NBER WORKING PAPER SERIES

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Working Paper 18508
http://www.nber.org/papers/w18508

NATIONAL BUREAU OF ECONOMIC RESEARCH
1050 Massachusetts Avenue
Cambridge, MA 02138
November 2012

First Draft: November 2009. We are particularly grateful to Robert Lucas, Samuel Kortum, Nancy Stokey for their continuous encouragement, support and advice. We also thank for helpful comments Fernando Alvarez, Costas Arkolakis, Thomas Chaney, Dave Donaldson, Jonathan Eaton, Rob Feenstra, Cecilia Fieler, Gordon Hanson, Timothy Kehoe, Kalina Manova, Brent Neiman, Ralph Ossa, Stephen Redding, John Romalis, Peter Schott, Robert Shimer, Bob Staiger, Daniel Sturm, Chang Tai Hsieh and Silvana Tenreyro, and many seminar participants for useful conversations and comments. Correspondence: Caliendo, lorenzo.caliendo@yale.edu, Parro, fernando.j.parro@frb.gov.

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NBER Working Paper No. 18508
November 2012
JEL No. F10,F11,F13,F14,F17

ABSTRACT

We build into a Ricardian model sectoral linkages and differing productivity levels across sectors to understand how the gains from tariff reductions in a given sector spread to the rest of the economy. We also propose a new method to estimate sectoral trade elasticities consistent with any trade model that delivers a gravity trade equation. We apply our model and use our estimated elasticities to identify the impact of NAFTA's tariff reductions on exports and imports of all members. We find that the trade and welfare effects of tariff reductions are reduced by more than 40% when the structure of production does not take into account intermediate goods in production and input-output linkages. We then decompose the effects of tariff changes for NAFTA members and find that 93% of Mexico's, 58% of Canada's and 55% of the United States' trade effects due to tariff reductions can be attributed to NAFTA's tariff reductions.

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1. INTRODUCTION

Sectors and countries are interrelated. When the United States reduces tariffs applied to Mexico in a given sector, it not only affects prices in that sector but also in industries that purchase intermediate inputs from that sector. Moreover, a tariff reduction affects prices in non-tradable good sectors that are using inputs from tradable good sectors. Of course, how important are these direct and indirect effects from tariff changes will depend on the extent to which sectors are interrelated. For instance, the larger is the share of tradable goods used in the production of non-tradable goods the larger are the gains for producers of non-tradable goods from a reduction in the price of tradables. Even more, if non-tradable goods are also used as inputs in the production of other goods, or as final goods in consumption, then the benefits spread to the rest of the economy. In fact, most of the final goods consumed are non-tradable goods.[1] However, recent developments in international trade pay little attention to understanding how the gains from tariff reductions spread across sectors.[2]

We study the importance of input-output linkages and non-tradable good sectors to evaluate the trade and welfare effects of tariff reductions. To capture this mechanism, we build into a multi-country, multi-sector Ricardian model the interaction across tradable and non-tradable good sectors observed in the input-output tables. We use the model to identify the trade and welfare effects of NAFTA's tariff reductions. We find that trade effects are at least 50% lower and welfare effects are at least 40% smaller if intermediate goods in production and input-output linkages are ignored. These results unmask the importance of accounting for intermediate goods in production and input-output linkages to evaluate gains from trade.

NAFTA took effect on January 1, 1994, and since then trade has increased considerably between NAFTA members. For instance, Mexico's exports over GDP increased more than 100% in the period 1993-2005, and for Canada and the United States the increase was around 30%. Are all of these trade effects due to NAFTA's tariff reductions? What were the welfare effects of NAFTA? We use our model to answer these questions. We find that Mexico had the largest increase in exports and imports, followed by the United States and Canada. We find that 93% of the increase in Mexico's total trade over GDP as a consequence of tariff reductions can be attributed to NAFTA's tariff reductions, 58% for Canada and 55% for the United States. Real wages increased in all

[1] Non-tradable goods, namely services, accounted for more than 80% of the total final goods demanded in the year 1993 for the United States.

[2] An exception is the work of Arkolakis, Costinot, and Rodriguez-Clare (2012) where they evaluate the welfare gains from trade openness implied by a variety of international trade models including multi-sector models.

NAFTA countries, with Mexico having the largest gains. We find that most of Mexicos's welfare gains from tariff reductions between 1993 to 2005 are due to NAFTA, while almost half of the gains from tariff reductions are due to NAFTA for the case of Canada and the United States.

Adding more detail into a model comes at the cost of loosing track of the mechanisms that deliver the main results. In fact, this has lead to criticism of computational general equilibrium (CGE) models in the past.[3] To address this issue we build on the seminal work of Eaton and Kortum (2002) to develop a tractable model for tariff policy evaluation. As a result, we can decompose and quantify the differential role that intermediate goods and sectoral linkages have as amplifiers of the gains from tariff reductions. We also show that regardless of the number of sectors and how complicated the interactions across sectors are, the model can be reduced to a system of one equation per country, and the solution depends on estimates of one set of parameters, the dispersion of productivity across sectors (trade elasticities). This simplifies considerably the data requirements and estimated parameters needed for the evaluation of tariff changes.

In our theory, production is at constant returns to scale and markets are perfectly competitive. Countries import intermediate goods subject to trade costs from the lowest cost supplier in the world.[4] Intermediate goods in a given sector are used for the production of a composite good which is then used for consumption and as an input in the production of tradable and non-tradable intermediate goods from all sectors. Productivity differences across individual producers in a sector is introduced in the same way as in Eaton and Kortum (2002). The larger is the dispersion of productivities across producers, the larger are the gains from trade integration. In our model, productivity, as well as the dispersion of productivity, varies across sectors. This heterogeneity in the dispersion of productivities together with the share of intermediate goods in production and sectoral interrelations are key in order to capture how a tariff reduction has differential impact across sectors.

We express the model in relative changes and identify the trade effects of NAFTA's tariff reductions.[5] Our simulations are performed with few data and parameter requirements. In particular,

[3] These models have been criticized for their complexity, lack of transparency and analytical foundations, and the arbitrary choice of the value of key parameters (Baldwin and Venables 1995 describe them as "black boxes").

[4] The importance of trade in intermediate goods has been documented by several studies. For instance, Feenstra and Hanson (1996) find that the share of imported intermediates increased from 5.3% of total U.S. intermediate purchases to 11.6% between 1972 and 1990. Campa and Goldberg (1997) find similar evidence for Canada and the United Kingdom. Hummels, Ishii, and Yi (2001), and Yeats (2001) show that international trade in intermediate inputs has increased more than that in final goods.

[5] We perform a model-based identification of the trade effects due to NAFTA's tariff reductions by holding technology and other trade costs fixed. By doing this, we are not saying that technology or other trade costs might not have changed as a consequence of the change in tariffs. We are agnostic about how they might have changed and focus instead on the direct effect of tariff changes over the allocation of resources. An alternative exercise could have been to quantify the implied changes in technology and other trade costs in order for the model to deliver the

we only use data on bilateral trade flows, production, and tariffs and an estimate of sectoral trade elasticities. We develop a new method to estimate sectoral trade elasticities. The estimations are performed using trade and tariff data, without assuming bilaterally symmetric trade costs as is standard in the literature. Moreover, the method is consistent with any trade model that delivers a gravity-type trade equation. We estimate the parameters of the model at a sectoral level using data from 1993, the year before NAFTA went into effect. Then, using the estimated parameters and incorporating the change in tariffs from 1993 to 2005, both between NAFTA members and with the rest of the world, we use the model to quantify the changes in exports and imports over GDP in aggregate and at the sectoral level.

The number of regional trade agreements (RTAs) signed in the world has increased dramatically in the last 20 years (see Figure 1). Also, as we observe in Figure 2, an increasing share of world trade is covered by RTAs. Quantifying potential welfare gains and costs from trade policies has become increasingly important in recent years. Our paper relates to a large literature that evaluates trade policy and is mostly related to studies that quantify the gains from trade from NAFTA.[6]

Our paper is closely related to a recent and growing literature that extends the Eaton and Kortum (2002) model to multiple-sectors. For instance Arkolakis, et al. (2012), Caliendo and Parro (2010), Chor (2010), Costinot, Donaldson, and Komunjer (2012), Donaldson (2010), Dekle, Eaton and Kortum (2008), Eaton, Kortum, Neiman, and Romalis (2011), Hsieh and Ossa (2011), and Shikher (2011).[7] Our paper differs from these studies in several dimensions. First, we explicitly consider sectoral linkages between tradable sectors and between tradable and non-tradable sectors unlike previous Ricardian trade models. In our model, producers of non-tradable goods differ in productivity levels, demand tradable and non-tradable intermediate goods for production and supply goods not only for consumption but also for production in all sectors.[8] This feedback in

observed change in trade flows after NAFTA. But the problem there is how to identify if these changes were due only to NAFTA. Unless a model of TFP or trade costs is written there is no hope for identification. In our case, we take as exogenous the observable change in tariff due to NAFTA to quantify the trade effects.

[6] Jacob Viner's (1950) work was among the first to study the welfare analysis of trade policy. Bhagwati, Krishna, and Panagariya (1999) put together many of the major theoretical contributions since Viner. More recents are Anderson and Wincoop (2004), Baier and Bergstrand (2009), Deardorff (1998), Redding and Venables (2004), Rose (2004), and Subramanian and Wei (2007). Bagwell and Staiger (2010) survey recent economic research on trade agreements, with special focus on the GATT/WTO. Several studies have focused on the case of NAFTA, for instance Krueger (1999) and the references therein, Lederman, Maloney, and Serven (2005), Romalis (2007), and Trefler (2006). For results on CGE models in general see Brown, Deardorff, and Stern (1994), Brown and Stern (1989), Kehoe and Kehoe (1994), and for the case of NAFTA refer to Fox (1999), Kehoe (2003), Rolleigh (2008) and Shikher (2010).

[7] The Eaton and Kortum (2002) has been extended in many other directions also. One of the earliest studies was Yi (2003) who uses the model to understand if vertical specialization can explain the large growth in trade. More recent sutides are Burstein, Cravino, and Vogel (2012), Burstein and Vogel (2012), Caselli, Koren, Lisicky, and Tenreyro (2012), Fieler (2011), Kerr (2009), Levchenko and Zhang (2011), Parro (2012), Ossa (2012), Ramondo and Rodriguez-Clare (2012), and Waugh (2010). For a comprehensive survey of recent extensions of the Ricardian model of trade refer to Eaton and Kortum (2012).

[8] Non-tradable good sectors are often modeled as an outside sector that does not use intermediate goods for

production turns out to be important in order to quantify the trade and welfare effects of tariff reductions. Second, we show how accounting for intermediate goods in production and sectoral linkages does amplify the trade and welfare effects of tariff reductions. Finally, we extend the Ricardian model to perform a thoroughly quantitative evaluation of the trade and welfare effects from changes in trade policies.

Our paper is also related to studies that propose new methods to estimate trade elasticities.[9] We propose a new method that identifies sectoral and aggregate trade elasticities by exploiting the cross sectional variation in trade shares induced by the cross sectional variation in tariffs. The method relies on the multiplicative properties of the gravity equation consistent with a large variety of trade models (Krugman 1981, Eaton and Kortum 2002, Anderson and Wincoop 2003, Melitz 2003, and Chaney 2008).

The paper is structured as follows. In Section 2 we motivate the importance of modeling trade in intermediates, multiple sectors, and sectoral linkages for tariff policy evaluation. In Section 3, we develop a methodology to evaluate the trade and welfare effects of tariff changes and present the equilibrium conditions of the model. In Section 4, we propose a new method to estimate trade elasticities, and we estimate the parameters of the model. In Section 5, we discuss how to take the model to the data and explicitly show how to reduce the system of equilibrium equations to one equation and one unknown per country. After doing so, we apply the model to evaluate the trade and welfare effects of NAFTA. In Section 6 we conclude.

2. TARIFFS AND SECTORAL LINKAGES

Tariff rates vary substantially across sectors (see Figures 3 through 6). In 1993, the year before NAFTA went into effect, sectoral tariff rates applied by Mexico, Canada and the United States were, on average, 12.6%, 4.2%, and 3.0%, respectively, with a large heterogeneity across sectors. By 2005 they dropped almost to zero between NAFTA members, but tariffs that Mexico, Canada and the United States applied to the rest of the world were, on average, 7.8%, 2.1%, and 2.0%, respectively.[10] The fact to take away is that by 2005 average tariffs had decreased considerably,

production. For example see Alvarez and Lucas (2007).

[9] For instance, Feenstra (1994), Head and Ries (2001), Anderson and van Wincoop (2004) and references therein, Romalis (2007), and Simonovska and Waugh (2012).

[10] The reason why tariffs decreased is mostly that several free trade agreements entered into force during the period 1993-2005. For instance, Mexico signed free trade agreements with Costa Rica in 1995, Nicaragua in 1998, Chile in 1999, the European Union in 2000, El Salvador, Guatemala and Honduras in 2001, and Japan in 2005; Canada signed agreements with Chile in 1997 and Costa Rica in 2002; and the United States signed agreements with Jordan in 2001, Chile, Costa Rica, the Dominican Republic, El Salvador, Guatemala, Honduras, Nicaragua and Singapore in 2004, and Australia in 2005.

but they still remained very dispersed across sectors. Trade and welfare effects of average changes in tariffs can be analyzed using simple one-sector trade models; however, the effects of changes in the dispersion of tariffs can only be analyzed with a model that includes multiple sectors.

Tradable and non-tradable good sectors are interconnected. Figure 7 is a contour plot of the input-output table (henceforth I-O table) for a constructed rest of the world with 20 countries.[11] The table indicates the proportion of spending from sectors described in the "purchase sector" axis on final and intermediate goods from sectors described in the "selling sector" axis. The darker colors represent larger shares. A larger share reflects that a larger proportion of purchases of final and intermediate goods corresponds to that particular industry. A salient characteristic in Figure 7 is that the I-O matrix presents a strong diagonal. However, shares are far from 1.[12] For example, the mean diagonal share is 27% and has a standard deviation of 11%. If we focus only on the tradable goods, the mean share of the diagonal elements is 32% (see Figure 8) while the mean share of the diagonal elements of the non-tradables is 22% (see Figure 9). This means that industries purchase mostly intermediate inputs from other industries. Moreover, we also have that tradable and non-tradable sectors are interrelated. The average share of tradable goods in the production of non-tradable goods is 22%, while the average share of non-tradable goods in the production of tradable goods is 25%. This casual inspection of the I-O table shows that sectors are strongly interrelated and that non-tradable sectors are a relevant input in the production of tradables and vice versa.

We now develop a quantitative general equilibrium model of international trade that takes into account the sectoral heterogeneity and linkages that we observe in the data.

3. THE MODEL

Our model builds on the Ricardian trade model of Eaton and Kortum (2002) and follows Alvarez and Lucas (2008) approach to characterize the equilibrium.

In each country $n = 1, ..., N$ there are J sectors and one factor of production L_n, labor. We will refer to countries by i and n and sectors by j and k. Sectors are of two types, either tradable or non-tradable. Labor is not mobile across countries but it can be costlessly allocated across sectors; therefore $\sum_{j=1}^{J} L_n^j = L_n$.

[11] Please refer to the data appendix at the end of the document for a more detailed explanation.

[12] Jones (2007) presents a more detailed description of the characteristics of I-O tables in general. He clearly makes the point that the diagonal is important but the elements are small—on average, 3.3% for the case of the United States using a 6-digit I-O table (480 x 480).

Households maximize utility by purchasing final goods C_n^j taken as given prices p_n^j subject to their budget constraint. The preferences of the households are

$$u\left(C_n\right) = \prod_{j=1}^{J} C_n^{j\ \alpha_n^j}, \quad \text{where } \sum_{j=1}^{J} \alpha_n^j = 1.$$

We denote by I_n households' income. Income is derived from two sources; households supply labor L_n at a wage w_n and receive transfers on a lump-sum basis (tariff revenues and transfers from the rest of the world, as we will see in a moment).

