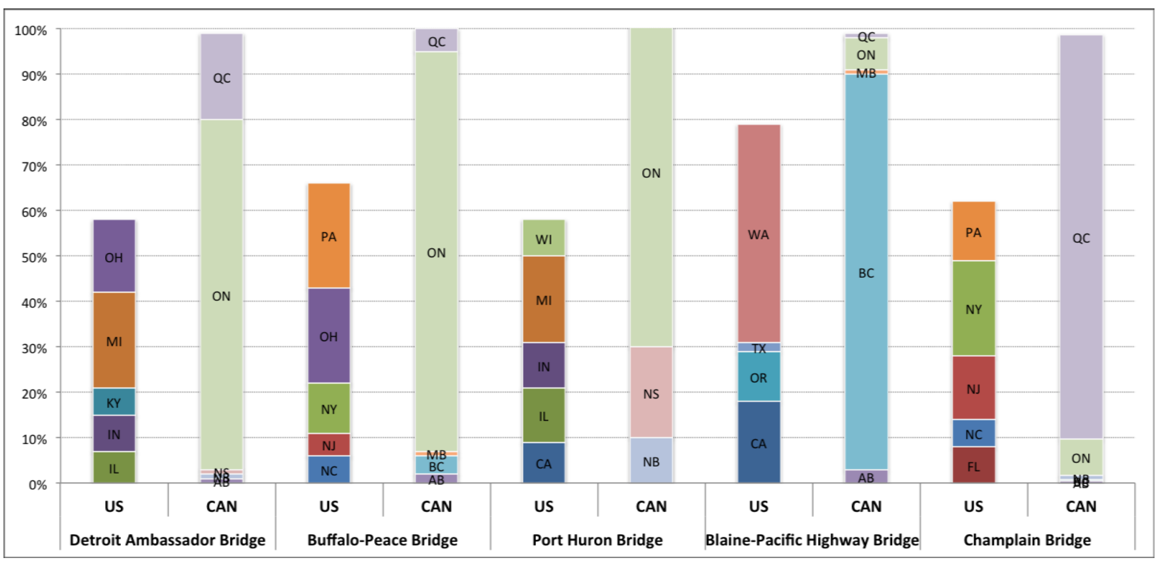


Figure 8. Proportion of Exporting TEU of Top 5 Regional Origins in Top 5 Border Bridges

Note: CAN = Canada
Source: WISERTrade (www.WISERTrade.org), generated by authors.

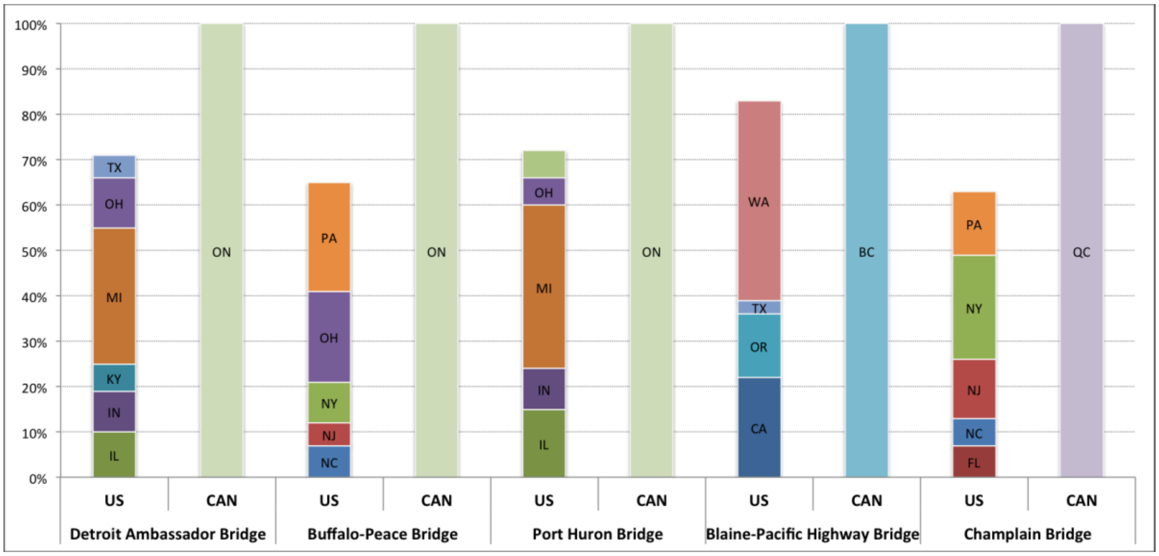


Figure 9. Proportion of Importing TEU of Top 5 Regional Destinations in Top 5 Border Bridges

Note: CAN = Canada
Source: WISERTrade (www.WISERTrade.org), tabulated by authors.

6. Conclusions and Discussion

As the largest trade partnership in the world, the US and Canada have highly integrated cross-border supply chains with final product exports destined for places across both countries and around the world. Upon building a bi-national trade dataset, we converted dollar value into TEU to measure transportation effects on the border crossings. Based on our border trade descriptive analysis, among many regional origins and destinations, Ontario and Quebec in the East and British Columbia in the West are the dominant provinces in Canada; Michigan, Ohio, Washington, and Illinois are the most important states in the US. It is different from the result of WES, especially in the US, due to the wider network scope of large US states. On the other hand, descriptive analysis and WES confirmed that Detroit-Ambassador Bridge, Buffalo-Peace Bridge, Port Huron, Blaine-Pacific Highway Crossing, and Champlain Crossing are the top five POE connecting the economies of the US and Canada.

