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Competitiveness and macroeconomic impacts of reduced wait times at U.S. land freight border crossings

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ABSTRACT

We analyze the macroeconomic and trade impacts of reducing wait times by adding one customs officer at each of the twelve major land freight crossings of the U.S. The change in wait time stemming from staffing changes is first estimated on the basis of primary data and then translated into changes in freight costs through a logistical model. The transportation cost changes are then fed into a multi-country computable general equilibrium model. We find that adding one customs officer at each land border crossing would, on average per crossing, generate an increase in U.S. GDP of $350 thousand and 3.58 additional jobs.

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1. Introduction

The gains from free trade are well established. Most studies on interference with it focus on tariffs, quotas, or subsidies. However, various costs of regulation to support the orderly flow and safety of trade also interfere with achieving efficient outcomes. These include direct costs of administering and monitoring trade, as well as unintended spillover effects resulting from delays. Ideally, these transactions costs would be minimized.

Freight transportation coming into the U.S. is subject to inspections by officials of the U.S. Customs and Border Protection (CBP) Agency for contraband and for national security purposes. These inspections cause delays that translate into an increased cost of doing business for shippers and their customers directly and for international trade indirectly. Although the border wait times are relatively short, the sheer volume of trade translates into potentially large impacts. Inspection delays are thus an important non-tariff barrier to trade. In this paper we analyze the macroeconomic and trade impacts of adding one CBP officer at each of the twelve major land freight crossings of the U.S.

Increased staffing by CBP will reduce the cost of transporting imports from Canada and Mexico into the U.S., and benefit the export industries of these countries, with the U.S. incurring all of the cost. However, several international trade analysts have argued that it is very important to take into account the flow of both intermediate and final goods through cross-border supply chains that link the U.S. economy to those of Canada and Mexico.[1] If a large proportion of U.S. imports are intermediate goods that are incorporated into U.S. production, reducing importing cost would lower the cost of production in U.S. industries,

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[1] See Taylor et al. (2003) and Haralambides and Londono-Kent (2004) for assessments of supply chains linking Canada and Mexico to the U.S., respectively. OECD (2013) exhaustively reviews existing literature on cross-border supply chains.

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thereby making U.S. exports more attractive not just to Mexico and Canada but worldwide. Due to these subtle considerations and others associated with the process of international trade, it is possible that increasing staffing at U.S. freight crossings would be a win–win outcome for all involved. To capture these effects, it is necessary to analyze the impact of change in importing cost using a model that distinguishes between flows of intermediate and final goods and incorporates a full accounting of all inputs and not just primary factors of production. We use a computable general equilibrium (CGE) model that makes these distinctions, and our results suggest that lowering importing costs into the U.S. does in fact reduce the cost of U.S. exports and increases U.S. income and employment.

Our analysis is based on data on wait times associated with primary inspections of freight shipments collected by CBP. The change in wait time is first estimated, and then translated into changes in freight costs through a logistical model. The resulting changes in transportation costs are then fed into the Global Trade Analysis Project (GTAP) CGE multi-country model of the world economy to analyze competitiveness and macroeconomic impacts on the economies of the U.S., Canada, and Mexico. We disaggregate the inputs into GTAP for each of the twelve border crossings that we examine to further analyze the factors that most influence the outcome, including differences in wait times, effects of additional CBP staffing, effects on transportation costs, and commodity mix traversing each crossing. Fig. 1 provides a schematic description of our analysis.

We find that adding one CBP officer at each land border crossing would, on average per crossing, generate an increase in U.S. GDP of $350 thousand and 3.58 additional jobs. Both Canada and Mexico would reap net macroeconomic gains as well, with those of Canada exceeding U.S. gains. We conclude with a discussion of the policy implications of our analysis.

2. Literature review

A number of non-price factors affect the movement of goods across international borders, and some have been analyzed. Trade facilitation involves activities that improve trade capacities of various countries. Wilson et al. (2003) refer to it as the improvement of logistics at both customs offices and ports of entry (POEs), as well as the design of more efficient administration and procedures. Arvis et al. (2012) introduce the Logistics Performance Index (LPI), which considers the effect of cargo clearance effectiveness, transport and information technology infrastructure quality for logistics, ease and reasonable pricing of shipping services, timely shipping to destination, etc. We focus on how the reduction of wait times at ports of entry through reduced paperwork, increased staffing at checkpoints, and simplification of trade procedures can lower transport costs and have a significant impact on timely delivery of intermediate and final consumption goods.

Hertel et al. (2001) estimate both the short- and long-run effects of the Free Trade Agreement (FTA) between Japan and Singapore on the output, consumption, investment, exports and imports, GDP and welfare of both trading partners. The authors argue that, with the decline in global manufacturing tariffs, free trade agreements began to focus on other issues, such as regulations of e-commerce, foreign investment, and customs procedures. The authors consider potential gains from the introduction of uniform e-commerce standards in Singapore and Japan. They study the effects of automating Japanese customs procedures to make them compatible with the computer systems used by customs in Singapore, thereby allowing faster transit times and lowering administrative costs and lag times for Japan's exports and imports. Using the dynamic GTAP model, Hertel et al. (2001) find that in the short- or medium- run the trade balance in both countries declines, but it improves in the long run due to increased exports. They conclude that the increase in trade volumes between the two trading partners is mainly due to customs automation. Moreover, these trade gains in Japan and Singapore positively affect their GDP and investment.

Minor and Tsigas (2008) use a database of tariff equivalents for time in trade by product and country pairs, and a computable general equilibrium framework to simulate the reductions in trade times for four different country groups defined by level of development. They note that over the last four decades the reduction in average import taxes significantly facilitated international trade. Moreover, changes in transportation technology also contributed to the growth in trade, resulting in an average annual increase of air transport services by 10%. The authors suggest that reduced tariffs and trade times enable countries to trade a wider variety of commodities that involve low-value bulk products in contrast to advanced high value goods and food products requiring faster delivery. The study finds that "trade facilitation" is one of the important factors affecting the growth in trade across borders of developing countries. Their results also indicate that countries that reduce trade time reap significant benefits, relative to those countries that make no such improvements. This finding is consistent with the theory of supply chain management, which suggests that the benefits from the reduction in shipping times for the fastest deliverer grow with the increase of the gap between that deliverer and the next fastest deliverer. Finally, Minor and Tsigas (2008) find that in Sub-Saharan Africa the reduction in delivery times increases the export share of high value products.

Furthermore, a number of studies show a strong relationship between transport costs and the transit time required to ship goods from origin to destination (Djankov et al., 2010; OECD, 2003). The OECD (2003) study shows that indirect costs associated with delays in transit times have more significant impact on trade levels than the direct costs. Additionally, Djankov et al. (2010) find that a delay in trade by one day decreases trade levels by 1%. A study by Hummels and Schaur (2013) analyzes firms' choice between fast but expensive air transport, and slow but inexpensive maritime transport, a choice that depends on the value placed by consumers on the fast shipping and the price elasticity of demand. The authors find that the cost of an extra day of transport is 60% higher for importers of intermediate goods than for importers of final goods. Hummels and Schaur (2013) state that their results show a strong relationship between the reduction in air transport costs and fast growth in trade.

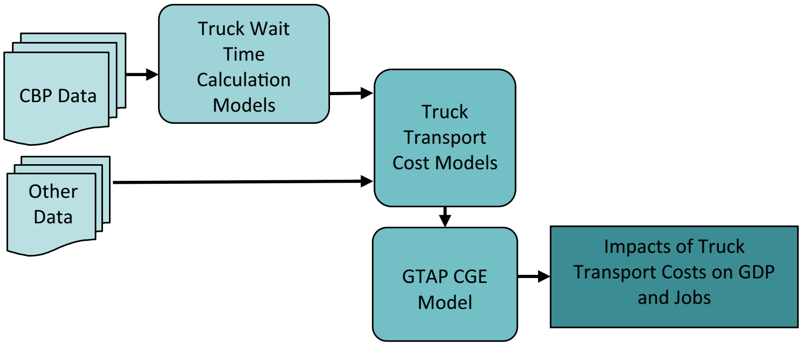

Fig. 1. Schematic description of the methodology.