A continuum of intermediate goods $\omega^j \in [0,1]$ is produced in each sector j. We denote by $q_n^j(\omega^j)$ to the production of good ω^j in country n. Labor and composite intermediate goods from all sectors are used for the production of each intermediate good ω^j. These goods are then used to produce composite intermediate goods as we will describe later. Let $l_n^j(\omega^j)$ be the amount of labor and let $m_n^{k,j}(\omega^j)$ be the amount of composite intermediate good from sector k used for the production of intermediate good ω^j in country n and sector j. Sectors are interrelated since sector j demands goods from sector k and vice versa. Also, tradable and non-tradable good sectors demand intermediate goods from each other. Countries differ in the efficiency of production of each intermediate good in each sector. Denote by $x_n^j\left(\omega^j\right)$ the inverse efficiency of producing intermediate good ω^j in country n and sector j. The production function of intermediate good ω^j is:

$$q_n^j(\omega^j) = x_n^j\left(\omega^j\right)^{-\theta^j}\left[l_n^j(\omega^j)\right]^{\beta_n^j}\left[\prod_{k=1}^{J} m_n^{k,j}(\omega^j)^{\gamma_n^{k,j}}\right]^{\left(1-\beta_n^j\right)},$$

where $\gamma_n^{k,j} \geqslant 0$ is the share of the composite intermediate good from sector k used in the production of intermediate good ω^j, with $\sum_{k=1}^{J}\gamma_n^{k,j} = 1$, and the parameter $\beta_n^j \geqslant 0$ is the share of value added. Note that β_n^j and $\gamma_n^{j,k}$ differ across countries and sectors**.** The parameters $\gamma_n^{j,k}$ are the shares from the I-O tables as we described before.

Efficiencies $x_n^j\left(\omega^j\right)$ are rescaled by the parameter θ^j, which is sector specific. A larger value of θ^j implies a larger dispersion of productivity across goods ω^j, a notion of comparative advantage.[13]

Denote by c_n^j the input cost in country n and sector j. Let p_n^k be the price of a composite intermediate good from sector k in country n. The cost of an input bundle is given by

$$c_n^j = \Upsilon_n^j w_n^{\beta_n^j}\left[\prod_{k=1}^{J} p_n^{k\ \gamma_n^{k,j}}\right]^{1-\beta_n^j}, \tag{1}$$

where Υ_n^j is a constant.[14] As we can see, the cost of this input bundle varies across sectors since they have different input shares. Equation (1) captures a key difference compared to the one-

[13] Eaton and Kortum (2002) use $1/\theta$ instead. In their case, θ is inversely related to the shape parameter of the Fréchet distribution.

[14] Specifically, $\Upsilon_n^j \equiv \prod_{k=1}^{J} \gamma_n^{k,j\,-\gamma_n^{k,j}\left(1-\beta_n^j\right)} \beta_n^{j\ -\beta_n^j}\left(1-\beta_n^j\right)^{-\left(1-\beta_n^j\right)}.$

sector model or the multi-sector model without interrelated sectors, as the cost of the input bundle depends on wages and on the price of all the composite intermediate goods in the economy, tradable and non-tradable. A change in policy that affects the price in any single sector will affect indirectly all the sectors in the economy via the input bundle. We show later that this interrelation plays an important role in evaluating the trade and welfare effects from trade openness.

We follow Alvarez and Lucas (2007) and note that in each sector j, the only parameter that varies across goods ω^j is the cost $x_n^j\left(\omega^j\right)$. Therefore, we re-label goods by their cost and refer to intermediate good ω^j with efficiency $x_n^j\left(\omega^j\right)$ by intermediate good x_n^j. Since the production of intermediate goods is at constant returns to scale and markets are perfectly competitive, firms price at unit cost, ${x_n^j}^{\theta^j} c_n^j$.

There are two types of trade costs, iceberg trade costs and an ad-valorem flat-rate tariffs. Iceberg costs are defined in physical units as in Samuelson (1954). One unit of any tradable intermediate good in sector j shipped from country i to country n requires producing $d_{ni}^j \geq 1$ units in i, with $d_{nn}^j = 1$. Goods imported by country n from country i have to pay an ad-valorem flat-rate tariff τ_{ni}^j applicable over unit prices. Proceeds are transferred in a lump-sum to the consumers in n. We combine both costs and represent them by $\kappa_{ni}^j = (1+\tau_{ni}^j)d_{ni}^j$. We also assume that the triangular inequality holds; therefore, $\kappa_{nh}^j \kappa_{hi}^j \geqslant \kappa_{ni}^j$ for all n, h, i.

Taking into account these costs, a unit of tradable intermediate good x_i^j produced in country i is available in country n at unit prices

$$p_{ni}^j(x_i^j) = {x_i^j}^{\theta^j} c_i^j \kappa_{ni}^j. \tag{2}$$

Equation (2) holds for both tradable and non-tradable sectors. We model non-tradable sectors in the same way as tradable sectors but impose that $\kappa_{in}^j = \infty$; thus, in some sectors goods are not traded because it is always cheaper to buy goods from local suppliers. Producers search across all sources to buy from the lowest cost supplier.[15] In order to facilitate exposition, we label a particular intermediate good in any tradable sector by the vector of inverse efficiencies $x^j = (x_1^j, ..., x_N^j)$, $x^j \in \mathbf{R}_+^n$. The effective price in country n of intermediate good x^j is $p_n^j\left(x^j\right)$, the lowest price of

[15] The way in which producers of intermediate goods search for the lowest cost supplier is a key distinction from models with Armington-type assumptions. In those models, because of the love for variety, regardless of the price, goods are always bought from all sources, since they are differentiated by country of origin. In the Eaton and Kortum (2002) model, the source from which goods are purchased is endogenously determined and can change as a consequence of tariff reductions. This is crucial in order to understand why this model conceptually takes into account changes at the extensive new goods margin and not only changes at the intensive old goods margin, as is the case in Armington-type models. However, there is a sense in which the Eaton and Kortum (2002) model resembles an Armington (1969) model. See footnote 19 in Eaton and Kortum (2002), the study by Anderson and Wincoop (2004), and Arkolakis et al. (2012) for a dicussion.

intermediate good x^j in sector j across all sources,

$$p_n^j\left(x^j\right) = \min_i \left\{p_{ni}^j(x_i^j);\ i = 1, .., N\right\}.$$

Notice that in the non-tradable sectors, $p_n^j\left(x^j\right) = p_{nn}^j(x_n^j)$. Ricardian motives to trade are introduced by assuming that countries differ in their technologies across sectors. We follow Eaton and Kortum's (2002) probabilistic representation of technologies, extending their representation to allow productivity to differ across sectors. For any $x \geq 0$, the measure of the set of goods x_n^j, such that $x_n^j \leq x$, is given by the cumulative distribution function of an exponential distribution.[16] We assume that the distribution of productivities is independent across goods, sectors and countries. The joint density of x^j is thus

$$\phi^j\left(x^j\right) = (\prod_{n=1}^N \lambda_n^j) \exp\left\{-\sum_{n=1}^N \lambda_n^j x_n^j\right\}.$$

The parameter $\lambda_n^j \geqslant 0$ governs the location of the distribution. In the context of this model, a higher λ_n^j (which we allow to be sector and country specific) makes the average productivity higher, a notion of absolute advantage.

Composite intermediate goods q_n^j in sector j are produced with an Ethier (1982) or Dixit and Stiglitz (1977) aggregator of intermediate goods from the same sector. We denote by $\eta^j > 0$ to the elasticity of substitution across intermediate goods within sector j, and let $r_n^j(x^j)$ be the demand of intermediate good x^j used to produce the composite intermediate good q_n^j. Producers of q_n^j in sector j solve the following problem:

$$p_n^j q_n^j = \min_{r_n^j(x^j)} \int p_n^j(x^j) r_n^j(x^j) \phi^j\left(x^j\right) dx^j,$$

subject to

$$\left[\int r_n^j(x^j)^{1-1/\eta^j} \phi^j\left(x^j\right) dx^j\right]^{\eta^j/\left(\eta^j-1\right)} \geq q_n^j,$$

where the integrations are over $\mathbf{R}_+^n$. The solution to the problem of the composite intermediate good producer gives the following demand of good x^j

$$r_n^j(x^j) = \left[\frac{p_n^j(x^j)}{p_n^j}\right]^{-\eta^j} q_n^j. \tag{3}$$

[16] Eaton and Kortum (2002) work with efficiencies instead of inverse efficiencies. They assume that efficiencies are distributed Fréchet. For a description of the properties of the Fréchet distribution, refer to Eaton and Kortum (2002). Donaldson (2010) relates this assumption to other standard assumptions used in models of international trade with heterogeneous firms, like those in Melitz (2003), Chaney (2008), and others. Costinot et al. (2012) consider the case of more general distributions.

Note that $r_n^j(x^j)$ is the demand of good x^j from the lowest cost supplier in the world. When j is a non-tradable goods sector the intermediate goods are only demanded from domestic producers, and therefore $r_n^j(x_n^j) = q_n^j(x_n^j)$.

It follows that the price of the composite intermediate good is

$$p_n^j = \left[\int p_n^j(x^j)^{1-\eta^j} \phi^j \left(x^j\right) dx^j \right]^{\frac{1}{1-\eta^j}},$$

where the integration is also over $\mathbf{R}_+^n$.

As we mentioned before the composite intermediate good q_n^j is used as an intermediate good for the production of intermediate good x_n^k in the amount $m_n^{j,k}(x_n^k)$ in all sectors k. They are also used as intermediate good to produce final good C_n^j with a constant return to scale technology.[17]

We now solve for the distribution of prices. Denote by $\mathbf{B}_{n,i}^j \subset R_+^n$ to the set in sector j of intermediate goods in which country i is the lowest cost supplier to country n. Then

$$\mathbf{B}_{n,i}^j = \left\{ x^j \in \mathbf{R}_+^n : p_n\left(x^j\right) = p_{ni}^j(x_i^j) \right\}.$$

Integrating over the sets $\mathbf{B}_{n,i}^j$, the price of the composite intermediate good is given by

$$p_n^j = A^j \left[\sum\nolimits_{i=1}^N \lambda_i^j \left[c_i^j \kappa_{ni}^j \right]^{-1/\theta^j} \right]^{-\theta^j}, \tag{4}$$

for all sectors j and countries n; where A^j is a constant. Denote by $\Phi_n^j = \sum_{i=1}^N \lambda_i^j \left[c_i^j \kappa_{ni}^j \right]^{-1/\theta^j}$. The object Φ_n^j plays a critical role in our model. It's a sufficient statistic of the states of technologies around the world, input costs, geographic barriers and tariff policies. In Eaton and Kortum (2002), this object is country specific, while in our model it is also sector specific. Note that Φ_n^j is correlated across sectors since sectors are interrelated and the input costs are functions of prices from all sectors. The shares $\gamma_n^{k,j}$ will determine the extent of the correlation. Note that (4) is also the price index of the non-tradable goods sector. The difference is that in that case $\kappa_{in}^j = \infty$ and thus the price index is given by $p_n^j = A^j {\lambda_n^j}^{-\theta^j} c_n^j$ and therefore $\Phi_n^j = \lambda_n^j \left[c_n^j \right]^{-1/\theta^j}$.

We now solve for the share of expenditure on goods from different locations. Let π_{ni}^j be the share in sector j of expenditure in country n on goods from country i. In particular, since the set $\mathbf{B}_{n,i}^j$ defines the set of goods in which country i is the lowest cost supplier for country n, then the

[17] The market clearing condition for the composite intermediate good in sector j is

$$q_n^j = C_n^j + \sum_{k=1}^J \int m_n^{j,k}(x_n^k) \lambda_n^k e^{-\lambda_n^k x_n^k} dx_n^k.$$

expenditure on these goods is given by the integral of total expenditure over the set $\mathbf{B}^j_{n,i}$. Therefore, the expenditure share is given by

$$\pi^j_{ni} = \int_{\mathbf{B}^j_{n,i}} \left(\frac{p^j_n(x^j) r^j_n(x^j)}{p^j_n q^j_n} \right) \phi^j\left(x^j\right) dx^j = \int_{\mathbf{B}^j_{n,i}} \left(\frac{p^j_n(x^j)}{p^j_n} \right)^{1-\eta^j} \phi^j\left(x^j\right) dx^j,$$

which uses (3). Following the same steps as we did for the solution to the price index p^j_n, we get

$$\pi^j_{ni} = \frac{\lambda^j_i \left[c^j_i \kappa^j_{ni}\right]^{-1/\theta^j}}{\sum_{i=1}^N \lambda^j_i \left[c^j_i \kappa^j_{ni}\right]^{-1/\theta^j}}. \tag{5}$$

Note that in non-tradable sectors, $\pi^j_{nn} = 1$. The bilateral trade share π^j_{ni} takes the form of a multi-sector version of a gravity equation. Changes in tariffs have a direct effect in trade shares via κ^j_{ni}, and from (1) note that changes in tariffs also have an indirect effect through the input bundle c^j_i since it incorporates all the information contained in the I-O tables.

Trade is not necessarily balanced either at the industry level, or even at the country level. Denote by S_n the net exports (trade surplus) of country n. It follows that $S_n = \sum_{k=1}^J S^k_n$, and $\sum_{n=1}^N S_n = 0$. Total expenditure on goods j is the sum of the expenditure on composite intermediate goods by firms and the expenditure by households. We denote by $X^j_n = p^j_n q^j_n$ to total expenditure on goods j in country n. Therefore, X^j_n is given by:

$$X^j_n = \sum_{k=1}^J \gamma^{j,k}_n (1-\beta^k_n) \left(F^k_n X^k_n + S^k_n\right) + \alpha^j_n I_n,$$

where I_n represents final absorption in country n, with $I_n = w_n L_n + R_n - S_n$ and $F^j_n = \sum_{i=1}^N \frac{\pi^j_{ni}}{1+\tau^j_{ni}}$. For the case of non-tradables, note that $F^j_n = 1$. Total final absorption is the sum of labor income ($w_n L_n$), tariff revenues ($R_n = \sum_{j=1}^J X^j_n[1 - F^j_n]$) and the aggregate deficit ($-S_n$). Gross production in sector k and country n is given by $F^k_n X^k_n + S^k_n$.

The trade surplus in sector k and country n, S^k_n, is by definition given by:

$$S^k_n = \left(\sum_{i=1}^N \frac{\pi^k_{in}}{1+\tau^k_{in}} X^k_i - F^k_n X^k_n\right). \tag{6}$$

Notice that (6) is also consistent with the non-tradable good sectors. Setting $\kappa^k_{in} = \infty$ then $\pi^k_{in} = 0$ and $\pi^k_{nn} = 1$, so $F^k_n = 1$; therefore $S^k_n = 0$ in the non-tradable sector k. Finally note that the aggregate trade deficit in each country is exogenous; however, sectoral trade deficits are endogenously determined.

Finally, using the definition of expenditure and trade surplus we have that

$$\sum_{j=1}^J \sum_{i=1}^N \frac{\pi^j_{ni}}{1+\tau^j_{ni}} X^j_n + S_n = \sum_{j=1}^J \sum_{i=1}^N \frac{\pi^j_{in}}{1+\tau^j_{in}} X^j_i. \tag{7}$$

This condition reflects the fact that total expenditure, excluding tariff payments, in country n plus net exports equals the sum of each country's total expenditure, excluding tariff payments, on tradable goods from country n. We are adding over all sectors whether a sector is tradable or non-tradable. The non-tradable sectors will appear in both sides of the equation and cancel out.

We now define formally the equilibrium under policies $\{\tau_{ni}^j\}$ in this model.

Definition 1 *Given L_n and S_n, an equilibrium under tariff structure τ is a wage vector $\mathbf{w} \in \mathbf{R}_{++}^N$ and prices p_n^j that solve equilibrium conditions* (1) , (4) , (5) *and* (7) *for all j and n.*

Instead of solving for an equilibrium under policy τ we solve for changes in prices and wages from moving from policy τ to policy τ'. There are several advantages of doing so. It allows us to use data for the base year to quantify the effects of a change in tariffs, and, it allows us to identify the effect on changes in equilibrium prices from a pure change in tariffs, which is what we are after, without needing to estimate λ_n^j and d_{ni}^j to solve for the general equilibrium of the model.

We now define the equilibrium of the model under policy τ' relative to a policy under tariff structure τ. This idea of expressing the equilibrium in relative changes follows Dekle et al. (2008) but in this case in a more general setting with changes in tariffs rather than deficit counterfactuals.