While TEUs are more evenly distributed across US states, one single province dominates as the origin of exports to US and, especially, the destination of imports from the US at all the top five border crossings. These crossings primarily provide a route for imports with a destination within the province that they connect with. Therefore, Canadian economic activity occurs in provinces with major border crossings because these provinces have a relatively larger share of trade and larger shares of population and GDP closer to the border compared to neighboring US states; however, those in the US are dispersed, indicating other major cities in the US that are not located near the US-Canadian border crossings consume diverse Canadian – or global – products via Canadian POE. It is worth noting, also, that Blaine-Pacific Highway, Buffalo/Niagara Falls–Peace Bridge, Detroit–Ambassador Bridge, Detroit–Windsor Tunnel, and Sumas registered as the crossings with the most commercial travel delay based on variations in hour, by day, and by month. It also should be noted that a small number of border crossings play a key role in connecting the US and Canadian economies. An unexpected event, for example, the lake-effect snowstorm that occurred in 2014 and disrupted operations at key border crossings, could result in severe commercial traffic re-routing and delays at crossings heading into both countries.

Disruption in these trade linkages would have tremendous consequences for global trade. This points to the tension between border security, on the one hand, and facilitating legitimate flows of goods across the US-Canadian border on the other hand. Although border policy historically has contended with these two interests, twenty-first century forces of globalization – both the beneficial and the dark – exacerbate this tension and make evident the inherent tradeoffs between the desire to maximize prosperity and minimize risks associated with terrorism and other transnational threats (Friedman, 2008).

In addition to these compelling and obvious threats, a "slow burn" is taking place on the northern border that may have more profound impacts on trade disruption – infrastructure investment at the border. Both the US and Canadian governments have set out a cross-border approach to strengthening the resiliency of border infrastructure. According to the Canada-US Action Plan for Critical Infrastructure (2010), critical infrastructures are the assets, systems, and networks that are essential to the security, public health and safety and economic vitality of the US and Canada. This infrastructure is at risk from a number of threats, with disruptions resulting in catastrophic losses in terms of economic effects, among others. These disruptions have direct impacts on businesses and regional economies on both sides of the border, as well as cascading effects far beyond the border.

However, Congress has not authorized funding for land ports of entry in fiscal years 2011-2013. In 2014, the CBP identified need to recapitalize land port of entry infrastructure is estimated somewhere in the neighborhood of $6 billion, yet Congress only appropriated $295 million for improvements at a few ports of entry along the US-Mexico border (US GSA, 2014). CBP and GSA (General Services Administration) are looking to alternative funding models, including public-private partnerships, to fill this gap. The jury is still out as to whether these efforts will succeed, but the point is clear: given that these border crossings play a critical role in the global economy, more attention and funding should be focused on this area.

One positive note is that the contracting process that has begun to construct the Gordie Howe International Bridge across the Detroit River. With an eye toward strengthening security and alleviating congestion, this bridge will serve as a third conduit to facilitate flows between Detroit, Michigan and Windsor, Ontario. Slated for completion in 2020, this much delayed project is considered to be a "transformational" part of Michigan's infrastructure. Yet, it is important to note that funding for this large-scale border infrastructure comes almost exclusively from the Canadian government, which has committed not only to fund the whopping $2.1 billion cost of the bridge, but a $250 million improvement to the customs plaza on the US side of the bridge. Thus, although this is seemingly a positive development in handling cross-border transportation disruptions and delays, the financing of this bridge underscores continued inattention on the US side.

This study provides various specific recommendations that are applied to business practice and the formulation and implementation of public policy. First of all, this study plays a key role in constructing a bi-national TransNIEMO-type model that can support the simulation of these border security and policy issues. The bi-national economic models' extension to transportation networks represents the trade freight flow of trucks to origin and destination locations using the bi-national highway system. This integrated bi-national model, therefore, can contribute to simulating freight traffic flows and the corresponding economic losses resulting from new burdens on or near border crossings. For example, auto and truck accidents may be the most frequently occurring negative events that inhibit the performance of any transportation system, at least for a short term. Accidents involving hazardous materials will result in more severe impacts, and possible cyber or physical terrorist attacks, or extreme events such as earthquakes, could result in even more significant impacts. In addition, this study can be extended to explore whether there are alternative supplies and economic structure changes in the event of a prolonged border crossing closure, considering industrial and spatial resilience (Okuyama *et al*., 1999; Sohn *et al*. 2004; Park et al., 2011; Park and Richardson, 2014). This extension would provide valuable information on border protection policy for US-Canada trade.

Further, because the disruptions could affect many supply chains in both countries, a spatially decomposed model representing metropolitan areas in each state and province must be developed. This spatial extension could contribute to a better understanding of how security procedures required at key border crossings impact freight flows in metropolitan areas. This is especially true in the Niagara Falls area; the highway network connecting Toronto to Hamilton, ON to Buffalo, NY is congested almost every day by passenger and freight vehicles. It is certainly valuable to measure how congestion cost externalities impact local economies – particularly given that no "one size fits all" policy applies across the border (Sands, 2009). Indeed, measures that provide for more regional autonomy and permit timely responses to local conditions tend to maximize efficiencies and facilitate trade without compromising security (UBRI/BPRI, 2008).