The high degree of sensitivity of intermediate goods such as parts and components to transport time suggests that border delays are particularly important in the context of cross-border supply chains, which are also often referred to as global value chains. Production of goods and services is increasingly taking place through supply chains in which different stages of production are specialized to countries that have a comparative advantage in carrying out a particular task needed to produce a good or service. Competition is thus increasingly taking place at the level of production tasks rather than sectors. The value added associated with the production of a good or service is split between the countries involved in the supply chain, and intermediate inputs in the chain can cross national borders several times in the course of production. OECD (2013) comprehensively reviews cross-border supply chains and shows that their importance in the global economy has risen dramatically in recent decades. As a result, trade in intermediate goods and services now accounts for a majority of international trade.[2] The direct and indirect import content of exports has also been rising sharply since 1995 in OECD economies (OECD, 2013, p. 25) Given these trends, increasing the competitiveness of imports can be expected to increase the competitiveness of exports in any sector in which cross-border supply chains are significant.

Taking these supply chains into account when analyzing the economic impact of trade impediments such as tariffs, quotas, and border delays is of fundamental significance. For example, even though tariff levels are now quite low in most countries and sectors, because intermediates typically flow across several national borders in a supply chain, low tariff levels can still result in a large cumulative impact on trade cost.[3] Tariff or non-tariff barriers erected to protect domestic producers could actually harm them if they are dependent on cross-border supply chains. Bringing these supply chains into trade policy analysis is still at a very early stage, and models such as GTAP do not yet explicitly incorporate all of their features. However, because GTAP does distinguish between trade in intermediate and final goods and captures the use of intermediates in the production of exports, it does capture a major portion of a cross-border supply chain.

3. Impact of increased staffing on primary inspection wait time at commercial vehicle crossings

When commercial vehicles arrive at a U.S. port of entry, CBP conducts an initial inspection, known as a primary inspection, in which required documents are checked and an initial evaluation is made of the vehicle. If a vehicle is deemed suspicious, it will be referred to secondary inspection to undergo a more intensive examination. We evaluate in this study the impacts of lowering the wait time associated with the primary inspection process for commercial vehicles. We do not evaluate the economic impacts associated with secondary inspection, which affects a minority of traffic crossing the border.[4]

Increased staffing is only one of a range of potential solutions to lower wait times at border crossings. Wait time is an outcome of a queuing process at which arriving traffic is processed (inspected) at booths. Any change that affects the level of traffic arrivals, the number of processors in the queuing system (booths), or the average time required for processing, which in this case is the time required to conduct primary inspection, will affect wait time outcomes. An increased number of staffed booths will lower wait time. An increased efficiency in accessing and processing information required to conduct primary inspections will lower wait time. A shift of traffic to trusted-traveler programs, whose primary inspection times are lower, will lower wait time. We focus here on the impact of adding an additional inspection officer to a crossing, but note that our methodological approach could be applied to other solutions as long as their impact on the level of traffic, the number of booths open, or the average processing time can be quantified.

[2] Recent evidence suggests that trade in intermediates account for 56% of goods trade and 73% of services trade (OECD, 2013, p. 24).

[3] This effect is amplified by the fact that tariffs are levied on the gross value of imported goods rather than on value added. See OECD (2013), particularly Box 3.1 on p. 90.

[4] The economic impacts associated with primary and secondary inspection are conceptually distinct and can be analyzed independently. All trucks must undergo a primary inspection, but only a minority must go through secondary inspection. We quantify the change in primary inspection wait time and associated economic impacts. Change in primary inspection wait time due to an extra customs officer does not affect the rate at which vehicles are sent to secondary inspection and thus the number of vehicles subjected to secondary inspection. Because the inspection processes are independent of each other in this respect, they can be analyzed independently.

The analysis at the level of individual POEs was carried out using CBP data and operations research and economic analysis methods. Our goal is to quantify how primary wait time for commercial vehicles falls if one extra CBP officer is added to a border crossing's staff. Quantifying how wait times change when staffing is added to or subtracted from a border crossing is challenging, because there is considerable adaptive behavior at these crossings, for both CBP officers and those traversing the border. At most crossings, traffic arrival mounts up and falls off with the rush hour cycle, and staff is added and then subtracted in reaction to the changing traffic flow. This endogenous behavioral reaction prevents the use of simple regression techniques to estimate the relationship between wait time and staffing.[5]

Rather than analyzing historical data on wait times and staffing levels, we developed a theoretical model that can be applied to any border crossing that processes vehicle traffic. This model is developed in Appendix A. We do not base our model on results from standard queuing theory, because this is only useful for queuing systems that are not "saturated," so that queues are not building up or building down in a deterministic fashion over time. However, at border crossings the dominant patterns are rush hour patterns. We have developed a model of a deterministic queuing system that is based on assuming that a stationary deterministic queue exists at the crossing that is neither rising nor falling over time. We then shock the stationary deterministic queue by adding one officer in a given hour of the crossing's operation and quantify how wait time changes using a simple algebraic approach. The approach yields a formula that contains variables for which empirical data are collected by CBP.

To carry out some validation of the theoretical model that we developed, we evaluated the results of a staffing experiment that was run at the San Ysidro port of entry on the weekend of July 21–22, 2012. Although this port processes passenger vehicles rather than commercial vehicles, the queuing systems for passenger vehicles and commercial vehicles are identical in all key respects, so we use the same theoretical model to estimate change in wait time with respect to a staffing increase for both types of crossings, so this validation is assumed to be relevant for commercial vehicle crossings as well. During the staffing experiment, CBP increased the number of open primary inspection booths by roughly 35% above the levels normally experienced on weekend hours, and wait time fell by 62%, implying an elasticity value of roughly -1.8. This experiment at San Ysidro provides some validation of our theoretical model: we used the model to predict how wait time should have changed at San Ysidro if a 35% increase in staffing took place on the 2012 survey dates and found that the predictions were very close to how wait time actually changed.[6]

We use the theoretical deterministic queuing model to evaluate how wait time would have changed if one officer had been added to CBP staff at a particular crossing in 2012. Adding one officer to a border crossing's staff creates 8 additional hours of primary inspection capability on the days that the officer works on enforcement activities, which is 153 days in a year. For each border crossing, we identified the 8 most congested contiguous hours of each day in 2012, assumed that an additional officer would be deployed to these hours, and used the theoretical formula to determine how wait time would have changed in each hour of these 8 hour (8-h) stretches.[7] We then calculated an average change in wait time for each 8-h stretch, and averaged across all 8-h stretches in 2012.[8] We also assumed that the officer would be assigned to process commercial vehicles in regular lanes rather than FAST lanes, which are dedicated to vehicles that participate in a trusted-shipper program and are subject to different conditions in primary inspection.[9] Because the commercial vehicle data sets do not distinguish between the total number of trips for regular lanes and FAST lanes, we chose to focus on regular lane wait times, and used the total number of trips and lanes as a proxy for the number of regular lane trips and regular lanes open.

Values for historical mean wait times at the 12 crossings evaluated in this study in 2012 are given in Table 3, as well as estimates of how these wait times would have changed if one officer had been added to the crossing's staff.[10] As shown in Table 1, the 8 ports of entry with 12 crossings that were selected for study are the largest commercial vehicle ports of entry on U.S. land borders by volume of vehicles processed and are the most important land entry corridors for the U.S. economy.[11]

The theoretical model developed to quantify the relationship between wait time and staffing is an approximation to the true relationship. However, it is known that the approximation underestimates the degree to which wait time falls with the addition of an extra officer (see Appendix A for discussion). This means that the impact results quantified in this study are conservative and understate the likely gains resulting from adding an extra officer.

[5] Regression analysis would require identifying suitable instruments to control for simultaneity, and no instruments have yet been found.

[6] See Roberts et al. (2013) for further discussion of this experiment and validation of model predictions.

[7] Wait times at border crossings almost always display a rush-hour cycle such that wait times peak when the crossing is most congested. Our analysis takes into account this rush-hour cycle and adds an extra officer to the wait time peak, which is the eight most congested hours of the cycle.

[8] We did not make any assumption on what 153 days of the year the extra officer would be deployed.

[9] It would always be optimal for CBP to add an extra officer to regular lanes rather than to FAST lanes, because wait time and queue length are almost always significantly greater in the former.

[10] Hourly wait times are estimated through one of two methods. First, up to 10 vehicles processed in an hour are queried as to how long they waited in minutes, and responses are averaged after dropping the highest and lowest values. Second, a CBP officer visually inspects where the queue ends and estimates how long the wait time is on the basis of this inspection. Both of these approaches involve measurement error and are approximations to the true wait time vehicles experience on average during an hour.

[11] The 3 ports of entry selected for study accounted for 50% of all trucks coming into the U.S. on the northern border in 2012, and the 5 ports of entry on the southern border accounted for 77% of all trucks on that border, so that 63% of all trucks coming into the U.S. in 2012 went through the 8 selected ports (calculated from data of the U.S. Bureau of Transportation Statistics, 2014). The distribution of trucks across the 79 ports of entry on the northern border is highly skewed, with the top 3 ports accounting for 56% of all trucks on that border, and the top 16 ports accounting for 90%. For the 21 ports on the southern border, the top 2 ports accounted for 50% of all trucks on that border, and the top 7 ports accounting for 91%. The share of time waited by trucks accounted for by the ports studied here is greater than 63%, because average wait time at smaller ports of entry is significantly less than at larger ports of entry.