Definition 2 *Let $(\mathbf{w}, p)$ be an equilibrium under tariff structure τ and let $(\mathbf{w}', p')$ be an equilibrium under tariff structure τ'. Define $(\hat{\mathbf{w}}, \hat{p})$ as an equilibrium under τ' relative to τ, where a variable with a hat "$\hat{x}$" represents the relative change of the variable, namely $\hat{x} = x'/x$. Using* (1) , (4) , (5) *and* (7) *the equilibrium conditions in relative changes solves:*

Cost of the input bundles:

$$\hat{c}_n^j = \hat{w}_n^{\beta_n^j} \left[\prod_{k=1}^J \left[\hat{p}_n^k\right]^{\gamma_n^{k,j}} \right]^{1-\beta_n^j}. \tag{8}$$

Price index:

$$\hat{p}_n^j = \left[\sum_{i=1}^N \pi_{ni}^j [\hat{\kappa}_{ni}^j \hat{c}_i^j]^{-1/\theta^j} \right]^{-\theta^j}. \tag{9}$$

Bilateral trade shares:

$$\hat{\pi}_{ni}^j = \left[\frac{\hat{c}_i^j}{\hat{p}_n^j} \hat{\kappa}_{ni}^j \right]^{-1/\theta^j}. \tag{10}$$

Trade balance:

$$\sum_{j=1}^J F_n^{j\prime} X_n^{j\prime} + S_n = \sum_{j=1}^J \sum_{i=1}^N \frac{\pi_{in}^{j\prime}}{1+\tau_{in}^{j\prime}} X_i^{j\prime}. \tag{11}$$

Total expenditure in each country n and sector j:

$$X_n^{j\prime} = \sum_{k=1}^J \gamma_n^{j,k} (1-\beta_n^k) \left(\sum_{i=1}^N \frac{\pi_{in}^{k\prime}}{1+\tau_{in}^{k\prime}} X_i^{k\prime} \right) + \alpha_n^j I_n', \tag{12}$$

for all j *and* n *where* $\hat{\kappa}_{ni}^j = (1+\tau_{ni}^{j\prime})/(1+\tau_{ni}^j)$ *and* $I_n^\prime = \widehat{w}_n w_n L_n + \sum_{j=1}^{J} X_n^{j\prime}[1 - F_n^{j\prime}] - S_n$.

From inspecting equilibrium conditions (8 through 12) we can observe that the focus on relative changes allows us to perform policy experiments without relying on estimates of total factor productivity or transport costs. We only need two sets of tariff structures (τ and τ'), data on bilateral trade shares (π_{ni}^j), the share of value added in production (β_n^j), value added ($w_n L_n$), the share of intermediate consumption ($\gamma_n^{k,j}$), and sectoral dispersion of productivity (θ^j). The share of each sector in final demand (α_n^j) is obtained from these data as we will show later on. Therefore, the only parameters to estimate are the sectoral dispersion of productivity θ^j, which we turn to in section 4.

After solving for the equilibrium prices and allocations given data for the base year, we can evaluate how welfare changes in each country by moving from tariff structure τ to tariff structure τ' measured as the change in real income:

$$\hat{W}_n = \frac{\hat{I}_n}{\prod_{j=1}^{J} \hat{p}_n^{j\ \alpha_n^j}}. \tag{13}$$

3.1 Sources of Gains From Trade

We now proceed to build some intuition of why adding more sectors and the interrelation across them is important for welfare comparisons. To clarify the exposition, consider the case where trade is balanced and the only source of trade costs are iceberg costs (d_{in}^j according to our notation above).[18] Then, the relative changes in real income are equal to changes in real wages, given by $\hat{W}_n = \prod_{j=1}^{J} (\hat{w}_n / \hat{p}_n^j)^{\alpha_n^j}$. From equation (8) and (10) we can solve for $\hat{w}_n / \hat{p}_n^j$ in each sector j as a function of the share of expenditure on domestic goods and sectoral prices, namely

$$\frac{\hat{w}_n}{\hat{p}_n^j} = (\hat{\pi}_{nn}^j)^{-\theta^j/\beta_n^j} \left(\prod_{k=1}^{J} [\hat{p}_n^k]^{\gamma_n^{k,j}} / \hat{p}_n^j \right)^{-\widetilde{\beta}_n^j}, \tag{14}$$

where $\widetilde{\beta}_n^j = (1 - \beta_n^j) / \beta_n^j$. Then, the percentage change in real income is given by:[19]

$$\ln \hat{W}_n = \underbrace{-\sum_{j=1}^{J} \alpha_n^j \theta^j \ln \hat{\pi}_{nn}^j}_{\text{Final goods}} \underbrace{-\sum_{j=1}^{J} \alpha_n^j \theta^j \widetilde{\beta}_n^j \ln \hat{\pi}_{nn}^j}_{\text{Intermediate goods}} \underbrace{-\sum_{j=1}^{J} \alpha_n^j \widetilde{\beta}_n^j \ln \left(\prod_{k=1}^{J} [\hat{p}_n^k]^{\gamma_n^{k,j}} / \hat{p}_n^j \right)}_{\text{Sectoral linkages}}. \tag{15}$$

[18] Note that by setting $\tau_{ni}^j = 0$ then $F_n^k = 1$; and by setting $S_n = 0$, the income of the household is only labor income: $w_n L_n$. Therefore $\hat{I}_n = \hat{w}_n$.

[19] To obtain the expression for the change in real wages take the product of (14) for all sectors j weighted by α_n^j to obtain:

$$\hat{W}_n = \prod_{j=1}^{J} (\hat{\pi}_{nn}^j)^{-\alpha_n^j \theta^j / \beta_n^j} \left(\prod_{k=1}^{J} [\hat{p}_n^k]^{\gamma_n^{k,j}} / \hat{p}_n^j \right)^{-\alpha_n^j \widetilde{\beta}_n^j}.$$

Finally, take logarithms from both sides and rearrange terms to obtain the expression for the percentage change in the real wage in country n, as presented in the text.

Where are the gains from trade coming from? This result shows that all the general equilibrium effects can be summarized by the change in the share of domestic expenditure in each sector ($\hat{\pi}_{nn}^j$ for all j) and the changes in sectoral prices $\left(\hat{p}_n^j \text{ for all } j\right)$.

Each term in this welfare decomposition measures an additional effect compared with a certain benchmark model. For instance, consider the case where $\beta_n^j = 1$ for all j and n, then goods are only produced with labor. From (14) we get $\ln \hat{w}_n / \hat{p}_n^j = -\theta^j \ln \hat{\pi}_{nn}^j$. The share spent on final goods from sector j is α_n^j, then $-\alpha_n^j \theta^j \ln \hat{\pi}_{nn}^j$ measures the contribution of the change in the real wage in sector j on aggregate welfare. Adding across all sectors, $-\sum_{j=1}^J \alpha_n^j \theta^j \ln \hat{\pi}_{nn}^j$ measures the aggregate contribution of trade in final goods on welfare. This effect depends on the share of each sector in final demand (α_n^j) and the sectoral trade cost elasticity (θ^j). Note that the more negatively correlated are $\alpha_n^j \theta^j$ with $\hat{\pi}_{nn}^j$ the larger are the welfare effects for small changes in $\hat{\pi}_{nn}^j$.[20] From this expression it is evident that sectoral heterogeneity in trade cost elasticities matters for welfare analysis.[21]

Consider the model where $\beta_n^j \neq 1$ and $\gamma_n^{j,j} = 1$ for all j and n. In this case the production of intermediate goods requires composite intermediate goods. Still, sectors are not interrelated because only composite intermediate goods from the same sector are used. A reduction in trade costs reduces the price of tradable intermediate goods and in turn reduces the price of the composite intermediate good. As a consequence, producers of intermediate goods gain from this reduction in the cost of their inputs. This additional effect on welfare compared to a model without intermediates goods is captured by the term $-\sum_{j=1}^J \alpha_n^j \theta^j \widetilde{\beta}_n^j \ln \hat{\pi}_{nn}^j$.

Finally consider our model with $\beta_n^j \neq 1$ and $\gamma_n^{j,j} \neq 1$ for all j and n; thus a model with intermediate goods and sectoral linkages. The term $\prod_{k=1}^J [\hat{p}_n^k]^{\gamma_n^{k,j}}$ reflects the effect of a change in the price of the composite intermediate good from sector k on real wages in sector j. The larger is $\gamma_n^{k,j}$ for sectors in which prices decline more, the larger is the reduction in the cost of intermediate inputs used in production. This term captures the input-output structure of the economy. The contribution to aggregate welfare is given by the term $-\sum_{j=1}^J \alpha_n^j \widetilde{\beta}_n^j \ln \left(\prod_{k=1}^J [\hat{p}_n^k]^{\gamma_n^{k,j}} / \hat{p}_n^j \right)$. Note that this term resembles a geometric weighted average of the change in sectoral goods. Only in the case where substantial symmetry in parameters is assumed this term will be equal to zero.[22]

[20] Arkolakis et al. (2012) show that within a variety of trade models there are two sufficient statistics to evaluate welfare gains: the share of expenditure on domestic goods and trade elasticities. Donaldson (2010) makes the same observation for the case of a multi-sector Eaton and Kortum model.

[21] In a recent study, Ossa (2012) evaluates the importance of sectoral variation in trade elasticities for welfare quantification.

[22] In fact, to see this consider the case of two sectors. Sectoral linkages are given by $\left(\alpha_n^1 \widetilde{\beta}_n^1 \gamma_n^{2,1} - \alpha_n^2 \widetilde{\beta}_n^2 \gamma_n^{1,2}\right) \ln \left(\hat{p}_n^1 / \hat{p}_n^2\right)$. Note that this term will only be zero if prices (or tariffs) change in the

In the next section, we propose a new method to estimate the dispersion of productivity (θ^j), and after that, we show how to take the model to the data in order to quantify the effects of tariff reductions. At the same time we quantify the importance for the trade and welfare effects of accounting for intermediate goods in production and sectoral linkages.

4. A NEW METHOD TO ESTIMATE TRADE ELASTICITIES

The trade elasticities θ^j are the key parameters for quantitative trade policy evaluation. In our model, these are the only parameters we need to estimate in order to identify the effects of tariff reductions. In the context of the Eaton and Kortum model, as well as ours, the trade elasticities are related to the dispersion of productivity parameter and it determines how trade flows react to changes in tariffs. If productivity is more dispersed, as indicated by a larger value of θ^j, then a change in tariffs will not change the share of traded goods in a substantial way. The reason is that goods are less substitutable. On the other hand, if the productivities are very concentrated -if there is low dispersion- small changes in tariffs can translate to large adjustments in the share of goods traded. The reason is that producers of the composite aggregate are more likely to change their suppliers, since goods are more substitutable. The change in the measure of goods traded is the adjustment at the extensive margin in this model.[23] To see these effects more formally, recall that X_{ni}^j is the expenditure at country n of sector j goods from country i. Let the total expenditure at country n of sector j goods be given by $X_n^j = \sum_{i=1}^N X_{ni}^j$. From (5) we get the following gravity equation

$$\frac{X_{ni}^j}{X_n^j} = \left(\frac{c_i^j}{p_n^j}\kappa_{ni}^j\right)^{-1/\theta^j} \lambda_i^j \left(A^j\right)^{-1/\theta^j}. \tag{16}$$

From (16) we can immediately see how changes in trade costs impact trade shares according to θ^j. We propose a new method to estimate the dispersion parameter that is consistent with any trade model that delivers a gravity equation like (16). Consider three countries indexed by n, i, and h. Take the cross-product of goods from sector j shipped in one direction between the three

same proportion, and-or if the share of final good in demand and the share of intermediate goods in production is the same across sectors together with a symmetric I-O table.

[23] In our model the elasticity of trade with respect to trade costs is given by the inverse of the dispersion of productivity, and not by the elasticity of substitution as in Armington models. If we restrict producers of the intermediate good aggregate to purchase goods from the same source, regardless of the change in trade costs, then the trade elasticity will be given by the elasticity of substitution as in Armington models. This is the sense in which the dispersion of productivity can be related to the elasticity of substitution in an Armington model. Both models, the Ricardian and the Armington, deliver a similar gravity-type equation. However, conceptually the models are very different. The reasons why there are adjustments from changes in tariffs are very different in the two models. In a Ricardian trade model like, Eaton and Kortum (2002), there are production-side gains from trade, while in a standard Armington model, like Anderson's (1979), gains are from the consumption side only.

countries, from n to i, from i to h, and from h to n, and then the cross-product of the same goods shipped in the other direction, from n to h, from h to i, and from i to n. Using equation (5) we can calculate each expression and then take the ratio:

$$\frac{X_{ni}^j X_{ih}^j X_{hn}^j}{X_{nh}^j X_{hi}^j X_{in}^j} = \left(\frac{\kappa_{ni}^j}{\kappa_{in}^j} \frac{\kappa_{ih}^j}{\kappa_{hi}^j} \frac{\kappa_{hn}^j}{\kappa_{nh}^j} \right)^{-\frac{1}{\theta^j}} . \tag{17}$$

All the terms involving prices and parameters $((A^j c_i^j / p_n^j)^{-1/\theta^j} \lambda_i^j)$ are canceled out and we end up with a relation between bilateral trade and trade costs.[24] The advantage of using (17) is that unobservable trade costs cancel out.[25] For example, consider the following model of asymmetric trade costs.[26] From the definition of κ_{ni}^j, trade costs are composed of tariffs (non-symmetric) and iceberg (also non-symmetric) trade costs, namely $\ln \kappa_{ni}^j = \ln \tilde{\tau}_{ni}^j + \ln d_{ni}^j$, where $\tilde{\tau}_{ni}^j$ is equal to $(1 + \tau_{ni}^j)$. Iceberg trade costs, $\ln d_{ni}^j$, can be modeled quite generally as linear functions of cross-country characteristics. For instance, let $\ln d_{ni}^j = \nu_{ni}^j + \mu_n^j + \delta_i^j + \varepsilon_{ni}^j$, where $\nu_{ni}^j = \nu_{in}^j$ captures symmetric bilateral trade costs like distance, language, common border, and belonging to an FTA or not. The parameter μ_n^j captures an importer sectoral fixed effect, for example, non-tariff barriers, and it is assumed to be common to all trading partners of country n. The parameter δ_i^j is an exporter sectoral fixed effect that can also capture non-tariff barriers, and it is assumed to be common to all trading partners of country i. Finally, ε_{ni}^j is a random disturbance term that represents remoteness deviation from symmetry and is assumed to be orthogonal to tariffs. Introducing these trade costs into (17) we get:

$$\ln \left(\frac{X_{ni}^j X_{ih}^j X_{hn}^j}{X_{in}^j X_{hi}^j X_{nh}^j} \right) = -\frac{1}{\theta^j} \ln \left(\frac{\tilde{\tau}_{ni}^j}{\tilde{\tau}_{in}^j} \frac{\tilde{\tau}_{ih}^j}{\tilde{\tau}_{hi}^j} \frac{\tilde{\tau}_{hn}^j}{\tilde{\tau}_{nh}^j} \right) + \tilde{\varepsilon}^j, \tag{18}$$

where $\tilde{\varepsilon}^j = \varepsilon_{in}^j - \varepsilon_{ni}^j + \varepsilon_{hi}^j - \varepsilon_{ih}^j + \varepsilon_{nh}^j - \varepsilon_{hn}^j$. Note that all the symmetric and asymmetric components of the iceberg trade costs cancel out. The terms $\kappa_{ni}^j/\kappa_{in}^j, \kappa_{ih}^j/\kappa_{hi}^j$, and $\kappa_{hn}^j/\kappa_{nh}^j$ will cancel the symmetric bilateral trade costs (ν_{ni}^j, ν_{ih}^j, and ν_{hn}^j). The terms $\kappa_{ni}^j/\kappa_{nh}^j$, $\kappa_{ih}^j/\kappa_{in}^j$, and $\kappa_{hn}^j/\kappa_{hi}^j$ cancel the importer fixed effects (μ_n^j, μ_i^j, and μ_h^j); and the terms $\kappa_{ni}^j/\kappa_{hi}^j$, $\kappa_{ih}^j/\kappa_{nh}^j$, and $\kappa_{hn}^j/\kappa_{in}^j$ cancel the

[24] The number of cross-product terms in our method is given by $\sum_{n=1}^{N-2} l_n$ where $l_n = n(n+1)/2$ and N is the number of countries in the sample. For instance, for a sample of 10 countries there will be a maximum of 120 observations.

[25] The method we propose is similar to the odds ratio method developed by Head and Ries (2001) and also presented in Head and Mayer (2001). Our method is also similar to the one Head, Mayer, and Ries (2009) denote as "tetrads." Other papers using the "tetrad" are Martin, Mayer, and Thoenig (2008), Hallak (2006) and Romalis (2007) and Anderson and Marcouiller (2002). These methods were constructed to estimate trade costs. We instead propose a method to estimate trade elasticities. Compared to the odds ratio, our method does not need to assume symmetric trade costs and we do not need to rely on information of domestic sales at the sectoral level. Compared to the "tetrad," our method uses fewer countries, which increases the sample size considerably, and we do not need to use a reference country.

[26] A standard assumption in the trade literature is to assume symmetric geographic trade costs; for instance, see Krugman (1991). With our method, we do not need to assume symmetry in order to get identification.

exporter fixed effects (δ_i^j, δ_h^j, and δ_n^j). The only identification restriction is that $\tilde{\varepsilon}^j$ is assumed to be orthogonal to tariffs.