Also, worth investigation is whether increases in border crossing capacity will reduce the congestion that adversely affects neighboring economies. Increased road capacity does not always bring congestion reductions or economic benefits to neighboring areas; instead, increased road capacities can have negative effects on the network system. This theory is known as Braess' paradox (1969); such phenomena have been reported in many cases (Easley and Kleinberg, 2008; Knödel, 1969; Kolata, 1990). This paradox could be examined in regards to the crossing infrastructure along the US-Canada border and how it affects neighboring economies.

It should be also noted that our border wait time analysis has limitations not only in its unit of analysis, but also because of its incomplete data periods. The hourly average data cannot capture wait time variation within an hour, and this data aggregation result is an underestimation of congestion effects. In addition, five-month data is not enough to examine seasonality of border congestion patterns. Demystifying these unknown variations is important to set the baseline border delay time for the Bi-national TransNIEMO and to support staffing management for border agencies. Using a full year hourly average dataset will clarify overall border delay patterns for future research, though the limited availability of data only at the hour may still result in an underestimation of the effects of congestion.

The Bi-national TransNIEMO has the potential to allow for a stronger understanding of how commodities affect specific border crossings. Trade policies, changes in transshipment mode (from truck to train, air, or vessel), and other structural changes which lead to an increased or diminished volume of goods crossing at a given border point have the potential to either positively or negatively impact border crossing congestion. This could help determine planning or policy solutions with the potential to reduce the transshipment of a given commodity across a specific border crossing, therefore reducing congestion and allowing for the more efficient movement of goods across a border crossing. This also could demonstrate that eschewing a “one size fits all” approach to border policy in Canada and the US is appropriate.

A further study could include forecasting and modeling the impact of the *Agreement on Land, Rail, Marine, and Air Transport Preclearance Between the Government of the United States of America and the Government of Canada*. This agreement was signed in March 2015 and allows for immigration, customs and agriculture inspections required for entry into either country to occur on foreign soil. It is expected that moving pre-clearance will reduce congestion and delays at the border and increase efficiency in cross-border transportation. The model could be modified to forecast and assess the economic impact and enhanced efficiencies associated with this agreement. Results might encourage both the US and Canada to enact legislation necessary in order to effectuate this agreement action which has yet to take place.

References

Ahuja, R. K. (1993). Network flows (Doctoral dissertation, TECHNISCHE HOCHSCHULE DARMSTADT).

Anderson, M., & Smith, S. (1999). Do national borders really matter? Canada–US regional trade reconsidered. Review of International Economics, 7(2), 219-227.

Andresen, M. A. (2009). The geographical effects of the NAFTA on Canadian provinces. The Annals of Regional Science, 43(1), 251-265.

Braess, D. (1969). “Über ein Paradoxon aus der Verkehrsplanung”, Unternehmensforschung 12, 258–268.

Canada-US Action Plan for Critical Infrastructure (2010), https://www.dhs.gov/xlibrary/assets/ip_canada_us_action_plan.pdf (accessed February, 2015).

Cantner, U., & Graf, H. (2006). The network of innovators in Jena: An application of social network analysis. *Research Policy*, *35*(4), 463-480.

Cho, J., Gordon, P., J. E. Moore II, Q. Pan, J.Y. Park, and H. W. Richardson, 2015, “TransNIEMO: Economic Impact Analysis Using a Model of Consistent Interregional Economic and Highway Network Equilibria,” *Transportation Planning and Technology,* 38(5): 483-502

De Montis, A., Barthélemy, M., Chessa, A., & Vespignani, A. (2005). The structure of inter-urban traffic: A weighted network analysis. *arXiv preprint physics/0507106*.