Table 1
Largest commercial U.S. land ports of entry (POE).

Port of entry	U.S. land freight imports (million 2007 $US)	POE share in total (%)
Southern border		
Calexico	6981	5
El Paso	25,949	19
Laredo	47,882	35
Nogales	8425	6
Otay Mesa	20,757	15
Other	27,041	20
Total	137,037	100
Northern border		
Blaine	5545	4
Buffalo-Niagara Falls	27,934	19
Detroit	50,408	34
Other	66,517	44
Total	150,404	100

Lower wait time reduces the monetary and non-monetary costs associated with making a cross-border trip, and the number of cross-border trips made by commercial vehicles may increase as a result. In this study, we make the assumption that the number of commercial vehicle trips across the southern and northern borders does not increase if wait time is reduced. It is not obvious how the impact of wait time on the number of commercial vehicle trips should be modeled. Shipping companies might plan a given number of trips regardless of wait time, so that the primary impact of an increase or fall in wait time is on shipping cost. At some point, an increasing wait time level will necessarily impact the number of commercial vehicle trips, but it is not clear that current levels are so high that this will be the case. Very high levels of wait time could also have longer-run impacts on decisions about where to locate production plants and supply chain activity. Given the lack of any empirical evidence on these responses, we conservatively assume that they equal zero.[12]

4. Impacts of reduced wait times on truck transportation costs

A decline in primary inspection wait time reduces the transportation cost associated with making import shipments into the U.S. by truck. This section estimates the changes in transportation costs for trucks using a logistical analysis of the border inspection process. The percent changes in freight transportation costs are then the primary input into the GTAP model to evaluate the macroeconomic impacts of changes in wait times for truck transportation.

4.1. Volumes of truck traffic at the border

The number of trucks that traveled through each of the POEs during FY 2012 is given in Table 2, both in total and for only the 8 most-congested hours of each day. Table 2 also lists the total number of trucks processed per block of 8 most-congested hours (excluding those days when the truck volume is zero – perhaps because the port is not open on that particular day). The additional CBP officer is assumed to be added to the 8 most-congested hours of each day, and to work 153 days (shifts) per year. Accordingly, the number of trucks with reduced wait time at the border is the total number of trucks processed per block of 8 most-congested hours multiplied by 153 days (see last column of Table 2).

We assume that only those trucks moving through the border during the hours and days when the additional customs officer is on duty will encounter benefit from the reductions in wait time caused by that officer's presence. While the wait time reductions induced by the additional officer's presence can extend beyond the 8-h when the officer is actually on duty (because they help thin out the queue), we lack a basis by which to assess these 'spillover' wait time reduction effects, so we conservatively assume that they are zero.

[12] The reduction in wait times at the border may generate secondary benefits beyond the reduction in standard transportation costs (see Section 4) related to supply chain efficiencies, such as reduced inventory carrying costs and greater reliance on low-cost suppliers abroad rather than higher-cost suppliers at home (see, e.g., Goodchild et al., 2007; Haralambides and Londono-Kent, 2004; Leung et al., 2006; OECD, 2013; SANDAG, 2006; Taylor et al., 2003). Reductions in border wait times may therefore have macroeconomic consequences beyond those quantified in this paper. A basic result of this paper is that a fall in wait time at commercial border crossings leads to an increase in trade due to lower transport costs. If the elasticity of truck trips with respect to trade is positive, then more trips will result from lower wait time, and this increased volume could to some extent offset the initial fall in wait time. This is sometimes called the "rebound effect." We found the rebound effect to be trivial, i.e., the increase in imports would lead to only a minimal amount of increased trucks over the course of a year, and would thus not undercut the improvement in wait times brought about by the increased staffing we simulate below.

Table 2
Truck volume for each U.S. land port of entry (POE) for FY 2012.

Port of entry	Crossing	No. of trucks processed[a]				
		Total	8 Most-congested hours	All other hours	Per block of 8 most-congested hours (average)	Per block of 8 most-congested hours × 153 days (average)
Southern border						
Calexico	Calexico/East	320,482	211,515	108,967	680	104,040
El Paso	Ysleta	360,470	203,124	157,346	653	99,909
	Bridge of the Americas	290,220	199,316	90,904	645	98,685
Laredo	Columbia Solidarity	215,701	145,353	70,348	709	108,477
	World Trade Bridge	1,356,418	841,894	514,524	2319	354,807
Nogales	Mariposa	298,730	230,501	68,229	688	105,264
Otay Mesa	Otay Mesa	644,925	443,118	201,807	1221	186,813
Sub-total (Southern POEs)		3,486,946	2,274,821	1,212,125	n.a.	1,057,995
Northern border						
Blaine	Pacific Highway	343,396	170,679	172,717	466	71,298
Buffalo-Niagara Falls	Lewiston Bridge	309,365	82,187	227,178	225	34,425
	Peace Bridge	625,651	256,453	369,198	701	107,253
Detroit	Windsor Tunnel	39,186	24,719	14,467	67.5	10,328
	Ambassador Bridge	1,425,757	574,819	850,938	1,571	240,363
Sub-total (Northern POEs)		2,743,355	1,108,857	1,634,498	n.a.	463,667
Total (all POEs)		6,230,301	3,383,678	2,846,623	n.a.	1,521,662

[a] Includes only those days for which data are available.
n.a.: not applicable.

4.2. Commercial vehicle wait times at the border

Our model does not include the time spent in or waiting for a secondary inspection, nor do we include the processing time for the primary inspection itself. Accordingly, the total time needed for the border crossing is simply the wait time for the primary inspection (WT), and the change in the total border crossing time is then equal to the change in the wait time (ΔWT). The wait times for trucks (WT) are summarized by POE in Table 3. Note that although our model uses hours as the calculational unit for time, the wait times in Table 3 are given in minutes, as their magnitudes are such that this makes for a more intuitive unit for display.

4.3. Truck travel distances

Owing to a lack of other data, we use the simplifying assumption that all trucks crossing the U.S. border are registered in the country from which they are departing (Canada or Mexico). The overall freight transport distances (from origin to destination, or O–D) are estimated by the proxy of the straight line distances between the population centroids of the U.S. and the country of origin of the goods (Canada or Mexico). In other words, *all* trucks crossing the U.S. border are assumed to begin at the population centroid of Canada or Mexico, and to end at the U.S. population centroid. This is a good central value to use, and allows for both short and long truck hauls within the country of origin (either Mexico or Canada). However, this is only an approximation, as freight movements travel by road, and therefore likely deviate from a straight line path.[13] These total (or O–D) travel distances must now be broken down by the country in which they occur. Within each country, we assume that the distance traveled is proportional to the average trip distance for domestic shipments (not imports) in that country, estimated as the ratio of domestic truck movement in ton–kilometers to domestic freight movement in tons.[14]

[13] Using data on the locations and populations of various sub-national administrative units (in the year 2000) from NASA (SEDAC, 2005) and the distance calculator from the U.S. National Hurricane Center (NHC, 2010), the total freight transport distances are determined as 674 miles for Canada–U.S. shipments, and 1240 miles for Mexico–U.S. shipments.
[14] Using data obtained from the North American Transportation Statistics Database (NATSD, 2012) for 2010 (the most recent year for which data are available for all three countries), the trip distances for domestic shipments work out to 279 km for Canada, 469 km for Mexico, and 251 km for the U.S.

Table 3
Wait times for trucks in the default (status quo) case and the expected changes in wait times for adding one customs officer to each U.S. land port of entry (POE).