It is important to notice that our methodology is consistent with a wide class of gravity-trade models and therefore the estimated trade cost elasticity from using this method does not depend on the underlying microstructure assumed in the model. We estimate the dispersion-of-productivity parameter sector by sector using the proposed specification (18) for 1993, the year before NAFTA was active.[27] Table 1 presents the (negative of the) estimates ($1/\theta^j$) and heteroskedastic-robust standard errors. As we can see, the coefficients have the correct sign and the magnitude of the estimates varies considerably across sectors. The estimates range from 0.37 to 51.08. This heterogeneity was confirmed by being able to reject the null hypothesis of common estimates (we performed an F-test and the result is presented at the bottom of Table 1).

The estimation gives an equal weight to all countries; thus, as a robustness check we dropped observations with small trade flows. Table 1 shows the estimates for 99% of the sample and 97.5% of the sample. The 99% and 97.5% samples were constructed in the following way: in each sector, we ranked the countries according to the share of trade they contribute in that particular sector. We dropped the countries with the lowest 1% share and re-estimated the productivity parameter. Then we dropped the lowest 2.5%. As we compare across estimates, we note that three sectors are not robust since they changed sign as we restricted the sample.[28] These sectors are Basic metals, Machinery n.e.c., and Auto.[29]

Our estimates are in the range of the trade elasticities estimated in the literature.[30] Our benchmark estimates are the estimates presented in Table 1 for the 99% sample, since they control for outliers. For the sectors Basic metals, Machinery n.e.c., and Auto we replace them by the mean

[27] We estimate (18) by OLS, dropping the observations with zeros. Zeros in the bilateral trade matrix are very frequent and several studies are focused on understanding how robust the estimates of trade elasticities are if zeros are taken into account. For instance, Santos-Silva and Tenreyro (2010).

[28] For the case of Chemicals China was an outlier. The estimates including China were 1.39 for the full sample, -0.64 for the 99% sample and -0.93 for the 97.5% sample. The numbers without China are presented in the table. China represented 5% of the share of trade in that sector.

[29] Machinery n.e.c. corresponds to manufacture of electrical machinery and apparatus not elsewhere classified.

[30] The magnitudes of the sectoral trade elasticities are within the range of the coefficient estimated by Eaton and Kortum (2002) for the manufacturing sector as a whole using data from 1990. Their estimate ($1/\theta$ in our case) ranged between 3.60 and 12.86, and their preferred estimate is 8.28. Other studies, for example: Anderson, Balistreri, Fox, and Hillberry (2005) document that the average elasticity is 17. Broda and Weinstein (2006) find that the simple average of the elasticities is 17 at the seven-digit (TSUSA), 7 at the three-digit (TSUSA), 12 at the ten-digit (HTS) and 4 at the three-digit (HTS) goods disaggregation. Clausing (2001) and Head and Ries (2001) find values between 7 and 11.4, Romalis (2007) finds values between 4 and 13. Bishop (2006) estimates the trade elasticity for the steel industry and finds values between 3 and 5. Yi (2003) compares several models and finds that in order to match the bilateral trade flows in the data, the Armington type models need a value of elasticity of 15. Imbs and Méjean (2011) make the point that the "true" elasticity of substitution is more than twice the elasticity implied by the aggregate data. Hertel, Hummels, Ivanic, and Keeney (2003) estimate sectoral trade elasticities with values between 3 and 30.

Table 1

Dispersion-of-productivity parameter									
	Full sample			99% sample			97.5% sample		
Sector Name	$1/\theta^j$	s.e.	N	$1/\theta^j$	s.e.	N	$1/\theta^j$	s.e.	N
Agriculture	8.11	(1.86)	496	9.11	(2.01)	430	16.88	(2.36)	364
Mining	15.72	(2.76)	296	13.53	(3.67)	178	17.39	(4.06)	152
Manufacturing									
Food	2.55	(0.61)	496	2.62	(0.61)	429	2.46	(0.70)	352
Textile	5.56	(1.14)	437	8.10	(1.28)	314	1.74	(1.73)	186
Wood	10.83	(2.53)	315	11.50	(2.87)	191	11.22	(3.11)	148
Paper	9.07	(1.69)	507	16.52	(2.65)	352	2.57	(2.88)	220
Petroleum	51.08	(18.05)	91	64.85	(15.61)	86	61.25	(15.90)	81
Chemicals	4.75	(1.77)	430	3.13	(1.78)	341	2.94	(2.34)	220
Plastic	1.66	(1.41)	376	1.67	(2.23)	272	0.60	(2.11)	180
Minerals	2.76	(1.44)	342	2.41	(1.60)	263	2.99	(1.88)	186
Basic metals	7.99	(2.53)	388	3.28	(2.51)	288	-0.05	(2.82)	235
Metal products	4.30	(2.15)	404	6.99	(2.12)	314	0.52	(3.02)	186
Machinery n.e.c.	1.52	(1.81)	397	1.45	(2.80)	290	-2.82	(4.33)	186
Office	12.79	(2.14)	306	12.95	(4.53)	126	11.47	(5.14)	62
Electrical	10.60	(1.38)	343	12.91	(1.64)	269	3.37	(2.63)	177
Comm	7.07	(1.78)	311	3.95	(1.77)	143	4.82	(1.83)	93
Medical	9.98	(1.25)	383	8.71	(1.56)	237	1.97	(1.36)	94
Auto	1.01	(0.80)	237	1.84	(0.92)	126	-3.06	(0.86)	59
Other Transport	0.37	(1.08)	245	0.39	(1.08)	226	0.53	(1.15)	167
Other	5.00	(0.92)	412	3.98	(1.08)	227	3.06	(0.83)	135
Manufacturing (average)	8.22			9.29			5.87		
Test equal parameters			F(17, 7294) = 7.52				Prob > F = 0.00		

estimate for the manufacturing sector. We also re-estimated the dispersion parameters including importer and exporters fixed effects to check for the stability of the estimates. Table B1, in Appendix B presents the estimates.

5. QUANTIFYING THE TRADE AND WELFARE EFFECTS OF NAFTA

In order to evaluate the trade and welfare effects from the change in the tariff structure caused by NAFTA we specialize the model to the case of $N = 4$ countries (Mexico, Canada, the United States, and the rest of the world) and $J = 40$ sectors (20 tradable and 20 non-tradable).[31] Our base year is 1993, the year before the agreement came into force. Therefore, the data on trade and production we use are for 1993. We use data on tariffs in 1993 and 2005 and introduce the change in the tariff structure from the one in 1993 to the actual tariff structure in 2005 into the model. This means tariffs applied to and from NAFTA members and also from and to the rest of the world. We then solve for the equilibrium in relative changes from the tariff structure in 1993 to the tariff structure in 2005. Of course, the observed tariff structure in 2005 incorporates the change in tariffs applied by NAFTA and also other policies.[32] Therefore, we evaluate the trade and welfare effects of NAFTA by fixing the tariff structure applied from and to the rest of the world to and by NAFTA members to the levels in 1993. In this way, the tariff structure will only change as a consequence of NAFTA's tariff reductions and we neutralize the effect of other changes in tariffs.

5.1 Taking the Model to the Data

The data requirements in order to solve the GE model are sectoral data on bilateral trade flows ($Z^j_{ni}-$ imports of n from i), value added (V^j_n), gross production (Y^j_n), and the I-O tables H_n. We show how to calculate country and sector shares to include in the model.

To obtain the bilateral trade share π^j_{ni}, we first calculate domestic sales in each country, Z^j_{nn}. This is the difference between gross production in n and total exports from n; $Z^j_{nn} = Y^j_n - \sum_{i=1,i\neq n}^{N} Z^j_{in}$. Then, we calculate net exports in each sector j and country n, $S^j_n = \sum_{i=1}^{N} Z^j_{in} - \sum_{i=1}^{N} Z^j_{ni}$. We then define expenditure by country n of sector j goods imported from country i as X^j_{ni}. We calculate X^j_{ni} by multiplying trade flows by tariffs, that is, $X^j_{ni} = Z^j_{ni}(1 + \tau^j_{ni})$.

[31] The Data Appendix presents the list of tradable and non-tradable good sectors.

[32] The change in the tariff structure between NAFTA members is a consequence of signing NAFTA. However, the change in tariffs that NAFTA members applied to the rest of the world and the one the rest of the world applied to NAFTA has many consequences. As we documented earlier, NAFTA members signed independently free trade agreements with other countries.

We obtain π_{ni}^{j} for each sector j and pair of countries n, i in the following way:

$$\pi_{ni}^{j} = X_{ni}^{j} / \sum\nolimits_{i=1}^{N} X_{ni}^{j}. \tag{19}$$

The share of value added in each sector and country (β_{n}^{j}) is given by:

$$\beta_{n}^{j} = V_{n}^{j} / Y_{n}^{j}. \tag{20}$$

The share of sector k's spending on sector j's goods is $\gamma_{n}^{j,k}$. This is calculated from the I-O matrix. The intermediate consumption of sector j in sector k is

$$\gamma_{n}^{j,k} = \frac{\text{intermediate consumption of sector } j \text{ in sector } k}{\text{total intermediate consumption of sector } k}. \tag{21}$$

Finally, calculate α_{n}^{j} in the following way:

$$\alpha_{n}^{j} = \frac{Y_{n}^{j} - S_{n}^{j} - \sum_{k=1}^{J} \gamma_{n}^{j,k} (1 - \beta_{n}^{k}) \left(Y_{n}^{k} \right)}{I_{n}}, \tag{22}$$

where I_n is total final absorption in the data.

5.2 Solving the Model

Solving the model in relative changes allows us to use information under policy τ to construct the new equilibrium under policy $\hat{\tau}$. We now proceed to solve for the equilibrium. First, we construct the elements of $\hat{\kappa}_{ni}^{j}$ using the information of policy τ and the new policy τ'. Then we calculate π_{ni}^{j}, as shown in (19). After that, we calculate γ_{n}^{j}, β_{n}^{j}, and α_{n}^{j} as shown in $(20 - 22)$. Finally, θ^{j} comes from the estimation presented in Table 1, column 5.

To solve for the equilibrium, we first guess a vector of wages $\hat{\mathbf{w}} = (\widehat{w}_1, ..., \widehat{w}_N)$, for example, $\hat{\mathbf{w}} = 1$. Then using the equilibrium conditions (8 through 12) note that we can reduce the system of equilibrium conditions to a system of N equations, one per country, with N unknowns, $\hat{w}_n$. Given a vector of wages, the equilibrium conditions (8) and (9) are JxN equations in JxN unknown prices. Therefore, we can solve for prices in each sector and each country. Let $\hat{p}_{n}^{j}(\hat{\mathbf{w}})$ and $\hat{c}_{n}^{j}(\hat{\mathbf{w}})$ be the solution for the price and cost of the input bundle in each sector j and country n consistent with the vector of wages $\hat{\mathbf{w}}$. Then use π_{ni}^{j} and θ^{j} together with the calculated $\hat{p}_{n}^{j}(\hat{\mathbf{w}})$ and $\hat{c}_{n}^{j}(\hat{\mathbf{w}})$ and solve for $\pi_{ni}^{j\prime}(\hat{\mathbf{w}})$ using (10). Given $\pi_{ni}^{j\prime}(\hat{\mathbf{w}})$, τ', γ_{n}^{j}, β_{n}^{j}, and α_{n}^{j}, solve for total expenditure in each sector j and country n consistent with the vector of wages $\hat{\mathbf{w}}$ in the following way. Total expenditure in the counterfactual scenario is given by

$$X_{n}^{j\prime} = \sum\nolimits_{k=1}^{J} \gamma_{n}^{j,k} (1\text{-}\beta_{n}^{k}) \sum\nolimits_{i=1}^{N} \frac{\pi_{in}^{k\prime}(\hat{\mathbf{w}})}{1 + \tau_{in}^{k\prime}} X_{i}^{k\prime} + \alpha_{n}^{j} (\widehat{w}_n w_n L_n + \sum\nolimits_{j=1}^{J} X_{n}^{j\prime} [1\text{-}F_{n}^{j\prime}(\hat{\mathbf{w}})]\text{-}S_n). \tag{23}$$

Equation (23) is a system of $J \times N$ equations in $J \times N$ total expenditures. Notice that if $\tau' = \tau$, then $\hat{\mathbf{w}} = 1$ and $X_n^{j\prime}(1) = X_n$. It is convenient to re-write the system of equations in matrix form:

$$\mathbf{\Omega}(\hat{\mathbf{w}})\,\mathbf{X} = \mathbf{\Delta}(\hat{\mathbf{w}}),$$

where $\mathbf{X}$ is the vector of expenditures for each sector and country and $\mathbf{\Delta}(\hat{\mathbf{w}})$ is a vector containing the shares of each sector and country in final demand, value added and aggregate trade surplus by country. Concretely,

$$\mathbf{X} = \begin{pmatrix} X_1^{1\prime} \\ \vdots \\ X_1^{J\prime} \\ \vdots \\ X_n^{1\prime} \\ \vdots \\ X_N^{J\prime} \end{pmatrix}_{JN\times 1} \quad ; \quad \mathbf{\Delta}(\hat{\mathbf{w}}) = \begin{pmatrix} \alpha_1^1(\hat{w}_1 w_1 L_1 - S_1) \\ \vdots \\ \alpha_1^J(\hat{w}_1 w_1 L_1 - S_1) \\ \vdots \\ \alpha_N^1(\hat{w}_N w_N L_N - S_N) \\ \vdots \\ \alpha_N^J(\hat{w}_N w_N L_N - S_N) \end{pmatrix}_{JN\times 1}.$$

The matrix $\mathbf{\Omega}(\hat{\mathbf{w}})$ is a square matrix of dimensions $JN \times JN$. $\mathbf{\Omega}(\hat{\mathbf{w}})$ captures the general equilibrium effects of how changes in tariffs from one sector and one country impact expenditure in all other sectors of the economy and the world. $\mathbf{\Omega}(\hat{\mathbf{w}})$ is constructed by adding three square matrices, I, $\digamma(\hat{\mathbf{w}})$ and $\tilde{H}(\hat{\mathbf{w}})$. The matrix I is the identity matrix with dimensions $JN \times JN$. The square matrix $\digamma(\hat{\mathbf{w}})$ is constructed using the following vectors,

$$A_n = \begin{pmatrix} \alpha_n^1 \\ \vdots \\ \alpha_n^J \end{pmatrix}_{J\times 1}, \tilde{F}_n'(\hat{\mathbf{w}}) = \begin{pmatrix} \left(1 - F_n^{1\prime}(\hat{\mathbf{w}})\right) & \cdots & \left(1 - F_n^{J\prime}(\hat{\mathbf{w}})\right) \end{pmatrix}_{1\times J},$$

where $F_n^{j'}(\hat{\mathbf{w}})$ are the counterfactual values of $F_n^j(\hat{\mathbf{w}})$ that were defined before. Then the matrix $\digamma(\hat{\mathbf{w}})$ is defined as

$$\digamma(\hat{\mathbf{w}}) = \begin{pmatrix} A_1 \otimes \tilde{F}_1'(\hat{\mathbf{w}}) & 0_{J\times J} & \cdots & 0_{J\times J} & 0_{J\times J} \\ 0_{J\times J} & A_2 \otimes \tilde{F}_2'(\hat{\mathbf{w}}) & \cdots & \vdots & \vdots \\ 0_{J\times J} & 0_{J\times J} & \ddots & 0_{J\times J} & 0_{J\times J} \\ \vdots & \vdots & \cdots & A_{N-1} \otimes \tilde{F}_{N-1}'(\hat{\mathbf{w}}) & 0_{J\times J} \\ 0_{J\times J} & 0_{J\times J} & \cdots & 0_{J\times J} & A_N \otimes \tilde{F}_N'(\hat{\mathbf{w}}) \end{pmatrix}_{JN\times JN}.$$

The square matrix $\tilde{H}(\hat{\mathbf{w}})$ is given by:

$$\tilde{H}(\hat{\mathbf{w}}) = \begin{pmatrix} \gamma_1^{1,1}\tilde{\pi}_{1,1}^{1\prime}(\hat{\mathbf{w}}) & \cdots & \gamma_1^{1,J}\tilde{\pi}_{1,1}^{J\prime}(\hat{\mathbf{w}}) & \cdots & \gamma_1^{1,1}\tilde{\pi}_{N,1}^{1\prime}(\hat{\mathbf{w}}) & \cdots & \gamma_1^{1,J}\tilde{\pi}_{N,1}^{J\prime}(\hat{\mathbf{w}}) \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ \gamma_1^{J,1}\tilde{\pi}_{1,1}^{1\prime}(\hat{\mathbf{w}}) & \cdots & \gamma_1^{J,J}\tilde{\pi}_{1,1}^{J\prime}(\hat{\mathbf{w}}) & \cdots & \gamma_1^{J,1}\tilde{\pi}_{N,1}^{1\prime}(\hat{\mathbf{w}}) & \cdots & \gamma_1^{J,J}\tilde{\pi}_{N,1}^{J\prime}(\hat{\mathbf{w}}) \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ \gamma_N^{1,1}\tilde{\pi}_{1,N}^{1\prime}(\hat{\mathbf{w}}) & \cdots & \gamma_N^{1,J}\tilde{\pi}_{1,N}^{J\prime}(\hat{\mathbf{w}}) & \cdots & \gamma_N^{1,1}\tilde{\pi}_{N,N}^{1\prime}(\hat{\mathbf{w}}) & \cdots & \gamma_N^{1,J}\tilde{\pi}_{N,N}^{J\prime}(\hat{\mathbf{w}}) \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ \gamma_N^{J,1}\tilde{\pi}_{1,N}^{1\prime}(\hat{\mathbf{w}}) & \cdots & \gamma_N^{J,J}\tilde{\pi}_{1,N}^{J\prime}(\hat{\mathbf{w}}) & \cdots & \gamma_N^{J,1}\tilde{\pi}_{N,N}^{1\prime}(\hat{\mathbf{w}}) & \cdots & \gamma_N^{J,J}\tilde{\pi}_{N,N}^{J\prime}(\hat{\mathbf{w}}) \end{pmatrix}_{JN\times JN},$$

where $\tilde{\pi}_{in}^{k\prime}(\hat{\mathbf{w}}) = \frac{1-\beta_n^k}{1+\tau_{in}^{k\prime}}\pi_{in}^{k\prime}(\hat{\mathbf{w}})$. Finally, $\mathbf{\Omega}(\hat{\mathbf{w}}) = I - \digamma(\hat{\mathbf{w}}) - \tilde{H}(\hat{\mathbf{w}})$.