Easley, D. and J. Kleinberg (2008), Networks, Cornell Store Press.
Fagiolo, G., Reyes, J., & Schiavo, S. (2010). The evolution of the world trade web: a weighted-network analysis. *Journal of Evolutionary Economics*, *20*(4), 479-514.
Friedman, K. B. (2008). Through the Looking Glass: Implication of Canada-United States Transgovernmental Networks for Democratic Theory, International Law, and the Future of North American Governance. Alta. L. Rev., 46, 1081.
Hewings, G. J., Sonis, M., Guo, J., Israilevich, P. R., & Schindler, G. R. (1998). The Hollowing-Out Process in the Chicago Economy, 1975–2011. Geographical Analysis, 30(3), 217-233.
Hitomi, K., Okuyama, Y., Hewings, G. J., & Sonis, M. (2000). The role of interregional trade in generating change in the regional economies of Japan, 1980–1990. Economic Systems Research, 12(4), 515-537.
Integrated decision support tool for intermodal freight transport.
Knödel, W. (1969). Graphentheoretische Methoden und ihre Anwendungen. Springer-Verlag.
Kolata, G. (1990). “What if They Closed 42d Street and Nobody Noticed?”, The New York Times. December 25, 1990.
McCallum, J. (1995). National borders matter: Canada-US regional trade patterns. The American Economic Review, 615-623.
Okuyama, Yasuhide, Geoffrey J.D. Hewings, Tschangho J. Kim, David E. Boyce, Heejoo Ham, and Jungyul Sohn. (1999) “Economic Impacts of an Earthquake in the New Madrid Seismic Zone: A Multiregional Analysis,” in William M. Elliott and Peter McDonough eds. Optimizing Post-Earthquake Lifeline System Reliability, Technical Council on Lifeline Earthquake Engineering, Monograph No.16: 592-601.
Park, J., Cho, J., Gordon, P., Moore Ii, J. E., Richardson, H. W., & Yoon, S. (2011). Adding a freight network to a national interstate input–output model: a TransNIEMO application for California. Journal of Transport Geography, 19(6), 1410-1422.
Park, J., H.W. Richardson, P. Gordon, J. E. Moore II., Q. Pan and J. Cho, (2014b) The Economic Impacts of Bridge and Tunnel Closure in the National Highway System (TransNIEMO), 24-43: in Richardson HW, JY Park, JE Moore II, and Q Pan eds, National Economic Impact Analysis of Terrorist and Natural Disasters, Edward Elgar
Park, J., Kwon, C., & Son, M. (2014a). Economic implications of the Canada–US border bridges: Applying a binational local economic model for international freight movements. Research in Transportation Business & Management, 11, 123-133.
Park, JY and Richardson H. W. (2014). Refining the Isard Multiregional Input-Output Model Theory. in Peter Nijkamp, Adam Rose, and Karima Kourtit eds. Regional Science Matters – Studies in Honour of Walter Isard, Springer-Verlag.
Sabean, J., & Jones, C. (2008). Inventory of Current Programs for Measuring Wait Times at Land Border Crossings. Transport Canada and Federal Highway Administration. May, 21, 2008.
Sands, Christopher (2009), “Toward a New Frontier: Improving the US-Canadian Border,” Washington, D.C.: The Brookings Institution.
Shih, H. Y. (2006). Network characteristics of drive tourism destinations: An application of network analysis in tourism. *Tourism Management*, *27*(5), 1029-1039.
Sohn, Jungyul, Geoffrey J.D. Hewings, Tschangho John Kim, Jong Sung Lee and Sung-Gheel Jang, (2004) “Analysis of Economic Impacts of an Earthquake on

Transportation Networks," In Y. Okuyama and S. Chang (Eds.), Modeling Spatial and Economic Impacts of Disasters Heidelberg, Springer.
UBRI/BPRI. (2008). Adapting the Border to Regional Realities, Border Brief, September, http://regional-institute.buffalo.edu/wp-content/uploads/sites/3/2014/10/Adapting-the-Border-to-Regional-Realities-Policy-Brief.pdf (accessed February, 2015).
US Department of Homeland Security (2011). Beyond the Border Facilitating Travel at the United States–Canada Border. http://www.dhs.gov/beyond-border-action-plan (accessed October, 2014).
US General Service Administration (2014). Port of Entry Infrastructure: How Does the Federal Government Prioritize Investments?, http://www.gsa.gov/portal/content/194547 (accessed February, 2015)
Wasserman, S. (1994). Social network analysis: Methods and applications (Vol. 8). Cambridge university press.

Appendices

Appendix 1. Sample of Bi-national Freight Network Dataset

From-node ID	To-node ID	HS2 Code	Freight Value ($US)	TEU	Country	Freight Flow
103	ME	3	3114836.014	63.64089826	US	Import
103	ME	5	57945.57893	1.972222959	US	Import
103	NH	3	201158.7053	4.10998224	US	Import
103	NY	3	90752.66702	1.854216794	US	Import
105	MA	68	302445.6962	6.982860004	US	Import
105	ME	39	416176.7507	10.1089261	US	Import
…						
AK	118	88	270	0.000109926	US	Export
AK	3017	88	531	0.000216188	US	Export
AK	3017	49	223	0.001191311	US	Export
AK	3017	73	172	0.001951046	US	Export
AK	3020	85	72	0.000217	US	Export
AK	3064	85	1233	0.003712	US	Export
…						
205	NB	48	10143	0.620187644	CA	Import
205	NB	84	1050839	3.826967931	CA	Import
205	NB	68	61427	1.418225311	CA	Import
205	NB	95	96891	0.414618042	CA	Import
205	NB	87	238001	1.29297978	CA	Import
205	NB	38	452	0.006817823	CA	Import
…						
AB	218	10	18008	3.176991957	CA	Export
AB	219	10	111250	19.62685225	CA	Export
AB	314	11	686067	46.8774171	CA	Export
AB	314	44	513879	94.75111108	CA	Export
AB	314	10	604909	106.7187377	CA	Export
AB	314	12	361959	37.19026	CA	Export