Port of entry	Crossing	No. of trucks with wait time reductions	Average wait time, default/status quo case (minutes)			Change in wait time during 8 most-congested hours, +1 officer case[a,b]	
			Overall	8 Most-congested hours	All other hours	Percent	Minutes
Southern border							
Calexico	Calexico/East	104,040	25.3	28.8	18.7	−69.6	−20.0
El Paso	Ysleta	99,909	10.1	13.1	6.3	−72.9	−9.5
	Bridge of the Americas	98,685	14.6	17.5	8.4	−58.4	−10.2
Laredo	Columbia Solidarity	108,477	7.4	8.6	5.0	−95.5	−8.2
	World Trade Bridge	354,807	23.8	29.0	15.3	−69.0	−20.0
Nogales	Mariposa	105,264	30.4	37.5	6.1	−54.6	−20.5
Otay Mesa	Otay Mesa	186,813	29.4	34.2	18.9	−38.1	−13.0
Northern border							
Blaine	Pacific Highway	71,298	11.0	16.4	5.7	−83.0	−13.6
Buffalo-Niagara Falls	Lewiston Bridge	34,425	2.3	8.1	0.19	−71.0	−5.8
	Peace Bridge	107,253	5.3	11.2	1.1	−47.1	−5.3
Detroit	Windsor Tunnel	10,328	3.5	4.6	1.6	−100.0	−4.6
	Ambassador Bridge	240,363	4.6	7.0	2.9	−61.2	−4.3

[a] Optimally allocated to the eight most congested hours of each day.
[b] Relative to the default values.

The ratio of the domestic distance for Mexico to that for the U.S. is (469 km/251 km) = 1.87, so we assign 87% more of the total Mexico–U.S. transport distance (1240 miles) to Mexico. For Mexico–U.S. shipments, this results in estimated trip distances of 808 miles in Mexico and 432 miles in the U.S. Applying this procedure to Canada–U.S. shipments gives 355 miles traveled in Canada and 319 miles traveled in the U.S. Additionally for Canada, in 2009, trucks weighing 4.5 metric tons or more drove some 1969 million vehicle-miles for "trips across Canada and United States border" (Statistics Canada, 2010). With a total of 5,020,633 truck trips into the U.S. from Canada in 2009 (BTS, 2012), and assuming that all of these trucks are Canadian-registered (see above), this equates to 392 miles traveled per trip in Canada. The average estimated trip distance in Canada is therefore 373.5 miles.

4.4. Truck operating costs

Unless otherwise noted, all costs are specified on a per truck and per trip basis, and are in 2011$.[15] The fuel consumed is equal to the ratio of the distance traveled to the truck fuel efficiency (*TFE*; miles/gallon), which is a function of the average truck speed. Similarly, the distance traveled by the truck is the product of the truck's speed (S) and the total travel time. We use an average truck speed of 40 miles/h for the open highway (S_h) (ATRI, 2011), and 5 miles/h when at the border crossing (S_b) (i.e., in the queue and during the inspections). Accordingly, the truck's fuel economy when at and away from the border crossing stations are $TFE_b = TFE(S = S_b)$ and $TFE_h = TFE(S = S_h)$, respectively. The truck fuel efficiency for U.S. trucks is specified using the regression equation of Schrank et al. (2011) for *TFE*, based on average truck speed. However, the data used by Schrank and others applies only to U.S. trucks, and these results must be corrected in the case of non-U.S. trucks. While not addressing 18-wheel trucks specifically, the American Transportation Statistics Database (NATSD, 2012) does include fuel efficiency data for "new light-duty trucks." These data indicate that Canadian trucks are, on average, around 1% more fuel efficient than U.S. trucks, and that Mexican trucks are around 9% more fuel efficient than U.S. trucks, so we make these adjustments. For the cost of diesel fuel, we use $3.42/gallon for Mexico, $4.03/gallon for the U.S., and $4.94/gallon for Canada (all deflated from 2013$ to 2011$), all obtained from MyTravelCost.com (2013).

So that they can be readily linked to the reduced wait times at the border, in cases where truck operating cost data from the literature are used that are specified on a per mile (rather than per hour) basis, we first convert them to hourly costs using an overall average truck speed of 40 miles/h (ATRI, 2011). The average hourly wage for "heavy and tractor-trailer truck drivers" in the U.S. is $19.15/h, according to the U.S. Bureau of Labor Statistics (BLS, 2012). The American Transportation Research Institute gives figures of $18.74/h excluding benefits, and $24.68/h including benefits (ATRI, 2011). Averaging all of these values together gives $20.86/h for U.S. truck drivers. Workers in Canada's "transportation and warehousing"

[15] Inflation adjustments are made using the Producer Price Index (PPI–across all commodities), and conversions from Canadian to U.S. dollars using the Bank of Canada's currency converter (Bank of Canada, 2013).

industry earn, on average, \$22.99/h (Statistics Canada, 2012). Transport Canada (2005) also provides numerous truck driver wage estimates, working out to around \$23.10/h, on average. Averaging these two values together gives \$23.05/h for truck drivers in Canada. Driver wage data for Mexico could not be found, so this was estimated by adjusting the wage rates for the U.S. and Canada, using the relative GDPs per capita of the two countries (GDP data from World Bank, 2013), working out to \$4.48/h (average value). While somewhat crude, an adjustment based on per capita GDP was the only means available to estimate these costs for Mexico (other than World Bank data to be disused below).

The Minnesota Department of Transportation estimates a average cost of \$12.80/h for truck repairs, maintenance, tires, and depreciation (MDOT, 2003). The American Trucking Research Institute proposes \$23.95/h (ATRI, 2011). Boyer (1997) posits \$25.28/h for vehicle depreciation, licensing, interest, tires, and maintenance, which we have inflated to 2011 dollars. After excluding driver wages (i.e., with the average wage rate subtracted out), Schrank et al. (2011) determine a value of \$76.85/h for vehicle depreciation, interest, insurance, general maintenance, tires, and repairs (Ellis, 2009). The average operating cost for U.S. trucks is therefore about \$34.72/h. Data from Transport Canada (2005) indicates an average cost of about \$77.60/h for truck repairs, cleaning, tires, depreciation, licenses, profit margin, interest, insurance, and administration. For truck operating costs in Mexico, as with the truck driver wages (above), we adapt the values for the U.S. and Canada using relative per capita GDP, yielding \$11.37/h, on average.

Customs broker fees (per truck trip) are generally \$50–\$150 on the northern border, and \$20–\$30 on the southern border (where the process is more repetitive/organized) (Gould, 2012). We use the range midpoints, or \$25 for the southern border and \$100 for the northern border, which we assume do not depend on the wait times at the border. Based on interviews conducted with various trucking carriers, Haralambides and Londono-Kent (2004) estimate an average cost of about \$154/trip associated with the drayage operation at the U.S.–Mexico border, which we adopt. The drayage cost is associated with unloading the goods from the truck that transports them within Mexico, loading them onto another truck that takes then across the U.S.–Mexico border, and then loading them onto another truck that transports them within the U.S. interior. All trucks traveling into the U.S. from Mexico are assumed to undergo drayage.

4.5. Changes in truck transportation costs

The origin–destination (O–D) transport cost for trucks is the sum of: the transport costs that are incurred *at* the border crossing (TC_b), and the transport costs incurred *away from* the border crossing. The only component of the O–D transport cost that is affected by wait time changes at the border crossing is the border-related transport costs (TC_b), and so the change in the O–D transportation cost is therefore equal to:

$$\Delta TC = \Delta TC_b = (\Delta WT) \cdot \left[UC_w + UC_v + UC_f \cdot \left(\frac{S_b}{TFE_b} \right) \right] \tag{1}$$

where UC_w, UC_f, and UC_v are the unit costs of driver wages (\$/h), fuel (\$/gallon), and all other vehicle-related operating expenses (\$/h), respectively. In Eq. (1), the values of all of the unit costs (UC_w, UC_f, and UC_v) and TFE_b are country-specific (i.e., Mexico or Canada), and the value of ΔWT is specific to the particular port of entry. Note that the customs broker and drayage fees are assumed unaffected by wait time changes, and hence why they do not appear in Eq. (1) (which gives the *change in* transport costs). Eq. (1) shows that the change in the total freight transportation costs is linear in the change in wait time at the border (ΔWT). The input for the CGE modeling (Section 5) is the *percent change* in the O–D truck transport costs, which is equal to 100% times ΔTC_b (given by Eq. (1)) divided by TC, where TC is the O–D transportation cost in the default (i.e., status quo) wait time scenario. Table 4 summarizes the truck transportation cost results for adding one customs officer to each POE during the eight most congested hours of each day. The changes in truck transport costs range (in magnitude) from a low of −0.053% (−\$0.37 M per year) for the El Paso (Ysleta) POE, to a high of −0.252% (−\$1.81 M per year) for the Blaine POE. The reduction in aggregate freight transportation costs (considering all trucks and all POEs) is \$11.67 M annually.

4.6. Sensitivity analysis

Rather than examining the sensitivity of the results at all of the various POEs, sensitivity analysis was performed only on the Nogales (Mariposa) POE (southern border). The values of 16 model parameters were changed simultaneously by +/−25% so as to yield 'high' and 'low' truck transport cost cases, respectively. The various parameters whose values were varied are the: broker and drayage costs, unit fuel costs (3, one for each country involved), unit wage costs (3), unit truck operating costs (3), truck speeds (2, highway and queue), and travel distances in each country (4). Note that 'low' and 'high' sensitivity cases refer to the values of the *transport costs*, and not to the values of the input parameters. This is why the higher truck speeds are used in the '*low*' cost sensitivity case, and not in the 'high' cost sensitivity case.