The interactions presented in $\mathbf{\Omega}(\hat{\mathbf{w}})$ are the key differences compared to a one-sector model and a multi-sector model without I-O linkages. For example, in the special case in which $\gamma_n^{j,j} = 1$, tariffs do not appear in $\mathbf{\Omega}(\hat{\mathbf{w}})$ and expenditures in each country can be solved independently of the expenditures from other countries. For the case in which there is only one sector, $\mathbf{\Omega}(\hat{\mathbf{w}})$ collapses to a scalar as in Alvarez and Lucas (2007) and Eaton and Kortum (2002). In a two-sector model without tariffs and exogenous sectoral deficit, as in Dekle, Eaton and Kortum (2008), $\mathbf{\Omega}(\hat{\mathbf{w}})$ depends only on technology and preference parameters, (γ, β, α).

We solve for the vector $\mathbf{X}(\hat{\mathbf{w}})$ by inverting the matrix $\mathbf{\Omega}(\hat{\mathbf{w}})$.

$$\mathbf{X}(\hat{\mathbf{w}}) = \mathbf{\Omega}^{-1}(\hat{\mathbf{w}})\,\mathbf{\Delta}(\hat{\mathbf{w}}).$$

Denote by $X_n^{j\prime}(\hat{\mathbf{w}})$ the entry j of the vector $\mathbf{X}(\hat{\mathbf{w}})$ (the expenditure in sector j and country n). This expression is crucial in order to solve for the general equilibrium, since it allows us to express all the equilibrium conditions as a function of one vector of unknowns, the vector of factor prices, $\hat{\mathbf{w}}$. Substituting $\pi_{in}^{j\prime}(\hat{\mathbf{w}})$, $\mathbf{X}(\hat{\mathbf{w}})$, τ', and S_n into (11) we obtain:

$$\sum\nolimits_{j=1}^{J} F_n^{j\prime}(\hat{\mathbf{w}})\,X_n^{j\prime}(\hat{\mathbf{w}}) + S_n = \sum\nolimits_{j=1}^{J}\sum\nolimits_{i=1}^{N}\frac{\pi_{in}^{j\prime}(\hat{\mathbf{w}})}{1+\tau_{in}^{j\prime}}X_i^{j\prime}(\hat{\mathbf{w}}). \tag{24}$$

Notice that we have just reduced the system of equilibrium conditions (8 through 12) to a system of N equations (one trade balance per country) and N unknowns (one wage per country). Therefore, given our initial guess of $\hat{\mathbf{w}}$ we verify if the trade balance holds. If not, we adjust our guess of $\hat{\mathbf{w}}$ until equilibrium condition (24) is obtained.

Table 2

Changes in trade flows relative to GDP						
	Data	Model				
Country	1993-2005	τ'	(τ', S')	$\beta_n^j = 1$	No I-O	NAFTA
Mexico's imports	12.3 %	11.9%	13.9%	5.6%	6.6%	11.1%
Mexico's exports	10.1 %	11.4%	7.9%	5.3%	6.3%	10.6%
Canada's imports	9.6 %	7.5%	9.9%	3.1%	3.7%	4.4%
Canada's exports	10.4 %	7.4%	8.5%	3.0%	3.5%	4.3%
U.S. imports	6.2 %	2.0%	5.5%	1.0%	1.1%	1.1%
U.S. exports	1.5 %	2.0%	0.2%	1.0%	1.1%	1.1%

5.3 Results

We incorporate the change in tariffs from 1993 to 2005, both between NAFTA members and with the rest of the world, into the model to quantify the trade effects from tariff eliminations. Table 2 presents the model outcomes and the observed changes in exports and imports over GDP from 1993 to 2005. The trade responses from tariff reductions represent a substantial fraction of the changes in trade flows observed for Mexico and Canada. The relative and absolute magnitudes simulated from the model resemble the observed changes in the data except for the United States (column τ'). Of course, changes in technology, trade costs and aggregate trade deficits explain the difference between the observed and simulated changes from the model. We also present the simulated response from the model after introducing the change in tariffs and the observed change in trade deficits into the model (column (τ', S')). As we can see, the model is able to capture most of the trade effects when the exogenous deficit is included.[33]

We quantify the role of intermediate goods and sectoral linkages by comparing the results of our model to a model in which there are no intermediates in production and to a model in which there are no I-O connections. By setting $\beta_n^j = 1$, the production function of tradable goods collapses to a multi-sector model without intermediate goods used in production. We re-calibrate the model taking into account that there are no intermediate goods in production and compute the trade response for tariff reductions. Trade effects from a tariff decline are reduced by half in the case of

[33] The difference between the simulated changes in trade flows and the observed changes can be used to identify changes in iceberg trade costs as well as changes in technology. This exercise is interesting but outside of the scope of this paper. Eaton et al. (2011) and Parro (2012), in the context of answering different questions, identify changes in technology in that way.

no intermediate goods in production as presented in Table 2. The intuition for this result is that in the case of $\beta_n^j = 1$ goods are traded to produce composite goods that are only used for consumption and not for the production of intermediates. When $\beta_n^j < 1$ composite intermediate goods are also used for the production of intermediate goods. Then, a tariff reduction delivers a larger trade effect due to the increase in demand of tradable goods for the production of intermediates.

We also compare the implied changes in trade flows from a model with intermediate goods in production but no sectoral linkages. In this case we are zeroing out the off-diagonal elements of the I-O matrix. The column "No I-O" in Table 2 presents the results. The trade effects from tariff reductions are higher than in a model without intermediate goods but still substantially lower than in the model with sectoral interrelations. The reason is that since producers are only using inputs from one sector they are not exploiting the benefits of having access to cheaper intermediate goods from other sectors. This in turn delivers smaller trade effects from tariff changes.

The last column in Table 2 presents the effect of NAFTA's tariff reductions on trade flows. Mexico had the largest trade effects. If we compare with column τ' we can infer that around 93% of the simulated change in Mexico's total trade over GDP are attributed to NAFTA, 58% for Canada and 55% for the United States.

Figures 10 through 12 present scatter plots comparing the change in imports and exports over GDP from the model to the ones observed in the data for each country.[34] A 45-degree line is included in each figure to guide the reader. As we can see, most of the sectors are located close to the 45-degree line. This indicates that tariff reductions accounted for most of the observed trade effects in the data. However, this is not the case for several sectors, in particular, resource-based sectors or sectors that are very dependent on these sectors, such as petroleum, chemicals, and mining.

We now turn to welfare analysis. Table 3 presents the simulated change in real wages implied by different models. The first three columns present the results from the change in the tariff structure from 1993 to 2005. The first column shows the effect on real wages for the model with no intermediate goods in production, $\beta_n^j = 1$. The second column presents the result from the model with intermediate inputs but without sectoral linkages. As the calculations show, intermediate

[34] Concretely, what we are comparing is the difference between $x_{i,t+1}^j / \, y_{i,t+1}$ - $x_{i,t}^j / \, y_{i,t}$ from the model and the data, where $x_{i,t}^j$ are imports (or exports) from sector j and country i at time t and $y_{i,t}$ is GDP from country i at time t. Comparing the model with the data in this way it implicitly weights trade changes according to their relative importance. Alternatively, one could compare relative change in exports and imports over GDP weighted by the share of exports or imports of that sector in the base year, i.e.: $((x_{i,t+1}^j/y_{i,t+1})/(x_{i,t}^j/y_{i,t})$ -1$)(x_{i,t}^j/\sum_{j=1}^J x_{i,t}^j)$. We also used this measure and the results are similar to the ones presented here.

Table 3

Change in real wages across different models				
	Model			
	$\beta_n^j = 1$	No I-O	τ'	NAFTA
Mexico	1.00%	1.01%	1.61%	1.30%
Canada	0.89%	0.97%	1.65%	0.96%
U.S.	0.15%	0.18%	0.32%	0.17%

goods in production amplify the change in real wages from tariff reductions for all countries. In particular, Mexico's figure increases by 1%, Canada's by 9% and the United States by 20%. The third column presents the gains in real wages from our model. The implied change in real wages is substantially larger in this case compared to the previous two. Input-output linkages increase the change in real wages by 59%, 70% and 78% respectively for Mexico, Canada and the US relative to the model without sectoral linkages. These magnitudes are even larger if we compare them to a model that has no intermediate goods. In fact, intermediate goods and input-output linkages together increase gains in real wages by 61%, 85% and 113% for Mexico, Canada and the United States respectively.[35] This result unmasks the importance of accounting for intermediate goods in production and I-O linkages to evaluate the welfare gains from trade. Finally, the forth column in Table 3 presents the results from our model for the case of a change in tariffs implied by NAFTA, holding fixed the tariff from and to the rest of the world. As we can see from the figures, most of the gains in real wages for Mexico over the period 1993-2005 are a consequence of NAFTA's tariff changes. On the other hand, Canada and the United States gain from NAFTA but the gains from changes in trade policy with the rest of the world are more important.

In our model tariff revenues are lump-sum transferred to consumers. When we add the change in tariff revenues to our measure of welfare, we find that Mexico suffers the largest tariff revenue losses. This is a clear consequence of Mexico having the biggest tariff reduction among NAFTA members. The change in real income in Mexico (considering the tariff revenue losses) is -0.1%. The revenue effect is smaller in the case of Canada and the United States, since the change in tariffs applied by these countries is also smaller. Real income changed -0.1% in Canada and 0.1% in the United

[35] An alternative way to compare the welfare effects implied by different models is to condition on the observed change in domestic expenditure shares in equation (15) and quantify how welfare changes by adding intermediate goods and sectoral linkages. Doing this exercise for the period 1993 to 2005 we find that the gains from trade increase by a similar magnitude as the one reported in Table 3 as we account for I-O linkages. Such an exercise is informative of the gains from trade from reductions in trade costs more broadly and not only from the reduction in tariffs.

States due to NAFTA. If we include the observed trade deficit in the model, the welfare effects increase considerably. For instance, the welfare gains for Mexico and the United States increase to 6% and for Canada the figure is 1.5%. Of course, these figures have to be interpreted with caution in our model, since we assume that all revenue is transferred in a lump-sum to consumers and an exogenous change in the trade deficit is a direct transfer from, or to, the rest of the world.

Table 4

Model $\tau^{2005} \rightarrow \tau^{1993}$			
Country		Trade effects	Change in real wages
Mexico's	Imports	-8.8%	-1.5%
	Exports	-8.5%	
Canada's	Imports	-5.7%	-1.4%
	Exports	-5.5%	
U.S.	Imports	-1.5%	-0.3%
	Exports	-1.6%	

We also consider an alternative quantification of the trade and welfare effects of NAFTA by redefining the base year to the year 2005 and changing the tariff vector to the levels observed in 1993. To do so, we recalibrate the model to 2005. The counterfactual experiment in this case is to quantify the trade and welfare effects from leaving NAFTA, or in the same way, to quantify the trade responses from a tariff increase from the levels observed in 2005 back to the levels observed in 1993. The result of this counterfactual exercise is presented in Table 4.

As we can see, there are large negative trade effects as tariff increase. As in the case considered before, Mexico is the country that experiences the largest trade effects. Table 4 also presents the change in real wages associated with this increase in tariffs. All countries present a reduction in real wages and Mexico and Canada are the countries most affected by this policy. These results are consistent with the findings we presented before.

6. CONCLUSION

This study develops a general equilibrium model to quantify the trade and welfare effects of tariff changes. The model is able to perform complex trade policy evaluations for an arbitrary number of sectors and countries in a parsimonious way with few data and parameter requirements. Using the model we decompose the different channels by which a reduction in tariffs can spread the gains across sectors in the economy. We show that accounting for sectoral interrelations is quantitatively and economically meaningful. With the model, one can quantify and decompose the effects that a reduction or increase in a tariff in a particular sector can have on the price of intermediate inputs in that sector and in the rest of the economy, the general equilibrium price effects of tariff reductions at home and abroad, the impact on factor allocations across sectors, the change in factor payments and the extent to which the structure of production of a particular economy can spread the gains from having access to cheaper intermediate goods and more efficient technology.

Evaluating the effects of NAFTA has receive considerable attention in the economic literature. Therefore, it is important to clarify how our results about NAFTA should be interpreted. We use the model to perform a model-based identification of the effects of NAFTA's tariff reductions. Unquestionably, NAFTA had more provisions than only reducing tariff between members and by no means our results should be interpreted as the trade and welfare effects of the entire agreement. For instance, non-tariff barriers or unobservable trade costs might also have changed as a consequence of NAFTA. Moreover, NAFTA might have even influenced the rate of technological change of each member. Certainly, we could have used the model to quantify what is the implied change in TFP and trade costs such that the model matches the trade patterns observed in the data. However, understanding how TFP changed as a consequence of NAFTA is outside of the scope of this paper. In our model TFP is exogenous and by holding it fixed during the period of analysis we are able to identify the pure direct effect of tariff reductions. Our study uses the case of NAFTA to show how the effects of tariff reductions are amplified as we take into account the interrelation across sectors observed in the data. We find that the trade and welfare effects from tariff reductions are at least 40% lower if intermediate goods in production and input-output linkages are ignored in the analysis. With this results we hope to convey the message that modelling sectoral interrelations is not only feasible but also important for quantitative analysis.