Source: WISERTrade (www.WISERTrade.org), processed and tabulated by authors

Appendix 2. Paired POE of the US and Canada

Canada			United States		
Port ID	Port Name	Province	Port ID	Port Name	State
205	St. Croix	NB	105	Vanceboro	ME
211	St. Stephen	NB	115	Calais	ME
212	Woodstock, New Brunswick	NB	106	Houlton	ME
213	Edmundston	NB	109	Madawaska	ME
214	Andover	NB	107	Fort Fairfield	ME
215	Centreville	NB	127	Bridgewater	ME
216	Clair	NB	110	Fort Kent	ME
218	St. Leonard	QC	108	Van Buren	ME
219	Gillespie Portage	NB	118	Limestone	ME
225	Campobello	NB	103	Lubec	ME
307	Trout River	QC	715	Trout River	NY
314	Stanstead Highway 55	QC	209	Derby Line Rt. 91	VT
318	Abercorn	QC	203	Richford	VT
328	StArmand/Philipsburg	QC	212	Highgate Springs	VT
329	Armstrong	QC	104	Jackman	ME
351	Lacolle	QC	712	Champlain	NY
354	Stanhope	QC	211	Norton	VT
409	Cornwall	ON	704	Massena	NY
410	Fort Erie	ON	901	Buffalo-Peace Bridge	NY
439	Prescott	ON	701	Ogdensburg	NY
440	Sarnia	ON	3802	Port Huron	MI
441	Sault Ste. Marie	ON	3803	Sault Ste. Marie	MI
453	Windsor Ambassador Bridge	ON	3801	Detroit-Ambassador Bridge	MI
456	Lansdowne	ON	708	Alexandria Bay	NY
475	Pigeon River	ON	3613	Grand Portage	MN
478	Fort Frances	ON	3604	International Falls	MN
488	Rainy River	ON	3424	Baudette	MN
502	Emerson	MB	3401	Pembina	ND
503	Gretna	MB	3404	Neche	ND
505	Sprague	MB	3423	Warroad	MN
506	South Junction	MB	3426	Roseau	MN
507	Boissevain	MB	3422	Dunseith	ND
508	Goodlands	MB	3421	Carbury	ND
509	Snowflake	MB	3408	Hannah	ND
518	Winkler	MB	3407	Walhalla	ND
519	Windygates	MB	3416	Maida	ND
520	Crystal City	MB	3409	Sarles	ND
521	Cartwright	MB	3415	Hansboro	ND
522	Lena	MB	3405	St. John	ND
523	Lyleton	MB	3413	Antler	ND
524	Coulter	MB	3419	Westhope	ND

602	North Portal	SK	3403	Portal	ND
607	Regway	SK	3301	Raymond	MT
612	Carievale	SK	3414	Sherwood	ND
613	Northgate	SK	3406	Northgate	ND
615	Coronach	SK	3309	Scobey	MT
616	Oungre	SK	3417	Fortuna	ND
618	West Poplar River	SK	3317	Opheim	MT
619	Climax	SK	3306	Turner	MT
620	Monchy	SK	3319	Morgan	MT
705	Coutts	AB	3310	Sweetgrass	MT
706	Aden	AB	3321	Whitlash	MT
707	Carway	AB	3316	Piegan	MT
708	Del Bonita	AB	3322	Del Bonita	MT
813	Pacific Highway	BC	3004	Blaine-Pacific Highway	WA
815	Boundary Bay	BC	3017	Point Roberts	WA
816	Cascade	BC	3016	Laurier	WA
817	Huntington	BC	3009	Sumas	WA
818	Kingsgate	BC	3302	Eastport	ID
819	Osoyoos	BC	3019	Oroville	WA
822	Rykerts	BC	3308	Porthill	ID
824	Roosville	BC	3318	Roosville	MT
828	Nelway	BC	3025	Metaline Falls	WA
832	Paterson	BC	3020	Frontier	WA
834	Carson	BC	3012	Danville	WA
835	Midway	BC	3013	Ferry	WA
841	Aldergrove	BC	3023	Lynden	WA
891	Pleasant Camp	BC	3106	Dalton Cache	AK
893	Fraser	BC	3103	Skagway	AK

Source: WISERTrade (www.WISERTrade.org), processed and tabulated by authors

Appendix 3. Letter Abbreviation for US and Canadian States and Provinces

Abbreviation	**Province Name**	**Abbreviation**	**Province Name**
AB	Alberta	NU	Nunavut
BC	British Columbia	ON	Ontario
MB	Manitoba	PE	Prince Edward Island
NB	New Brunswick	QC	Quebec
NL	Newfoundland and Labrador	SK	Saskatchewan
NS	Nova Scotia	YT	Yukon
NT	Northwest Territories		
Abbreviation	**State Name**	**Abbreviation**	**State Name**
AL	Alabama	MT	Montana
AK	Alaska	NE	Nebraska
AZ	Arizona	NV	Nevada
AR	Arkansas	NH	New Hampshire
CA	California	NJ	New Jersey
CO	Colorado	NM	New Mexico
CT	Connecticut	NY	New York
DE	Delaware	NC	North Carolina
FL	Florida	ND	North Dakota
GA	Georgia	OH	Ohio
HI	Hawaii	OK	Oklahoma
ID	Idaho	OR	Oregon
IL	Illinois	PA	Pennsylvania
IN	Indiana	RI	Rhode Island
IA	Iowa	SC	South Carolina
KS	Kansas	SD	South Dakota
KY	Kentucky	TN	Tennessee
LA	Louisiana	TX	Texas
ME	Maine	UT	Utah
MD	Maryland	VT	Vermont
MA	Massachusetts	VA	Virginia
MI	Michigan	WA	Washington
MN	Minnesota	WV	West Virginia
MS	Mississippi	WI	Wisconsin
MO	Missouri	WY	Wyoming