The sensitivity analysis results indicate that the aggregate change in truck transport costs (relative to the default/status quo officer case) are −\$0.640 M and −\$1.020 M in the 'low' and 'high' transport cost cases, respectively. Relative to the change in the 'middle' cost case (of −\$0.832 M, as presented in Table 4), this represents changes (in magnitude) of about 23%. This indicates that the cost changes are essentially linear, as the various input parameters were all varied by 25% (in magnitude).

Table 4
Changes in truck transportation costs for adding one customs officer to each U.S. land port of entry (POE).

Port of entry	Crossing	No. of trucks with less wait time	Change in truck wait time[a]		Changes in total truck transport costs (all trucks)	
			Percent	Per truck (minutes)	Total (million 2011 US$)	Percent
Southern border						
Calexico	Calexico/East	104,040	−69.6	−20.0	−$0.81	−0.131
El Paso	Ysleta	99,909	−72.9	−9.5	−$0.37	−0.053
	Bridge of the Americas	98,685	−58.4	−10.2	−$0.39	−0.070
Laredo	Columbia Solidarity	108,477	−95.5	−8.2	−$0.34	−0.083
	World Trade Bridge	354,807	−69.0	−20.0	−$2.74	−0.105
Nogales	Mariposa	105,264	−54.6	−20.5	−$0.83	−0.145
Otay Mesa	Otay Mesa	186,813	−38.1	−13.0	−$0.94	−0.076
Sub-total (Southern POEs)					−$6.42	n.a.
Northern border						
Blaine	Pacific Highway	71,298	−83.0	−13.6	−$1.81	−0.252
Buffalo-Niagara Falls	Lewiston Bridge	34,425	−71.0	−5.8	−$0.37	−0.057
	Peace Bridge	107,253	−47.1	−5.3	−$1.06	−0.081
Detroit	Windsor Tunnel	10,328	−100.0	−4.6	−$0.09	−0.109
	Ambassador Bridge	240,363	−61.2	−4.3	−$1.92	−0.065
Sub-total (Northern POEs)					−$5.25	n.a.
Total (all POEs)					−$11.67	n.a.

[a] Relative to the default/status quo case.
n.a.: not applicable.

When the changes in total truck transport costs are viewed in percentage terms, however, the results are less straightforward. In this case, the percentage change in costs (relative to the default/status quo officer case) is actually greater (in magnitude) in the 'low' cost case than in the 'middle' cost case (−0.217% versus −0.145%, respectively), and also greater in the 'middle' cost case than in the 'high' cost case (−0.145% versus −0.096%, respectively). The reason for this is because the total truck transportation costs (from origin to destination, including the border crossing) change at a different rate than the border-related truck transport cost savings (induced by the reduced wait time). For example, the total transport cost in the 'middle' and 'low' cost cases differ by a factor of 1.95 ($1927/truck and $989/truck, respectively), yet the change in the truck transport costs between the two cases differ only by a factor of about 1.30 (−$2.79/truck and −$2.14/truck, respectively). Consequently, the magnitude of the percentage change in truck transport costs is greater in the 'low' cost case than in the 'middle' case.

5. Macroeconomic analysis

The majority of U.S. trade with its largest trading partners, Canada and Mexico, is conducted via land transport through its northern and southern borders, respectively. In 1994, the United States, Canada, and Mexico signed the North American Free Trade Agreement (NAFTA), which eliminated various trade duties and restrictions, thereby creating the largest free trade zone in the world (the remaining restrictions were removed in 2008). According to the Office of the United States Trade Representative (2012), NAFTA has better connected 450 million people that produce goods and services worth a total of $17 trillion. In 2009, the total value of the U.S. trade with its NAFTA partners was $1.6 trillion, with exports and imports worth $397 billion and $438 billion, respectively.

Although NAFTA eliminated trade restrictions and tariffs, it only moderately improved border crossing procedures (e.g., inspections/processing). Regarding the U.S.–Canada border, Taylor et al. (2003) argue that the trade, border, and immigration policies across the U.S.–Canada border remain heavily influenced by pre-NAFTA practices. Moreover, the economies of both countries have incurred significant cost impacts due to such policies, and these cost impacts became even more significant after tightened border security following the 9/11 terrorist attacks.

We estimate the impacts of the changes in freight transportation costs on U.S. international trade with a computable general equilibrium (CGE) model. This is a multi-market model of behavioral responses of individual producers and consumers to price signals within the limits of available labor, capital, natural resources (Dixon and Rimmer, 2002). CGE is a state-of-the-art approach to economic consequence analysis. It overcomes the major limitations of I–O because it allows for non-linearities such as input substitution, has behavioral content, provides an explicit role for prices and markets, and can distinguish between intermediate and final consumption goods (Rose, 1995).

CGE models have been widely applied to trade and transport-related issues. Sandoval et al. (2009) use a CGE model of the global economy to analyze the economic feasibility of hydrogen transportation and trade under various carbon stabilization and tax policy scenarios. Pilegaard and Fosgerau (2008) use a spatial CGE model to analyze the impact of reduced transport costs on increased employment search over longer distances. Lloyd and MacLaren (2010) suggest "semi-general equilibrium" measures, including non-tariff measures, to capture general-equilibrium effects neglected in partial-equilibrium forms of the Trade Restrictiveness Index and the Mercantilist Trade Restrictiveness Index. Finally, a recent study by Winchester et al. (2013) uses a recursive dynamic CGE model to study the impacts of a representative carbon policy on U.S. aviation operation and emissions. The topic of the CGE application in this paper is unique, as is the methodological refinement of our approach.

Changes in border wait times translate into changes in transportation costs, which, in turn, translate into changes in relative competitiveness of U.S. imports and exports. Ironically, although the costs of reductions in wait times (e.g., additional customs personnel) will be borne by the U.S., reducing the wait times for goods entering the U.S. makes them relatively cheaper, and spurs U.S. imports from its northern and southern neighbors. This has the effect of initially advantaging Canada and Mexico relatively more than the U.S. However, the vast majority of the imports are unfinished (intermediate) goods rather than finished (final, or consumer) goods. This lowers the cost of production in the U.S. and makes its exports more competitive, not only to Canada and Mexico, but to all countries. This stimulates U.S. exports worldwide, and causes increases in U.S. GDP, personal income, and employment. The extent to which the negative effect of increased import competitiveness for U.S. major trading partners is offset by the effect of increased U.S. export competitiveness requires a sophisticated economic modeling framework, such as the CGE approach.

5.1. GTAP model

We utilize a version of the Global Trade Analysis Project (GTAP, 2012) CGE model that allows substitution among modes of transport (Avetisyan and Hertel, 2015). GTAP was developed in conjunction with the U.S. International Trade Commission (ITC) and the World Trade Organization (WTO) and is currently the most widely used international CGE model. The model consists of 129 country economies, each of which is comprised of 57 industry commodity groupings, and incorporates the import/export trade linkages between them. In our analysis, we aggregate the model to 4 regions (United States, Canada, Mexico, and Rest of World).

5.1.1. Production

The production structure is an overall constant elasticity of substitution (CES) form for aggregate factors of production, though fixed coefficient relationships are used for intermediate inputs. Value added from primary factors together with intermediate inputs generates the final output in the model.

5.1.2. Consumption

Household consumption in the GTAP model is represented by constant-difference of elasticities (CDE) functional form, whereas the household's preferences over consumption, government spending and saving are characterized by Cobb–Douglas relationship.

5.1.3. Trade and transport

International trade and transport in the Global Trade Analysis Project (GTAP) model are represented by merchandise goods and "margin" services (shipping services, or transport costs). These data are contained in a "trade matrix," which includes bilateral flows of regular commodity components, while the margins preserve the balance between global imports (CIF values) and exports (FOB values).[16] The difference between imports and exports of global merchandise represents global exports of transport services (transport margins).

In the GTAP model, the origins and destinations of traded goods are specified. However, this is not the case for transport services, which are grouped into a single Global Transport Services Industry, and then allocated to the various importing countries using the share of exports of traded merchandise (non-margins) for each country in the global exports of traded goods. More specifically, when the source country, *r*, exports a commodity to the country of destination, *s*, the export commodity (at FOB price) is combined with the composite international transport good (which is a mix of air, water, and other transport modes), thereby generating the CIF price of the commodity in the destination country. Fig. 2 summarizes the structure of the standard GTAP model.