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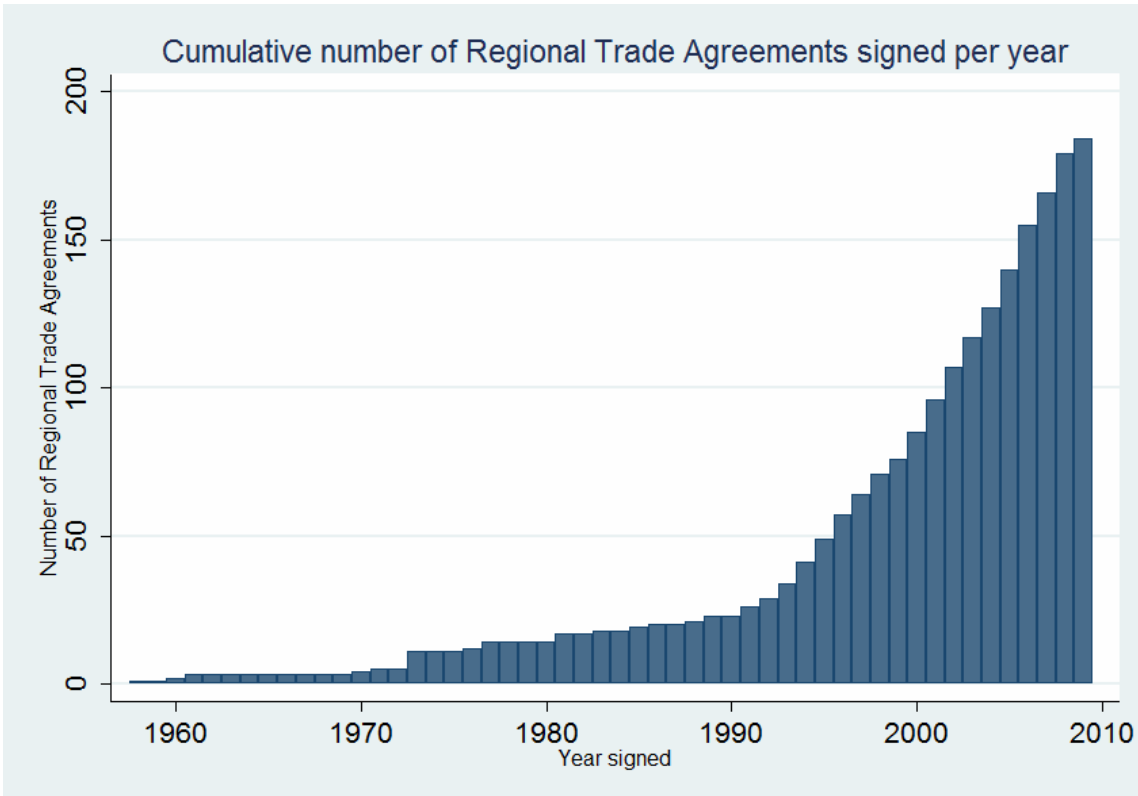
Figure 1

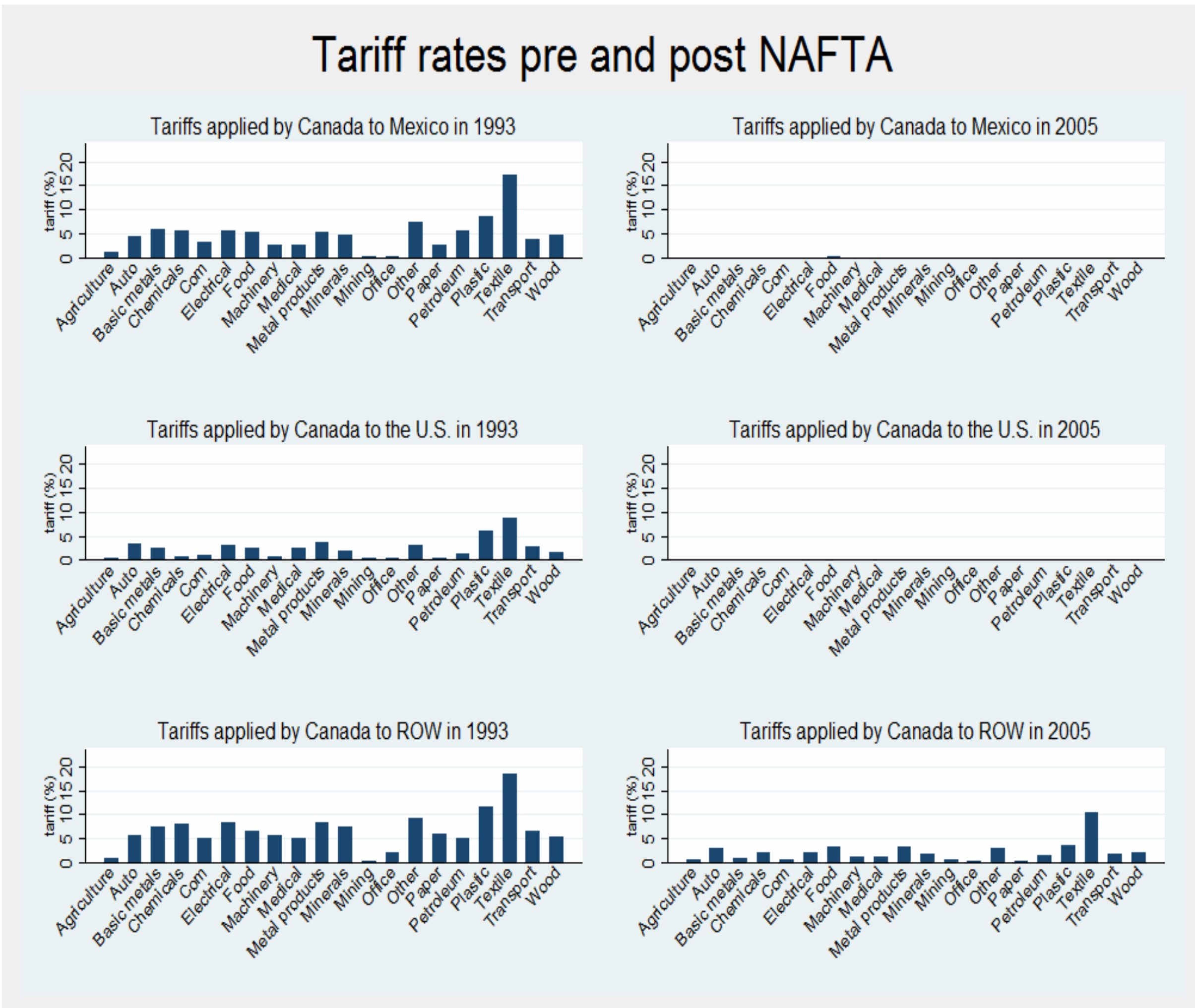


Note: This picture considers all types of Regional Trade Agreements: preferential trade agreements (PTAs), free trade agreements (FTAs), custom unions (CUs) and regional economic integrations (REI) Source: World Trade Organization.

Figure 2

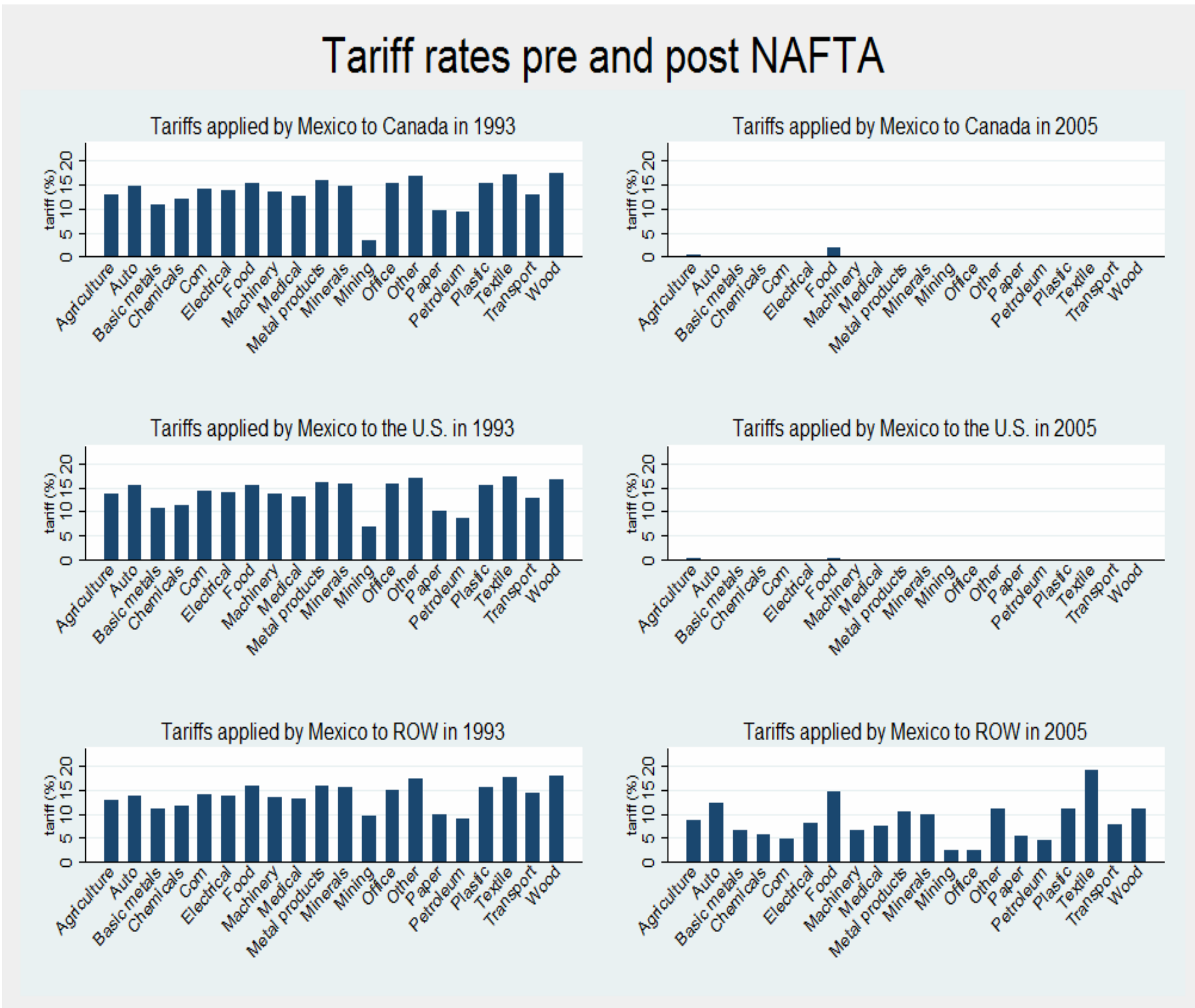
Note: The share is calculated as the total trade between members of Regional Trade Agreements over total trade in the world for each year. Source: World Trade Organization.

Figure 3



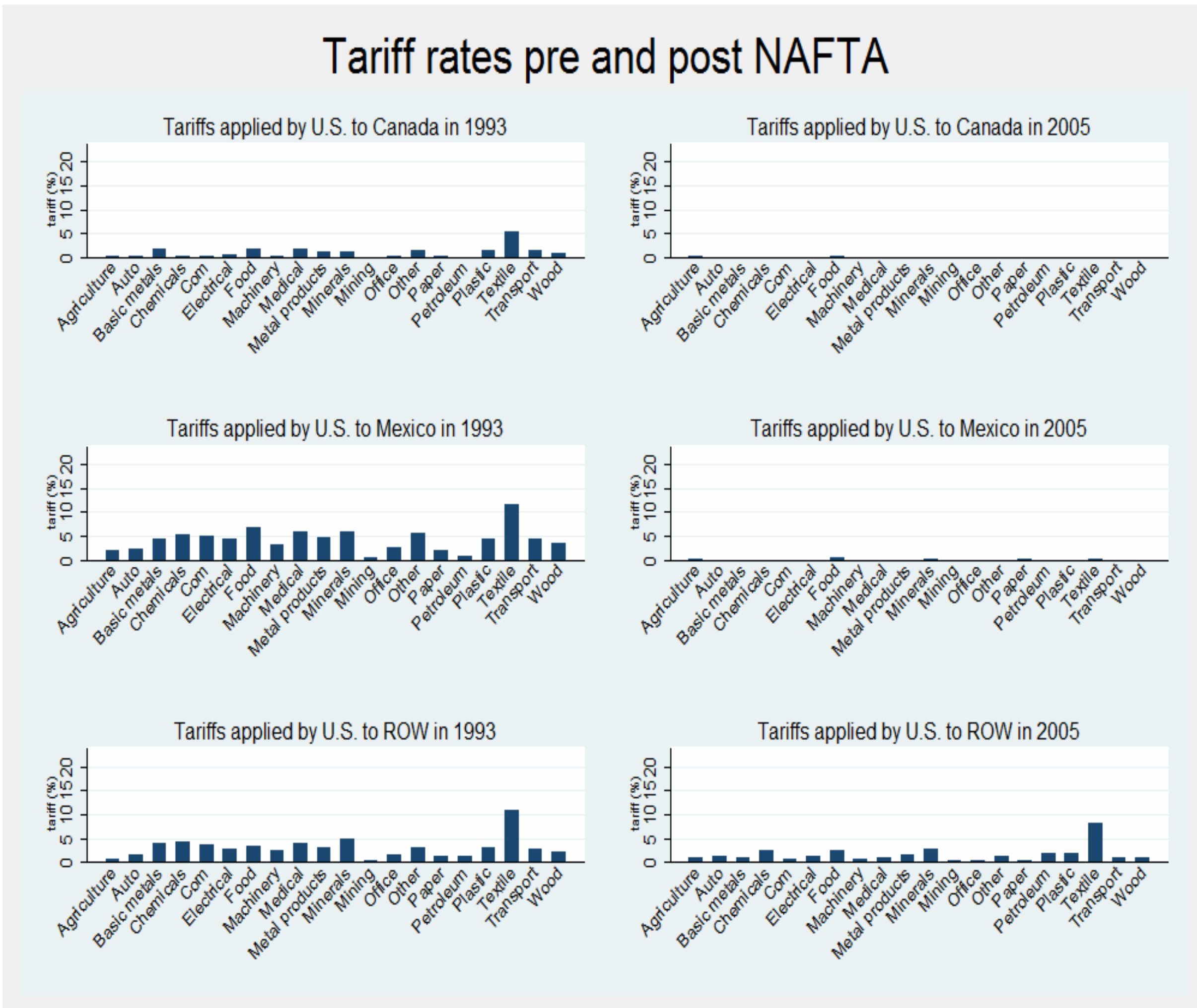
Note: Tariffs applied by sector (ISIC rev. 3). This figure presents the tariffs applied by Canada to NAFTA members and ROW (rest of the world). Figures on the left side show tariffs in 1993 and on the right side tariffs in 2005. See the Data Appendix for more details.

Figure 4



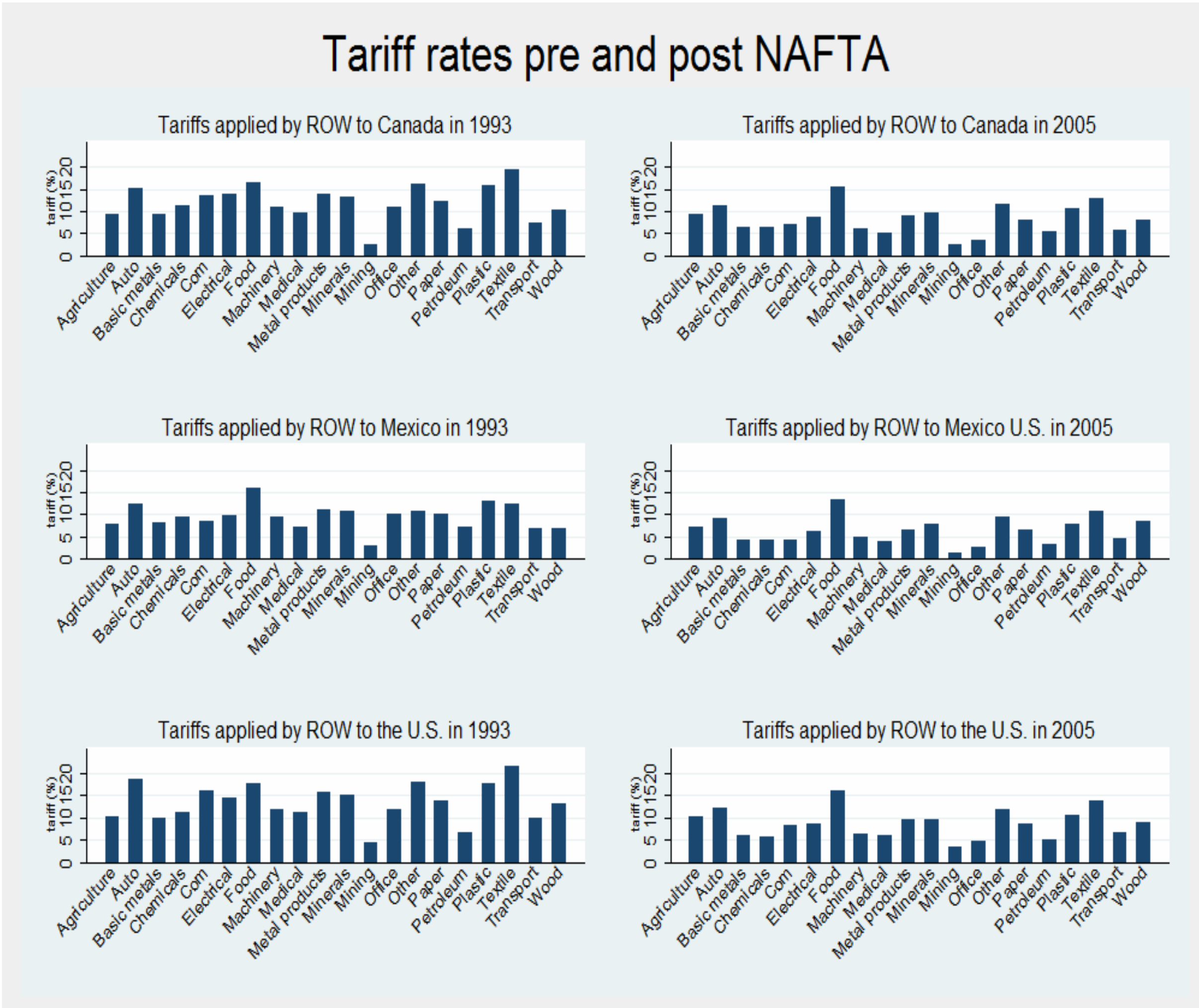
Note: Tariffs applied by sector (ISIC rev. 3). This figure presents the tariffs applied by Mexico to NAFTA members and ROW (rest of the world). Figures on the left side show tariffs in 1993 and on the right side tariffs in 2005. See the Data Appendix for more details.