Source: WISERTrade (www.WISERTrade.org), processed and tabulated by authors

Appendix 4. Definition of 2-digit HS Codes

Description	Code
Live Animals	1
Meat And Edible Meat Offal	2
Fish, Crustaceans & Aquatic Invertebrates	3
Dairy Prods; Birds Eggs; Honey; Ed Animal Pr Nesoi	4
Products Of Animal Origin, Nesoi	5
Live Trees, Plants, Bulbs Etc.; Cut Flowers Etc.	6
Edible Vegetables & Certain Roots & Tubers	7
Edible Fruit & Nuts; Citrus Fruit Or Melon Peel	8
Coffee, Tea, Mate & Spices	9
Cereals	10
Milling Products; Malt; Starch; Inulin; Wht Gluten	11
Oil Seeds Etc.; Misc Grain, Seed, Fruit, Plant Etc	12
Lac; Gums, Resins & Other Vegetable Sap & Extract	13
Vegetable Plaiting Materials & Products Nesoi	14
Animal Or Vegetable Fats, Oils Etc. & Waxes	15
Edible Preparations Of Meat, Fish, Crustaceans Etc	16
Sugars And Sugar Confectionary	17
Cocoa And Cocoa Preparations	18
Prep Cereal, Flour, Starch Or Milk; Bakers Wares	19
Prep Vegetables, Fruit, Nuts Or Other Plant Parts	20
Miscellaneous Edible Preparations	21
Beverages, Spirits And Vinegar	22
Food Industry Residues & Waste; Prep Animal Feed	23
Tobacco And Manufactured Tobacco Substitutes	24
Salt; Sulfur; Earth & Stone; Lime & Cement Plaster	25
Ores, Slag And Ash	26
Mineral Fuel, Oil Etc.; Bitumin Subst; Mineral Wax	27
Inorg Chem; Prec & Rare-Earth Met & Radioact Compd	28
Organic Chemicals	29
Pharmaceutical Products	30
Fertilizers	31
Tanning & Dye Ext Etc; Dye, Paint, Putty Etc; Inks	32
Essential Oils Etc; Perfumery, Cosmetic Etc Preps	33
Soap Etc; Waxes, Polish Etc; Candles; Dental Preps	34
Albuminoidal Subst; Modified Starch; Glue; Enzymes	35
Explosives; Pyrotechnics; Matches; Pyro Alloys Etc	36
Photographic Or Cinematographic Goods	37
Miscellaneous Chemical Products	38
Plastics And Articles Thereof	39
Rubber And Articles Thereof	40
Raw Hides And Skins (No Furskins) And Leather	41
Leather Art; Saddlery Etc; Handbags Etc; Gut Art	42
Furskins And Artificial Fur; Manufactures Thereof	43
Wood And Articles Of Wood; Wood Charcoal	44
Cork And Articles Of Cork	45
Mfr Of Straw, Esparto Etc.; Basketware & Wickerwrk	46
Wood Pulp Etc; Recovd (Waste & Scrap) Ppr & Pprbd	47
Paper & Paperboard & Articles (Inc Papr Pulp Artl)	48
Printed Books, Newspapers Etc; Manuscripts Etc	49
Silk, Including Yarns And Woven Fabric Thereof	50
Wool & Animal Hair, Including Yarn & Woven Fabric	51
Cotton, Including Yarn And Woven Fabric Thereof	52
Veg Text Fib Nesoi; Veg Fib & Paper Yns & Wov Fab	53
Manmade Filaments, Including Yarns & Woven Fabrics	54
Manmade Staple Fibers, Incl Yarns & Woven Fabrics	55
Wadding, Felt Etc; Sp Yarn; Twine, Ropes Etc.	56
Carpets And Other Textile Floor Coverings	57

Spec Wov Fabrics; Tufted Fab; Lace; Tapestries Etc	58
Impregnated Etc Text Fabrics; Tex Art For Industry	59
Knitted Or Crocheted Fabrics	60
Apparel Articles And Accessories, Knit Or Crochet	61
Apparel Articles And Accessories, Not Knit Etc.	62
Textile Art Nesoi; Needlecraft Sets; Worn Text Art	63
Footwear, Gaiters Etc. And Parts Thereof	64
Headgear And Parts Thereof	65
Umbrellas, Walking-Sticks, Riding-Crops Etc, Parts	66
Prep Feathers, Down Etc; Artif Flowers; H Hair Art	67
Art Of Stone, Plaster, Cement, Asbestos, Mica Etc.	68
Ceramic Products	69
Glass And Glassware	70
Nat Etc Pearls, Prec Etc Stones, Pr Met Etc; Coin	71
Iron And Steel	72
Articles Of Iron Or Steel	73
Copper And Articles Thereof	74
Nickel And Articles Thereof	75
Aluminum And Articles Thereof	76
Lead And Articles Thereof	78
Zinc And Articles Thereof	79
Tin And Articles Thereof	80
Base Metals Nesoi; Cermets; Articles Thereof	81
Tools, Cutlery Etc. Of Base Metal & Parts Thereof	82
Miscellaneous Articles Of Base Metal	83
Industrial Machinery, Including Computers	84
Electric Machinery Etc; Sound Equip; Tv Equip; Pts	85
Railway Or Tramway Stock Etc; Traffic Signal Equip	86
Vehicles, Except Railway Or Tramway, And Parts Etc	87
Aircraft, Spacecraft, And Parts Thereof	88
Ships, Boats And Floating Structures	89
Optic, Photo Etc, Medic Or Surgical Instrments Etc	90
Clocks And Watches And Parts Thereof	91
Musical Instruments; Parts And Accessories Thereof	92
Arms And Ammunition; Parts And Accessories Thereof	93
Furniture; Bedding Etc; Lamps Nesoi Etc; Prefab Bd	94
Toys, Games & Sport Equipment; Parts & Accessories	95
Miscellaneous Manufactured Articles	96
Works Of Art, Collectors Pieces And Antiques	97
Special Classification Provisions	98
Special Classification Transactions	99