While the transport input is a fixed composite good, our modified version of the model allows for substitution among modes within the composite transport good. The transport modal substitution is determined by a Constant Elasticity of Substitution (CES) production function. The CES elasticity of substitution, with a typical value of 0.9–2.8, governs modal choice changes in response to variations in the relative cost of the different transport options.

The substitution among different modes of transport is incorporated in the GTAP model by estimating the elasticities of modal substitution for land–air and water–air transport pairs (Avetisyan and Hertel, 2015). The modal substitution

[16] Cost, insurance, freight (CIF) value includes the cost of goods, insurance, and freight up to the destination. Free on Board (FOB) value does not include the cost of shipping and insurance. The seller is required to deliver merchandise on board of a vessel specified by the buyer.

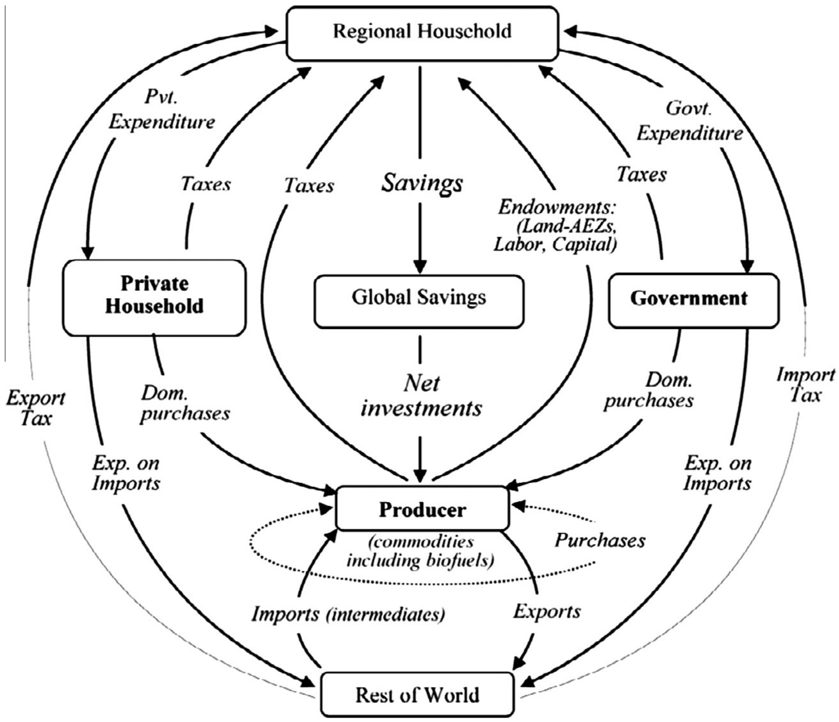

Fig. 2. Structure of the GTAP model. *Source*: Hertel et al. (2010).

elasticities by commodity, source, and destination are then generated by applying the weighted transport cost shares from the GTAP data base to the estimated elasticities of substitution between land–air and water–air transport modes. The study also shows that improvement in logistics reduces the cost and amount of transportation services required to transport a given product along a particular route using a given mode.

In the GTAP model, transportation costs are endogenously determined. A transport cost reduction scenario can be modeled by exogenizing and perturbing the corresponding transportation price variables ($ptrans_{i,r,s}$ and pt_m) in the modal substitution Eq. (2) from the GTAP model.[17] Specifically, $ptrans_{i,r,s}$ is the price of composite transport services in Global Transport Industry for shipping good i from source r to destination s, and pt_m is the price of global transport services by mode m. The latter is a price index for each mode that applies globally, and is not differentiated by industry, source, or destination.

$$qm_{m,i,r,s} = -am_{m,i,r,s} + qx_{i,r,s} - \sigma_{i,r,s}.(pt_m - am_{m,i,r,s} - ptrans_{i,r,s}) \tag{2}$$

where

$qm_{m,i,r,s}$ is the international usage of transport mode m to ship good i from region r to s;
$am_{m,i,r,s}$ is the change in transportation technology of mode m to ship good i from region r to s;
$qx_{i,r,s}$ is the export sales of commodity i from region r to s;
$\sigma_{i,r,s}$ is the elasticity of modal substitution to ship good i from region r to s;
pt_m is the price of composite transportation services;
$ptrans_{i,r,s}$ is the cost index for international transport shipping good i from region r to s.

If transportation costs decrease due to technological factors not included in the model, the transport cost variable $ptrans(i,r,s)$ needs to be "swapped" with another variable to maintain the equivalence of equations and variables in equilibrium models. Therefore, we use a variable representing the change in technology of shipping good i from source r to destination s. Ideally, the value of this now endogenous variable would remain zero or near zero because we do not change the transportation technology. Since the reduction of wait times at the U.S.–Canada border assumes an increase in U.S. security staff on the Canadian side, we conclude that it is best to model the corresponding reduction in transport costs as a change in transportation technology resulting from an increase in the labor input.

The other transport cost variable pt_m, representing the price index for transport commodity m in margin services usage, can become exogenous only by swapping it with the variable atm_m, representing the change in technology of transport mode

[17] Note that in Eq. (2) all variables represent percent changes in corresponding level variables.

m worldwide. This is the only candidate for the swap, since the transport cost variable pt_m is a source, industry, and destination generic variable.

The GTAP model has three transport industries: Other Transport, Water Transport, and Air Transport. The design of the transport cost reduction scenario becomes more complex due to a need to separate truck transport from the Other Transport industry, which also includes rail transport, pipelines, auxiliary transport activities, and travel agencies.

The U.S. Input–Output table, provides the use of imported truck transport services by each industry in the U.S. economy. Therefore, we use the following procedure to bridge the trucking industry of the U.S. Input–Output table and the GTAP model:

a. Identify the total use of imported truck transport services from the U.S. Input–Output table.
b. Use the GTAP international trade margins by commodity and source for shipments to the U.S. by Other Transport to create shares for allocating the total imports of truck transport services across industries and source countries in the GTAP model.
c. Apply the weights/shares to the total use of imported truck transport services to estimate U.S. truck transport costs by commodity and source country.

The GTAP model has many strengths but also a few shortcomings. These include the assumption of equilibrium adjustments, perfect competition and perfect information. While the assumptions are unrealistic, their departures from reality are considered relatively minor or not likely to have a significant effect on our results.

5.2. POE-level impact analysis

In the GTAP model the unit transportation costs ($ptrans_{i,r,s}$ – the price of composite transport services in the Global Transport Industry differentiated by commodity, source and destination) are endogenous, so we need to make the corresponding transportation price variables exogenous to simulate the reduction in transport costs and determine the impact of these cost changes on the U.S. economy. Since the transportation cost decreases due to production inputs not factored into the model, the transport cost variable $ptrans_{i,r,s}$ must be made exogenous, which we do by swapping it with the variable representing the change in production structure (often referred to as "technology," broadly defined) of shipping good i from source r to destination s.

In the GTAP model the original trade data are not available by port of entry. Therefore, in our analysis we disaggregate the baseline trade data by POE using the U.S. Bureau of Transportation Statistics (BTS) (2012) U.S. truck import data for each port of entry. With such level of disaggregation we generate more accurate results for each of the transport costs reduction scenarios. Table 5 shows the ten main and other commodities imported through each Northern POE, as well as changes in U.S. truck transport imports at those POEs.

The largest increases in U.S. truck imports from Canada occur in the Detroit POE crossings due to the combined effect of relatively large reduction in truck transport costs and large trade volumes there. In the Buffalo-Niagara Falls POE a similar reduction in truck transport costs generates a relatively smaller increase in truck imports due to relatively small import volumes transported through this POE. Even though the level of Blaine POE imports is only about 20% of the level of baseline imports transported through the Buffalo-Niagara Falls POE, there is a much greater percentage reduction in the Blaine POE transport costs, resulting in the increase in import volumes 33% of the Buffalo-Niagara increase. The other reason for the differential is due to variation in the mix of imported goods across the POEs. Table 6 shows the analogous changes in U.S. truck imports across the Southern Border, which vary across POEs due to the combined effect of decreasing transport costs and growing trade volumes through these crossings.

An example of the analysis of our macroeconomic results is presented for the Blaine, Washington, POE in Table 7. In this case, we adjust the 0.25% reduction of truck transport costs to 0.18% using the share (0.7) of Truck Transport in the Other Transport Industry of the GTAP model. The results of the simulation, in terms of reduced transport costs affecting total exports, imports and GDP in each region are shown. Overall, the results indicate that $a + 1$ change in staffing at the Blaine POE will cause a very small positive increase in U.S. GDP of $0.9 million in 2011 dollars.