Figure 5



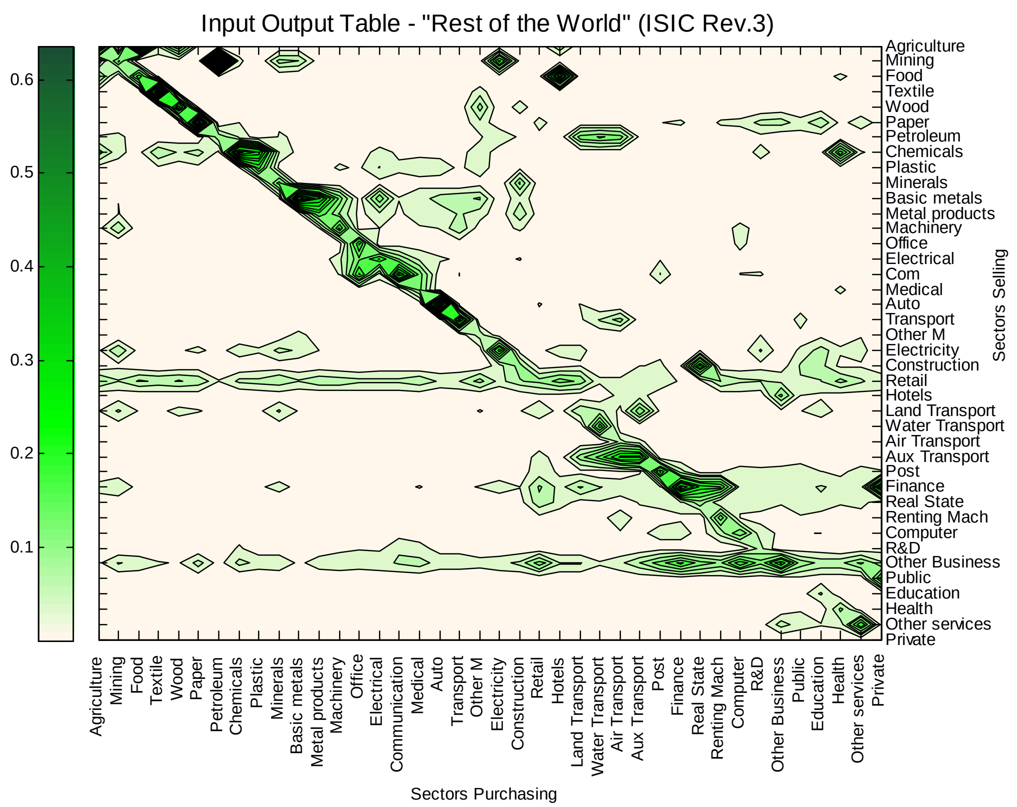
Note: Tariffs applied by sector (ISIC rev. 3). This figure presents the tariffs applied by the United States to NAFTA members and ROW (rest of the world). Figures on the left side show tariffs in 1993 and on the right side tariffs in 2005. See the Data Appendix for more details.

Figure 6



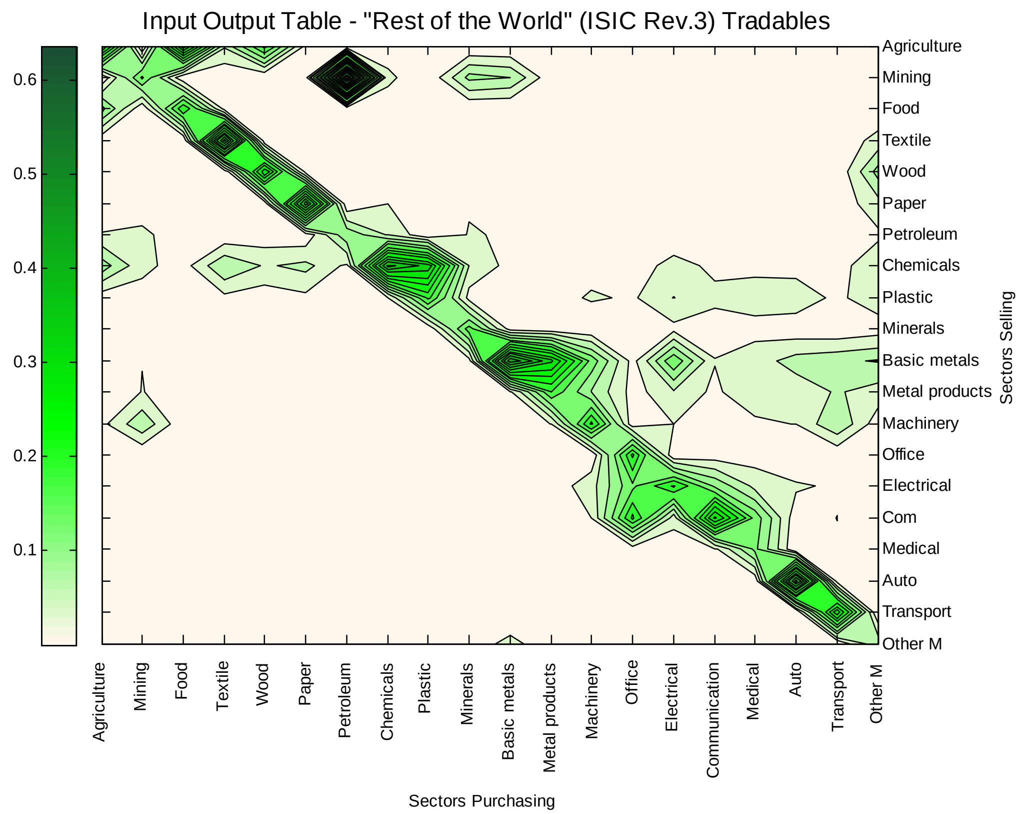
Note: Tariffs applied by sector (ISIC rev. 3). This figure presents the tariffs applied by the ROW (rest of the world) to NAFTA members. Figures on the left side show tariffs in 1993 and on the right side tariffs in 2005. See the Data Appendix for more details.

Figure 7



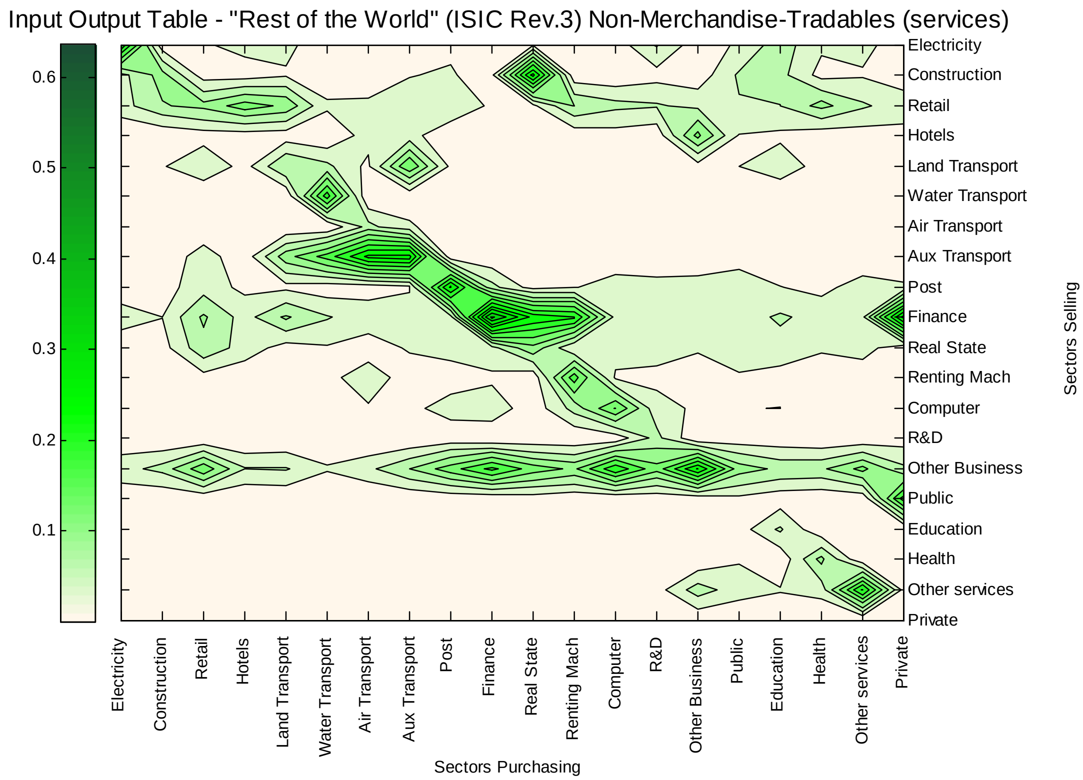
Note: I-O table for a construct rest of the world. We use the (OECD) STAN database 2002 edition (ISIC Rev.3) Input Output tables. The rest of the world was constructed with 22 countries that reported I-O tables for 2000. The list of countries are Austria, Belgium, Czech Rep, Germany, Denmark, Spain, Finland, France, United Kingdom, Hungary, Ireland, Italy, Japan, Korea, Netherlands, Norway, New Zealand, Poland, Portugal, Russia, Slovakia, and Sweden.

Figure 8



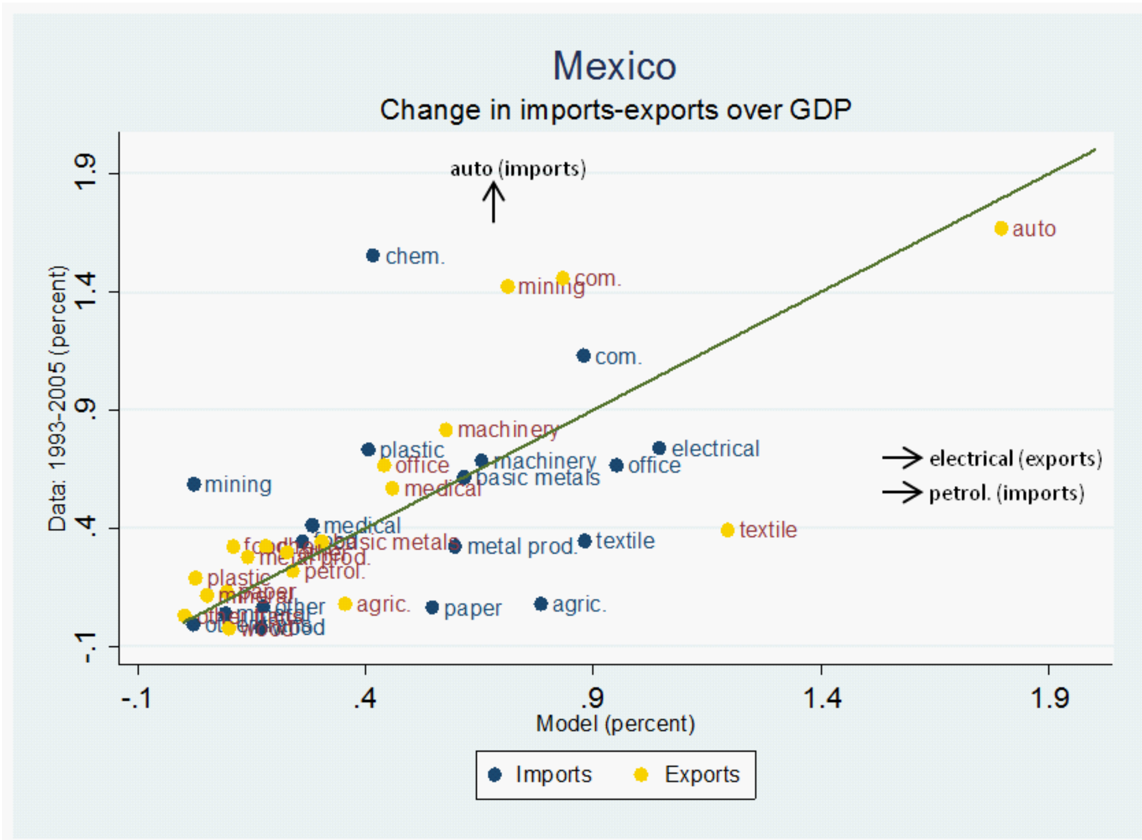
Note: I-O table for a construct rest of the world, tradable sectors.

Figure 9



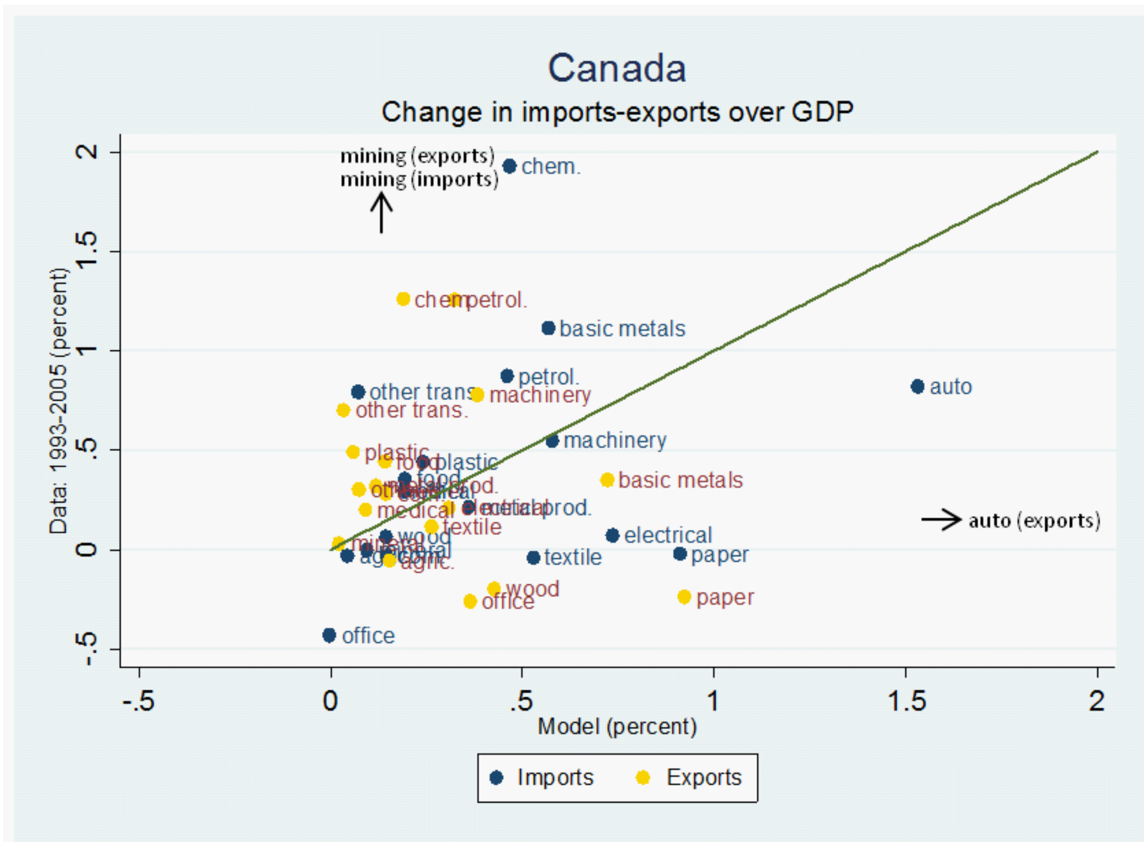
Note: I-O table for a construct rest of the world, non-tradable sectors.