Source: Foreign Trade (http://www.foreign-trade.com/reference/hscode.htm) Harmonized System Codes (HS Code), tabulated by authors

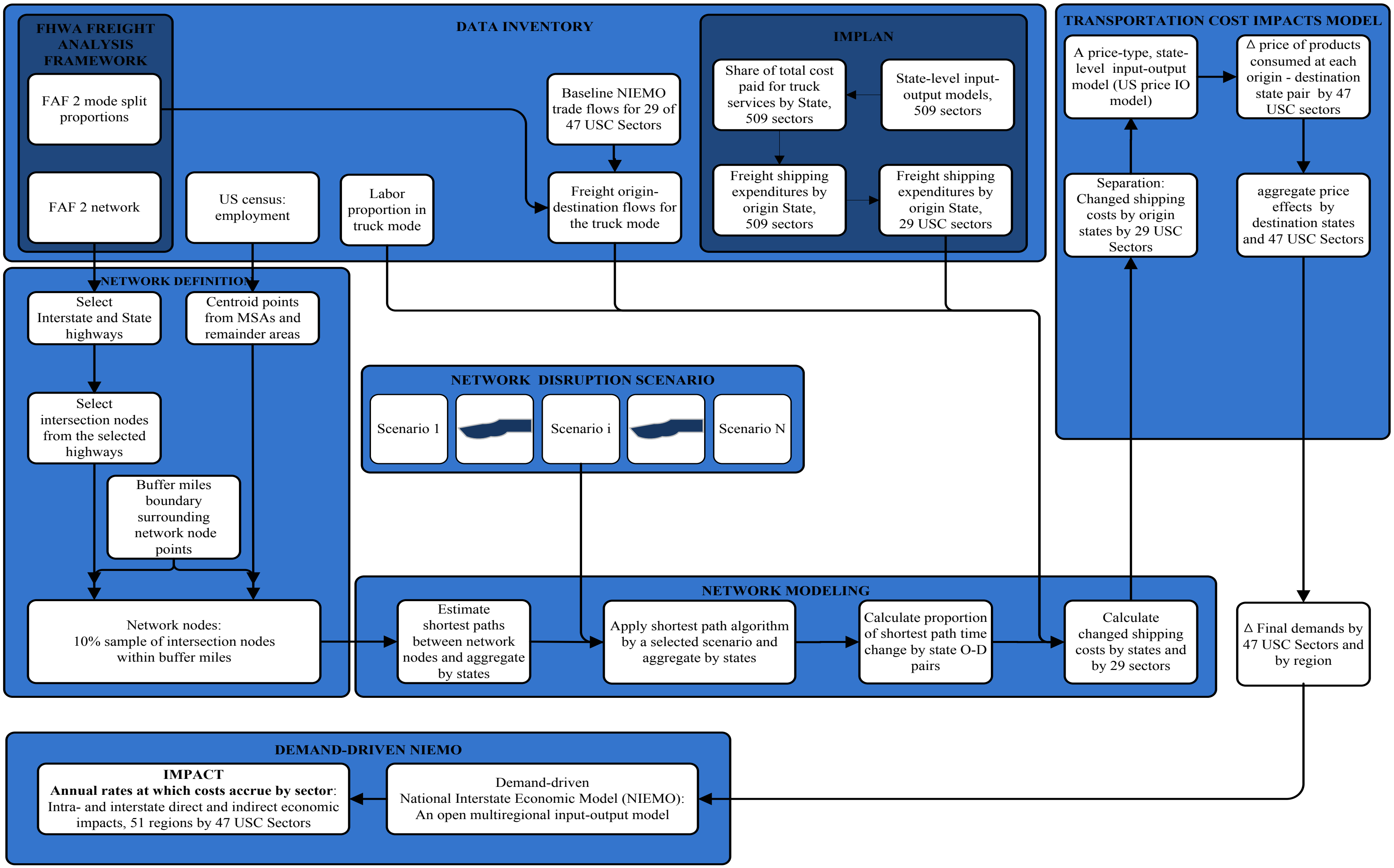
Appendix 5. The Ratio of TEU to Dollar Value by 2-digit HS Code