As expected, the reduction in transport costs for shipping goods from Canada to the U.S. results in the increase of total imports to the U.S. Interestingly, the total imports to Canada from the U.S. and the Rest of the World also increase, which can be explained by Canada's increased import demand for goods from the U.S. due to the lower cost of U.S.-produced commodities, which also ripples through the global economy. Our findings demonstrate a link between reduced transport costs and growth in trade, consistent with the work of Djankov et al. (2010) and Hummels and Schaur (2013).

In the U.S., the change in the trade balance is positive, because exports grow more than imports. In Canada, the change in the trade balance is negative, because imports grow more than exports. Also, the GDP of Canada increases by $2.47 million in 2011 dollars, or 0.00016%, due to increased exports. Note that, while the U.S. implements and pays for the changes that result in the reductions in border crossing times, it also gains from transport cost reduction policies because intermediate goods shipments reduce the cost of production in the U.S., thereby making U.S. exports more competitive world-wide.

Since the CBP officers reduce the wait time for imports to the U.S., our primary focus is on this type of trade flow, as opposed to exports. In our analysis we consider both imported intermediate goods and imported commodities for final consumption. We apply the share of imported goods used for final consumption in total demand to distinguish between these

Table 5
Changes in truck transport imports from Canada for adding one customs officer to each major northern U.S. land port of entry (POE).

Commodity	Port of entry/crossing				
	Blaine	Buffalo-Niagara Falls		Detroit	
		Lewiston Bridge	Peace Bridge	Windsor Tunnel	Ambassador Bridge
Truck imports from Canada (million 2011 US$)					
Motor vehicles and parts	380	5008		16,302	
Chemical, rubber, plastic products	1009	6958		8950	
Machinery and equipment	526	3583		8501	
Food products	846	1527		2446	
Paper products, publishing	538	1558		2272	
Metals	125	2314		1507	
Transport equipment	501	806		2555	
Metal products	133	1162		1830	
Ferrous metals	133	756		1151	
Mineral products	119	451		550	
Other commodities	691	1993		2691	
Total	4999	26,116		48,756	
Change in transport cost (%)	−0.25	−0.06	−0.08	−0.11	−0.07
Change in total truck imports by POE (million 2011 US$)	0.745	0.878	1.248	3.132	1.868

Table 6
Changes in truck transport imports from Mexico for adding one customs officer to each southern U.S. land port of entry (POE).

Commodity	Port of entry/crossing						
	Calexico	El Paso		Laredo		Nogales	Otay Mesa
		Ysleta	Bridge of the Americas	Columbia Solidarity	World Trade Bridge		
Truck imports from Mexico (million 2011 US$)							
Machinery and equipment	2650	11,237		17,398		2387	8635
Electronic equipment	1817	7059		8501		1605	5649
Chemical, rubber, plastic products	465	1799		5030		380	1602
Motor vehicles and parts	276	2123		5207		302	811
Food products	299	137		1571		1066	418
Mineral products	297	552		1944		107	498
Metal product	284	473		1301		296	528
Vegetables, fruit, and nuts	184	76		392		1464	435
Wearing apparel	15	523		1080		99	273
Textiles	57	152		818		98	197
Other commodities	347	824		3321		264	967
Total	6691	24,954		46,563		8069	20,013
Change in transport cost (%)	−0.13	−0.05	−0.07	−0.08	−0.11	−0.15	−0.08
Change in total truck imports by POE (million 2011 US$)	0.256	0.380	0.500	1.123	1.412	0.342	0.443

Table 7
Changes in U.S. trade volumes and GDP for adding one customs officer to the Blaine port of entry (POE).

Regions	Exports (%)	Imports (%)	Trade balance (million 2011 US$)	GDP (million 2011 US$)	GDP (%)
United States	0.0027	0.0004	3.901	0.899	0.000006
Canada	0.0037	0.0095	−2.279	2.473	0.000160
Mexico	−0.0002	−0.0001	−0.410	−0.087	−0.000007
Rest of World	−0.0002	0.0001	−36.661	−3.493	−0.000007

two types of imports. Specifically, if the share of final consumption imports in total demand is less than 35%, we classify these imports as intermediate commodity imports. We then adjust intermediate imports based on the characteristics of specific commodities in the GTAP model. Some of the U.S. truck imports from Canada with a significantly large share of intermediate consumption are 99%, 94%, 86%, and 84% for ferrous metals, petroleum and coal products, metal products, and transport equipment, respectively. The information about intermediate truck imports used in our study is summarized in Table 8.

Table 8
Trucked intermediate import intensities of imports to the U.S. at northern and southern U.S. land ports of entry (POE).

Port of entry	Crossing	Change in transport cost (%)	Trucked intermediate import intensity
Southern border			
Calexico	Calexico/East	−0.13	0.61
El Paso	Ysleta	−0.05	0.61
	Bridge of the Americas	−0.07	0.61
Laredo	Columbia Solidarity	−0.08	0.60
	World Trade Bridge	−0.11	0.60
Nogales	Mariposa	−0.15	0.52
Otay Mesa	Otay Mesa	−0.08	0.60
Weighted average		n.a.	0.59
Northern border			
Blaine	Pacific Highway	−0.25	0.63
Buffalo-Niagara Falls	Lewiston Bridge	−0.06	0.64
	Peace Bridge	−0.08	0.64
Detroit	Windsor Tunnel	−0.11	0.61
	Ambassador Bridge	−0.07	0.61
Weighted average		n.a.	0.62

n.a.: not applicable.

The gains, however, are not as great as those of Canada. Overall, for this POE the GDP of the U.S. and Canada increase, while the GDPs of Mexico and Rest of the World decline, because their exports to the U.S. are displaced a bit by Canadian exports. This is consistent with the results of Minor and Tsigas (2008) that countries that reduce trade time gain significant benefits when other regions make no improvements in trade. In terms of individual commodity trade, these results are consistent with the findings of Minor and Tsigas (2008), as summarized in Section 2. The reduced transport costs induce the U.S. to increase its imports of relatively cheaper intermediate goods from Canada, and reduce its imports of all these products from Mexico and Rest of World. This enables the U.S. to increase its exports of some intermediate and most final consumption products to the global economy.

The U.S. increases almost all its exports to Canada, except minerals, coal, metals, and transport equipment. Within the U.S. (that is, between U.S. states), trade declines for most U.S. industries due to the increased imports of relatively cheaper intermediate products from Canada.

The macroeconomic impacts for the remaining northern POEs are similar to the results of the Blaine example, but with some variation in scale. Analogously, the reduction in truck transport costs for all U.S. imports from Mexico through southern POEs increases the GDP of the U.S. and Mexico, while having a negative impact on the GDPs of Canada and the Rest of World regions. For all southern border POEs, the U.S. increases its imports of intermediate goods from Mexico and increases exports of commodities for final consumption to all world regions.

The difference in percentage change in freight costs between Canada and Mexico is a key factor explaining the difference in GDP impacts between the two countries. The weighted average percentage decreases in costs of trucked goods delivered to the U.S. through northern POEs is about 1.3 times higher than those delivered through southern POEs (this stems to a great extent from the significant reductions in wait times at the Blaine and Windsor Tunnel crossings than at any of the southern border POEs). This helps explain why the increase in Canadian GDP is more than 3.4 times that of Mexican GDP. This correspondence between truck transport costs and GDP impacts between countries is only minimally affected by indirect and induced effects through the global economy, as well as other considerations, such as non-linearities in the model. Also, the fact that Canada's GDP is about 50% greater than Mexico's more than offsets Mexico's trucked imports being about 33% greater than trucked goods to the U.S. from Canada.

5.3. Macroeconomic impacts

Table 9 summarizes the total GDP and employment impacts of adding one customs officer to each of the major southern and northern POE crossings. Overall, Canada is predicted to gain most from the +1 staffing change, with an increase in GDP of $5.3 million, or more than 3.4 times that of Mexico and nearly 1.3 times that of the U.S.

Overall, we find that adding one CBP agent at each land border crossing, on average per crossing, would generate an increase in U.S. GDP of $350 thousand and 3.58 additional jobs (over and above the additional CBP agents).[18] Both Canada and Mexico would reap net macroeconomic gains as well, with those of Canada exceeding U.S. gains. Note also that the implicit multiplier of 3.58 jobs generated for every new customs officer is not an ordinary economic impact multiplier calculated under

[18] We checked the sensitivity of our results with respect to alternative sources of data. For example, World Bank (2015) data indicate that total truck freight costs from Canada and Mexico are somewhat *higher* than those we used. Hence, our estimates of benefits of wait time reductions are *higher* than had we used these data (the input into GTAP is the *percentage change in the transport costs*, and the percentage change in the transport costs is *inversely* related to the total transport costs). Essentially, our estimates represent an upper bound for the findings with respect to imports from Canada and Mexico. However, this does not change the qualitative nature of our results with respect to a reduction in wait times stimulating net positive macroeconomic impacts on all three countries.