Figure 10



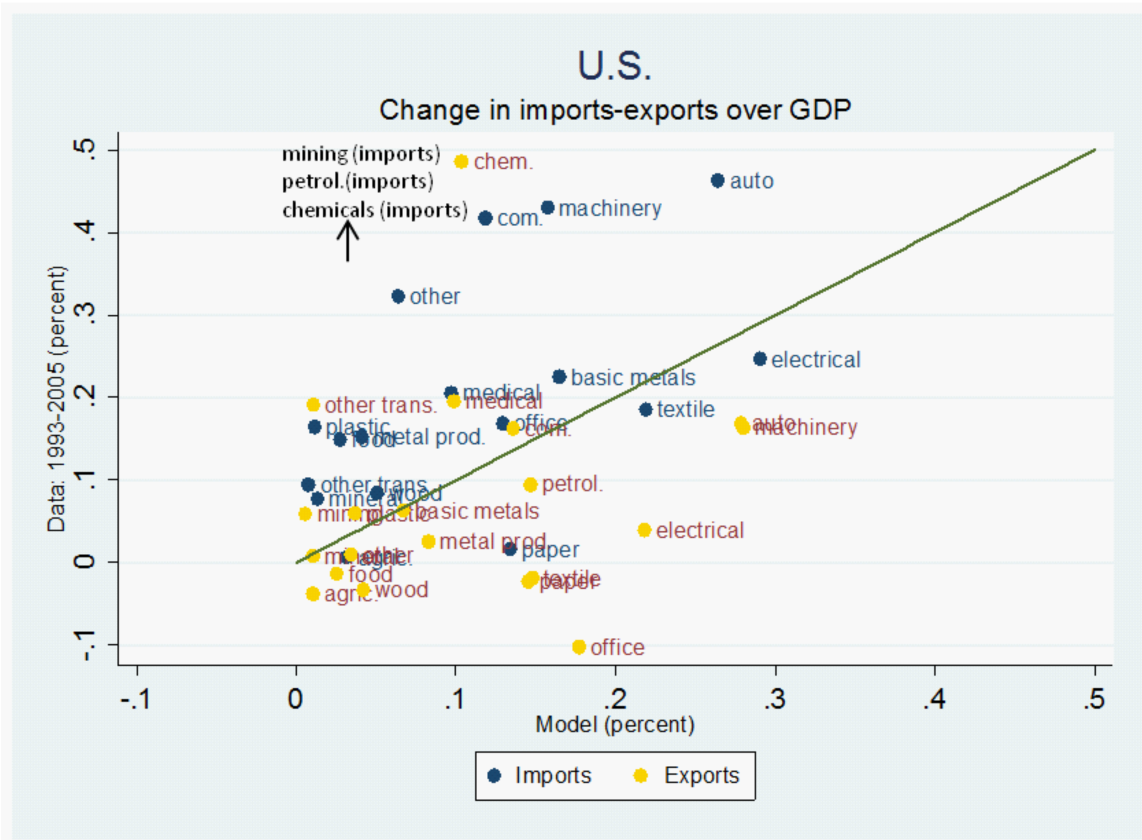
Note: The horizontal axis measures the difference between $x^j_{i,t+1}/\ y_{i,t+1}$ - $x^j_{i,t}/\ y_{i,t}$ from the model, where $x^j_{i,t}$ are imports (or exports) from sector j and country i at time t and $y_{i,t}$ is GDP from country i at time t. The vertical axis measures the difference between $x^j_{i,t+1}/\ y_{i,t+1}$ - $x^j_{i,t}/\ y_{i,t}$ observed in the data. Auto and petroleum imports and electrical machinery exports are outside of the scale in the figure. The arrows in the figure indicate if the model simulates larger or smaller changes in trade flows than the observed changes in the data in these sectors. Specifically, the changes in auto imports as a share of GDP from the model and data are 0.6% and 3.1%, respectively. For the case of petroleum imports these numbers are 2.4% and 0.8%. The changes in exports as a share of GDP in the electrical machinery sector from the model and data are 3.5% and 0.8%, respectively.

Figure 11



Note: The horizontal axis measures the difference between $x^j_{i,t+1}/\, y_{i,t+1}$ - $x^j_{i,t}/\, y_{i,t}$ from the model, where $x^j_{i,t}$ are imports (or exports) from sector j and country i at time t and $y_{i,t}$ is GDP from country i at time t. The vertical axis measures the difference between $x^j_{i,t+1}/\, y_{i,t+1}$ - $x^j_{i,t}/\, y_{i,t}$ observed in the data. Mining and auto exports and mining imports are outside of the scale in the figure. The arrows in the figure indicate if the model simulates larger or smaller changes in trade flows than the observed changes in the data in these sectors. Specifically, the changes in mining exports as a share of GDP from the model and data are 0.3% and 4.3%, respectively. For the case of mining imports these numbers are 0.04% and 2.3%. The changes in exports as a share of GDP in the auto sector from the model and data are 2.2% and 0.1%, respectively.

Figure 12



Note: The horizontal axis measures the difference between $x^j_{i,t+1}/\ y_{i,t+1}$ - $x^j_{i,t}/\ y_{i,t}$ from the model, where $x^j_{i,t}$ are imports (or exports) from sector j and country i at time t and $y_{i,t}$ is GDP from country i at time t. The vertical axis measures the difference between $x^j_{i,t+1}/\ y_{i,t+1}$ - $x^j_{i,t}/\ y_{i,t}$ observed in the data. Mining, petroleum and chemicals imports are outside of the scale in the figure. The arrows in the figure indicate if the model simulates larger or smaller changes in trade flows than the observed changes in the data in these sectors. Specifically, the changes in mining imports as a share of GDP from the model and data are 0.1% and 1.5%, respectively. For the case of petroleum imports these numbers are 0.03% and 0.6%. The changes in imports as a share of GDP in the chemical sector from the model and data are 0.1% and 0.6%, respectively.

APPENDIX A: DATA

Table A1

Tradable sectors

Product Classification System: International Standard Industrial Classification (ISIC) Revision 3.

Number	Industry	Description	ISIC Rev.3
1	Agriculture	Agriculture forestry and fishing	1 - 5
2	Mining	Mining and quarrying	10 - 14
3	Food	Food products, beverages and tobacco	15-16
4	Textile	Textiles, textile products, leather and footwear	17-19
5	Wood	Wood and products of wood and cork	20
6	Paper	Pulp, paper, paper products, printing and publishing	21-22
7	Petroleum	Coke refined petroleum and nuclear fuel	23
8	Chemicals	Chemicals	24
9	Plastic	Rubber and plastics products	25
10	Minerals	Other nonmetallic mineral products	26
11	Basic metals	Basic metals	27
12	Metal products	Fabricated metal products, except machinery and equipment	28
13	Machinery n.e.c	Machinery and equipment n.e.c	29
14	Office	Office, accounting and computing machinery	30
15	Electrical	Electrical machinery and apparatus, n.e.c.	31
16	Com	Radio, television and communication equipment	32
17	Medical	Medical, precision and optical instruments, watches and clocks	33
18	Auto	Motor vehicles trailers and semi-trailers	34
19	Other Transport	Other transport equipment	351 - 359
20	Other	Manufacturing n.e.c and recycling	36 -37

Table A2

Non-tradable sectors

Product Classification System: International Standard Industrial Classification (ISIC) Revision 3.

Number	Description	ISIC Rev.3
21	Electricity Gas and Water Supply	40 - 41
22	Construction	45
23	Wholesale and retail trade repairs	50 - 52
24	Hotels and restaurants	55
25	Land transport transport via pipelines	60
26	Water transport	61
27	Air transport	62
28	Support. & aux. transport act. travel agencies activ.	63
29	Post and telecommunications	64
30	Financial intermediation	65 - 67
31	Real estate activities	70
32	Renting of machinery and equipment	71
33	Computer and related activities	72
34	Research and development	73
35	Other business activities	74
36	Public admin. and defense compulsory social security	75
37	Education	80
38	Health and social work	85
39	Other community social and personal services	90 - 93
40	Private households with employed persons	95

APPENDIX B: ADDITIONAL TABLES

Table B1

Dispersion-of-productivity parameter (with importer and exporter fixed effects)

	Full sample			99% sample			97.5% sample		
Sector Name	$1/\theta^j$	s.e.	N	$1/\theta^j$	s.e.	N	$1/\theta^j$	s.e.	N
Agriculture	8.59	(2.00)	496	9.54	(2.11)	430	16.97	(2.48)	364
Mining	14.83	(2.87)	296	11.96	(3.84)	178	14.84	(4.38)	152
Manufacturing									
Food	2.84	(0.57)	496	3.02	(0.57)	429	2.89	(0.65)	352
Textile	5.99	(1.24)	437	8.55	(1.38)	314	0.61	(1.89)	186
Wood	10.19	(2.24)	315	10.72	(2.63)	191	9.30	(2.82)	148
Paper	8.32	(1.66)	507	15.20	(2.69)	352	0.51	(2.86)	220
Petroleum	69.31	(19.32)	91	68.47	(19.08)	86	65.92	(19.51)	81
Chemicals	3.64	(1.75)	430	3.23	(1.76)	341	-0.02	(2.07)	220
Plastic	0.88	(1.57)	376	3.10	(2.24)	272	1.95	(2.22)	180
Minerals	3.38	(1.54)	342	3.03	(1.73)	263	3.85	(2.07)	186
Basic metals	6.58	(2.28)	388	0.88	(2.58)	288	-1.31	(2.77)	235
Metal products	5.03	(1.93)	404	7.30	(2.01)	314	0.82	(2.83)	186
Machinery n.e.c.	2.87	(1.85)	397	3.88	(3.14)	290	0.70	(4.24)	186
Office	13.88	(2.21)	306	9.85	(5.60)	126	21.57	(5.78)	62
Electrical	11.02	(1.46)	343	13.95	(1.66)	269	4.66	(2.82)	177
Comm	4.87	(1.76)	311	3.27	(2.07)	143	3.33	(2.19)	93
Medical	7.63	(1.22)	383	7.49	(1.48)	237	2.45	(1.25)	94
Auto	0.49	(0.91)	237	1.59	(1.04)	126	-2.13	(1.34)	59
Other Transport	0.90	(1.16)	245	0.91	(1.15)	226	1.05	(1.22)	167
Other	4.95	(0.92)	412	3.52	(1.04)	227	2.61	(0.81)	135
Manufacturing (average)		9.04			9.33			6.60	

Note: The dependent variable is $\ln(X^j_{ni}X^j_{ih}X^j_{hn} \ / \ (X^j_{in}X^j_{hi}X^j_{nh}))$ where X^j_{ni} are trade flows from n to i. The independent variable is $\ln(\tilde{\tau}^j_{ni}\tilde{\tau}^j_{ih}\tilde{\tau}^j_{hn} \ / \ (\tilde{\tau}^j_{in}\tilde{\tau}^j_{hi}\tilde{\tau}^j_{nh}))$, where we also included importer and exporter fixed effects. $1/\theta^j$ is the negative of the estimated coefficient. The data is from 1993 or before. Heteroskedasticity-robust standard errors are reported. The estimate for manufacturing is the mean of the sector estimations.

APPENDIX C: DATA SOURCE

This appendix provides information on the data used in the paper "Estimates of the Trade and Welfare Effects of NAFTA." The NAFTA countries are Mexico, Canada and the United States. The list of countries used in the rest of the world construct are Australia, Austria, Belgium, Chile, China, the Czech Republic, Denmark, Finland, France, Germany, Greece, Hong Kong, Hungary, India, Indonesia, Ireland, Israel, Italy, Japan, the Netherlands, New Zealand, Norway, Poland, Portugal, Russia, Slovakia, South Africa, Spain, Sweden, Switzerland, Turkey, and the United Kingdom.

Bilateral Trade Flows

For the calibration of the model, we use data from the United Nations Statistical Division (UNSD) Commodity Trade (COMTRADE) database. Values are reported in thousands of U.S. dollars at current prices and include cost, insurance and freight (CIF). Commodities are defined using the Harmonized Commodity Description and Coding System (HS) 2002 at the 6-digit level of aggregation and were concorded to 2-digit ISIC Rev.3 using the United Nations concordance tables. The years we use are 1993 for the calibration and 2005 to compare results. To construct the rest of the world we use the total trade between each NAFTA member and all trading partners and subtract the trade with other NAFTA members.

For the estimation of dispersions of productivity, we use data from the COMTRADE database. Values are recorded in U.S. dollars and commodities are defined using the HS 2002 at the 6-digit level of aggregation and were also concorded to 2 digit ISIC rev.3 using the United Nations concordance tables. We downloaded data from 1993 to 2005. See Appendix Estimation for further details.

Tariffs

The tariff measures, τ_{in}^{j}, are from the United Nations Statistical Division-Trade Analysis and Information System (UNCTAD-TRAINS). The tariff measures are tariff lines and are reported in two ways: simple and weighted averages effective applied rates at a 4-digit ISIC rev.3 level. Effective applied rates refers to the actual tariff applied, taking into account whether there is any trade agreement between the countries. We also downloaded the most-favored-nation (MFN) tariffs for each country. Under the rules of the World Trade Organization (WTO), members cannot discriminate between their trading partners; therefore, they need to grant all countries the same favorable treatment as all other WTO members. The tariff that considers this rule is the MFN tariff. If countries sign bilateral and multilateral trade agreements, then they are exempt from this rule. We compared both measures to see if they were consistent, that is, if the effective applied rates are lower than the MFN tariffs.

Value Added and Gross Production

We use data for the value added and gross production from the Organization for Economic Cooperation and Development (OECD) STAN database for Industrial Analysis. The information is based on the ISIC Rev.3. Production (Gross Output STAN code PROD) and value added (STAN code VALU) are at current prices and in national currency. We used the values in 1993 to calibrate the model to the same year. We found some sectors with missing values. For Canada the sectors with missing values are C30 – C33, C60 – C63, and C72 – C74. For Mexico the sectors with missing values are C30 – C33, and C72 – C74. We use data at a more aggregate level (for example, C30TC33) and then apply the average share of each sub-sector using all the countries in the sample and years unless a country has data for more than four years, in which case we use the implied shares observed in that country in the rest of the years. For this, we downloaded data from 1989 to 2005. We also used data on exchange rates from OECD - STAN to convert all the variables to dollars. The values for the rest of the world are a weighted average of the 32 countries listed above.

Intermediate Consumption - Input Output Tables

The Input-Output (I-O) tables are from the (OECD) STAN database 2002 edition (ISIC Rev.3). For the United States we used the I-O from 1995 and for Canada we used the I-O from 2000. For Mexico the I-O table is from the Instituto Nacional de Estadística y Geografía (INEGI). The table was constructed in 2003, and industries are classified according to the North American Industry Classification System (NAICS) 2002. We used the correspondence table from the United Nations Statistic Division to concord the table to ISIC Rev.3. The rest of the world I-O table was constructed with 22 countries that reported I-O tables for 2000: Austria, Belgium, Denmark, Spain, Finland, France, Germany, Hungary, Ireland, Italy, Japan, Korea, the Netherlands, Norway, New Zealand, Poland, Portugal, Russia, Slovakia, Sweden, Switzerland, and United Kingdom.

Estimation of Dispersion of Productivity

To estimate the dispersion of productivity, we collect data on trade flows and tariff rates for 16 economies: Argentina, Australia, Brazil, Canada, Chile, China, the European Union, India, Indonesia, Japan, Korea, New Zealand, Norway, Switzerland, Thailand and the United States. Brazil was dropped from the sample because it was experiencing a currency crisis (large devaluation, high inflation). Bilateral trade data for 1993 are not difficult to find; however, we are restricted by the information on tariffs. Countries were included in the sample provided they had reliable tariff data and they had cross bilateral trade with many countries. In order to increase the sample size we had to input the values for some countries. If a country in the list did not have tariff data available in 1993, we input this value with the closest value available, searching up to four previous years, up to 1989. Our estimation is performed excluding Mexico from the sample. Canada and the United States are included in the estimation; however, we remove all the interaction (triple combinations in (18)) terms involving Canada and the United States. We leave the interaction of these countries with other countries in order to have a larger number of observations since these countries have a large number of trading partners. The sample of countries represented more than 80% of the world's trade in 1993 and at least 72% in each sector (see table C1). Data on trade flows are from the United Nations COMTRADE database for 1993. Values are recorded in U.S. dollars for commodities defined using the HS-1992 at two digits of aggregation, corresponding to 30 sectors. Using concordance tables we obtained trade flows for 20 ISIC-rev. 3 sectors. The reporter country is the importer, and imports are at CIF. values. Data on tariffs are from UNCTAD-TRAINS for 1989-1995. Tariffs represent the effective tariff rate applied by each country. Tariffs are available for industries at four digits ISIC-rev.3. and were aggregated up to two digits using a weighted average, where the weights are given by the import values. Whenever data on bilateral tariffs are not available in 1993, we input this value with the closest value available, searching up to four previous years. The total number of observations for the 20 sectors is 9138, with an average of 457 observations per sector.

Table C1

% of World's trade covered by the sample

Sectors	%	Sectors	%	Sectors	%	Sectors	%
Agriculture	83%	Paper	88%	Basic metals	84%	Com	72%
Mining	85%	Petroleum	88%	Metal products	82%	Medical	79%
Food	86%	Chemicals	83%	Machinery nec	84%	Auto	92%
Textile	73%	Plastic	83%	Office	83%	Other Transport	87%
Wood	87%	Minerals	82%	Electrical	78%	Other	75%
		Aggregate trade			82%		