HS Code (2-digit)	Ton by Vessels	Value by Vessels	TEU/Dollar
1	37,628	206,472,965	0.0000101244
2	5,051,077	11,130,655,936	0.0000252110
3	1,275,052	3,467,003,355	0.0000204315
4	1,267,425	3,749,785,364	0.0000187777
5	354,706	578,975,258	0.0000340358
6	39,355	81,866,501	0.0000267067
7	1,510,841	1,209,630,560	0.0000693895
8	3,067,592	9,537,777,818	0.0000178681
9	56,002	315,414,491	0.0000098640
10	56,619,431	17,829,631,198	0.0001764211
11	345,013	280,521,439	0.0000683278
12	44,470,866	24,045,470,598	0.0001027472
13	35,023	389,747,169	0.0000049922
14	88,975	47,142,723	0.0001048526
15	1,929,640	2,266,041,558	0.0000473081
16	311,521	842,845,117	0.0000205337
17	1,128,283	1,116,401,184	0.0000561468
18	154,065	715,284,055	0.0000119661
19	645,516	1,382,198,706	0.0000259456
20	2,082,561	2,755,676,868	0.0000419853
21	1,033,614	4,168,667,159	0.0000137749
22	2,710,036	4,060,577,227	0.0000370779
23	18,444,571	8,816,789,772	0.0001162213
24	211,311	1,543,892,120	0.0000076039
25	6,655,964	1,560,769,574	0.0002369189
26	10,456,941	4,730,841,290	0.0001227987
27	266,656,642	128,058,025,455	0.0001156839
28	15,152,848	8,591,823,622	0.0000979798
29	19,007,731	30,581,710,149	0.0000345300
30	138,194	6,534,832,920	0.0000011748
31	9,788,917	3,906,702,880	0.0001392040
32	992,956	3,588,624,733	0.0000153720
33	487,852	5,533,669,406	0.0000048978
34	1,170,078	3,882,540,885	0.0000167427
35	471,211	1,426,132,354	0.0000183562
36	13,992	234,190,305	0.0000033193
37	112,782	1,455,075,946	0.0000043061
38	3,426,344	12,619,762,306	0.0000150837
39	12,056,416	27,575,190,296	0.0000242900
40	1,542,925	6,172,781,526	0.0000138865
41	882,038	3,118,959,012	0.0000157110
42	22,774	333,172,127	0.0000037975
43	702	9,292,479	0.0000041972
44	19,261,493	5,803,553,564	0.0001843841
45	1,530	10,773,373	0.0000078923
46	1,010	4,717,313	0.0000118903
47	23,932,668	7,878,798,800	0.0001687558
48	7,760,757	7,051,393,019	0.0000611444
49	93,806	975,528,620	0.0000053422
50	971	2,261,537	0.0000238647

51	8,419	31,609,930	0.0000147975
52	3,053,903	6,659,944,552	0.0000254749
53	1,674	5,535,647	0.0000168023
54	158,341	900,029,471	0.0000097738
55	443,846	1,984,190,131	0.0000124273
56	188,210	1,212,887,792	0.0000086209
57	54,468	270,702,766	0.0000111783
58	24,709	168,772,284	0.0000081337
59	47,937	504,043,067	0.0000052836
60	76,775	631,930,934	0.0000067496
61	39,170	563,209,943	0.0000038638
62	22,694	419,522,260	0.0000030053
63	697,805	1,024,984,033	0.0000378220
64	40,237	444,963,674	0.0000050238
65	2,813	58,742,075	0.0000026600
66	1,439	9,731,009	0.0000082180
67	3,544	42,008,479	0.0000046864
68	493,876	1,188,391,518	0.0000230880
69	165,519	622,954,969	0.0000147611
70	574,986	1,849,116,752	0.0000172751
71	16,446	2,307,689,282	0.0000003959
72	18,476,645	9,635,458,424	0.0001065315
73	1,334,323	6,535,056,884	0.0000113433
74	1,283,938	5,232,448,109	0.0000136322
75	41,132	1,043,358,740	0.0000021901
76	2,142,938	5,695,324,009	0.0000209035
78	61,234	104,895,265	0.0000324312
79	116,073	173,231,166	0.0000372249
80	9,249	42,867,917	0.0000119864
81	47,764	1,161,909,822	0.0000022838
82	66,889	1,162,765,275	0.0000031959
83	157,362	937,412,783	0.0000093260
84	4,401,359	67,142,215,244	0.0000036418
85	1,123,188	20,726,861,239	0.0000030106
86	186,303	1,877,574,209	0.0000055125
87	5,513,620	56,383,413,010	0.0000054327
88	36,756	5,015,607,509	0.0000004071
89	197,145	1,782,341,283	0.0000061450
90	262,901	9,851,904,501	0.0000014825
91	1,439	70,615,858	0.0000011320
92	9,303	326,634,175	0.0000015823
93	25,621	2,240,812,764	0.0000006352
94	367,807	2,947,854,052	0.0000069317
95	167,010	2,168,231,058	0.0000042792
96	90,170	662,518,163	0.0000075612
97	3,022	290,013,918	0.0000005789
98	127,641	2,070,861,100	0.0000034243

Source: WISERTrade (www.WISERTrade.org), processed and tabulated by authors

Appendix 6. Framework of the US TransNIEMO



Source: Cho et al. (2015) TransNIEMO: Economic Impact Analysis Using a Model of Consistent Interregional Economic and Highway Network Equilibria, *Transportation Planning and Technology,* 38(5): 483-502