Table 9
Changes in U.S. GDP and employment for adding one customs officer to each U.S. land port of entry (POE).

Port of entry	Crossing	Change in transport cost (%)	Change in U.S. employment (no. jobs)	Change in U.S. GDP (million 2011 US$)	Change in Canada GDP (million 2011 US$)	Change in Mexico GDP (million 2011 US$)
Southern border						
Calexico	Calexico/East	−0.13%	4	0.414	−0.050	0.346
El Paso	Ysleta	−0.05%	2	0.166	−0.020	0.138
	Bridge of the Americas	−0.07%	2	0.218	−0.026	0.183
Laredo	Columbia Solidarity	−0.08%	3	0.263	−0.032	0.220
	World Trade Bridge	−0.11%	3	0.331	−0.040	0.277
Nogales	Mariposa	−0.15%	5	0.459	−0.055	0.384
Otay Mesa	Otay Mesa	−0.08%	2	0.241	−0.029	0.201
Sub-total		n.a.	21	2.093	−0.253	1.750
Northern border						
Blaine	Pacific Highway	−0.25%	9	0.899	2.473	−0.087
Buffalo-Niagara Falls	Lewiston Bridge	−0.06%	2	0.150	0.618	−0.025
	Peace Bridge	−0.08%	3	0.300	0.773	−0.025
Detroit	Windsor Tunnel	−0.11%	5	0.450	1.082	−0.037
	Ambassador Bridge	−0.07%	3	0.300	0.618	−0.025
Sub-total		n.a.	22	2.099	5.564	−0.199
Total all POEs		n.a.	43	4.192	5.311	1.551

n.a.: not applicable.

normal average conditions, but rather one related to alleviating a bottleneck (at the margin), so is not surprisingly relatively high.[19]

We warn against drawing inferences from our results at greater scales. Our national and international macroeconomic impact analysis of freight activity is undertaken using a non-linear model. However, we have evaluated the model using only unit changes in customs personnel staffing and can offer no explicit insights about possible non-linearities that might be associated with larger staffing changes, except referring to the law of diminishing returns.

6. Conclusion

We have developed macroeconomic impact estimates for adding an extra CBP officer to a particular port of entry to reduce primary inspection wait time. The paper provides some unambiguous results using primary data and a state of the art model. These results are useful to the U.S. government and other relevant stakeholders (other governments, importing firms, exporting firms and NGOs) for evaluating the optimal level of staffing of ports of entry and carrying out cost-benefit analysis related to inspections at ports of entry. They could also be used to support analysis of how port operations could be funded, for example, through budgetary appropriations or through user fees, and for designing an optimal user fee.

Our results also emphasize the importance of taking into account cross-border supply chains when conducting trade policy analysis and modeling. As tariff levels have been significantly lowered in most countries, non-tariff impediments such as inspection delays have become relatively more important as a component of trade cost. Both tariff and non-tariff barriers have cumulating impacts inside a cross-border supply chain that cause a seemingly low barrier to have a much larger impact than its level might suggest. U.S. land borders with Canada and Mexico are crossed intensively by production supply chains, and our results demonstrate that U.S. export competitiveness is significantly impacted by measures that affect importing

[19] According to the pure theory of international trade, any reduction in the trade impediments for one of the countries would shift out its production possibility frontier and result in gains from trade for both parties. Thus, there would be some small gain to the U.S., even if none of the traded goods were intermediate. We focus on the intermediate goods aspects, because they are dominant in the situation. Intermediate goods constitute around 60% of total goods shipments coming into the US across all of its major northern and southern POEs. Moreover, these goods have sizable supply-chain stimulus effects associated with US production, stemming from their direct reductions in US production costs, while final goods have minimal supply-chain effects. Thus, we can conclude that the vast majority of the gains to the U.S are due to intermediate goods.

cost across these land borders. We thus contribute to an emerging literature that stresses the need to more fully and explicitly integrate various aspects of cross-border supply chains into trade policy analysis and modeling.

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Appendix A. Algebraic approach to the wait time-staffing relationship for a saturated border crossing

Although no formal results from queuing theory are available for saturated queuing systems (e.g., rush hours), it is possible to develop a simple algebraic approach to quantifying how wait time changes if a staffed inspection booth is added to or subtracted from a saturated system. This requires that all variables be made deterministic, so that random fluctuations are stripped from the analysis. For a given hour, define the following variables as:

- V = total number of vehicles processed;
- B = average number of booths open (and each booth is staffed by one officer);
- W = average wait time in seconds spent in the queue;
- Q = average queue length expressed as number of vehicles waiting in the queue at any given time in the hour;
- $v = V/B$ = number of vehicles processed by the average booth;
- $s = 3600/v$ = seconds required to process a vehicle at an average booth;
- $n = Q/B$ = the number of time periods that are s seconds long that are required to eliminate a queue of size Q;
- Note also that $n = W/s$.

For all land border crossings, CBP has collected data on V, B, and W, and therefore v, s, and n, since November 2009. Q is not measured by CBP. However, because $n = Q/B$ and $n = W/s$, Q can be estimated using this equation:

$$Q = \left(\frac{W}{s}\right)B \tag{A.1}$$

Now consider a queue system that is in equilibrium, so that arrivals to the queue equal departures from the queue, and Q is not changing over time. Denote arrivals by A, and departures by D. If the system is in equilibrium, then every s seconds, it must be the case that arrivals equal departures. Because departures equal B, arrivals must equal B, so that the change in queue length Q is:

$$\Delta Q = (A - D) = (B - B) = 0. \tag{A.2}$$

Now consider adding one extra booth at the beginning of the hour, and keeping arrivals fixed at B every s seconds. Departures every s seconds become $B + 1$, and it must be the case that every s seconds, the change in Q is:

$$\Delta Q = (A - D) = (B - \{B + 1\}) = -1. \tag{A.3}$$

Over the course of an entire hour, Q falls by v vehicles

$$\Delta Q = -v, \tag{A.4}$$

and at the mid-point of the hour:

$$\Delta Q = -\left(\frac{v}{2}\right). \tag{A.5}$$

Denote the queue length at the start of the hour as Q_0. Then adding an extra booth leads to a new queue length at the mid-point of the hour equal to:

$$Q_{M=}Q_0 - \left(\frac{v}{2}\right). \tag{A.6}$$

Using the equation $Q = (W/s) * B$, wait time at the mid-point of the hour is:

$$W_M = \frac{sQ_M}{(B+1)} = \frac{s(Q_0 - \frac{v}{2})}{(B+1)} \tag{A.7}$$

The ratio of the new wait time to the old wait time is therefore:

$$\frac{W_M}{W} = \frac{\frac{s\left(Q_0 - \frac{v}{2}\right)}{(B+1)}}{\frac{sQ_0}{B}} \tag{A.8}$$

or:

$$\frac{W_M}{W} = \left(\frac{B}{B+1}\right)\left(\frac{Q_0 - \frac{v}{2}}{Q_0}\right). \tag{A.9}$$

For a given hour at a given border crossing for a given lane type, actual data can be used to calculate values for n and Q_0, and then the above equation can be used to estimate how much wait time would change if one booth was added. This is the approach taken to calculating the percentage change in wait time in an hour resulting from adding one booth. If a booth is subtracted, the equation becomes:

$$\frac{W_M}{W} = \left(\frac{B}{B-1}\right)\left(\frac{Q_0 + \frac{v}{2}}{Q_0}\right). \tag{A.10}$$

This approach gives a result that is an approximation, because the approach assumes that the queue is initially in equilibrium. There are two important limitations to this approach:

- *Q is not stationary*. In most hours of the day, Q is not stationary but is rising or falling;
- *Cross-hour spillover impact not captured*. When a booth is added in one hour, it reduces the queue in that hour, but it also reduces the queue length and wait time in subsequent hours. However, this spillover impact is not captured by the simple approach outlined here. We apply our analysis to each of the 8-h separately, and neglect the cumulative impact that lowering the queue in hour 1 has on all subsequent hours, in hour 2 has on all subsequent hours, etc. This causes the methodology to understate the true impact of the extra officer, and our approach thus gives a lower bound to the impact of adding one booth for a whole day.

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