Estimates of the Trade and Welfare Effects of NAFTA

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Abstract

In this paper we build into a Ricardian model the role of trade in intermediate inputs, sectoral linkages and differing productivity levels across sectors. The model can be used for both ex-ante and ex-post trade policy evaluation. We also propose a new method to estimate sectoral trade elasticities. Estimation requires only trade and tariff data and does not require the assumption of bilaterally symmetric trade costs. With the model and estimates of sectoral trade elasticities for the year 1993, we evaluate the trade and welfare effects of the North American Free Trade Agreement (NAFTA). We do so by incorporating into the model the change in tariffs from 1993 to 2005 to calculate the implied changes in exports and imports. We find that as a consequence of the tariff reductions, real wages increased in all NAFTA countries. Mexico had the largest gains, while Canada and the United States gained relatively more from trade liberalization against the rest of the world than from trade liberalization within NAFTA over the sample period.

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1 Introduction

In this paper we develop a Ricardian multi-sector and multi-country quantitative model of international trade for trade policy analysis. The model generalizes the Eaton and Kortum (2002) model by adding multiple sectors with trade in intermediate goods within each sector, the interaction across tradable and non-tradable sectors observed in the input-output tables and sectoral trade deficits that are endogenously determined. We also consider explicitly the heterogeneity in productivity and tariffs across sectors. By focusing on changes, we can perform policy experiments without relying on estimates of total factor productivity or transport costs, which are both difficult to estimate. We only need data on bilateral trade flows, production and tariffs and an estimate of sectoral trade elasticities. In the paper, we also propose a new method to estimate sectoral trade elasticities. The estimations are performed only using trade and tariff data and not assuming bilaterally symmetric trade costs. We use the model to estimate the trade and welfare effects of NAFTA.

NAFTA took effect on January 1, 1994. Trade has expanded dramatically between NAFTA members since then. For example, 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? What were the welfare effects of NAFTA? We use our model to answer these questions. Instead of estimating the parameters of the model to match the observed changes in trade flows from 1993 to 2005, we put the model to a harder test. 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.

We evaluate the trade effects of NAFTA by comparing the simulated changes to their observed counterparts. The observed changes of Canada's, Mexico's, and the United States exports of manufacturing goods over GDP were 24.4%, 130.6%, and 28.6%, while the simulated changes are 34.4%, 131.9% and 51.4%.

Table 1

Changes in trade flows relative to GDP (Manufacturing sector)

		Exports			Imports		
		Canada	Mexico	U.S.	Canada	Mexico	U.S.
Data	1993-2005	24.4%	130.6%	28.6%	16.0%	68.3%	49.4%
Model	Tariff	34.4%	131.9%	51.4%	23.8%	56.4%	24.8%

The observed changes in imports of manufacturing goods over GDP for Canada, Mexico, and the United States were 16.0%, 68.3% and 49.4%, and the simulated counterparts are 23.8%, 56.4% and 24.8%, respectively. These simulated values are conditional on fixing a set of variables like technology, geographic trade costs, and trade deficits. From the period 1993 to 2005 there were significant changes in the United States trade deficit due to reasons that are not related to trade policy. Therefore, when we incorporated the change in the United States trade deficit observed from 1993 to 2005 into the model, the simulated changes in manufacturing imports over GDP for the United States change to 49.6% and exports to 31.1%.

Are all of these trade effects due to NAFTA? We find that 94.9% of the increase in Mexico's manufacturing total trade over GDP can be attributed to NAFTA, 58.9% for the case of Canada and 48.3% for the case of the United States.

What were the welfare effects of NAFTA? Real wages increased in all NAFTA countries and Mexico had the largest gains. Access to cheaper intermediate goods and sectoral linkages are the main explanations to the increase in real wages in Mexico and Canada. For the case of the United States the change in real wages is mainly due to trade in intermediate goods and to a decline in the cost of producing goods relative to the rest of the world.

In order to reach this conclusion, we build into a multisector Ricardian model for trade policy analysis the role of trade in intermediate inputs, sectoral linkages and differing productivity levels across sectors[1]. The model can be used for both ex-ante and ex-post trade policy evaluation. Trade in intermediate inputs and sectoral linkages play an important role when considering tariff reductions, as a change in a tariff on any single sector will affect indirectly all the sectors in the economy.[2] For example, without trade in intermediates the simulated changes in imports over GDP from Mexico, Canada and the United States are 19.9%, 7.3% and 12.5% instead of the ones presented in Table 1. With trade in intermediates but without sectoral linkages these changes are 23.2%, 10.3% and 14.6%. Therefore, tariff reductions can generate substantial trade and welfare effects and that the source of these effects can differ across countries according to the importance of intermediate inputs in production.

Quantifying potential welfare gains and costs from trade policies has become increasingly important in recent years.[3] The number of regional trade agreements (RTAs) signed in the

[1] We combine the models of Eaton and Kortum (2002), Alvarez and Lucas (2008), Cecilia Fieller (2009), Dekle, Eaton and Kortum (2008); and the insights from Jones (2008) and Yi, Key-Miu (2003) to develop a new multisector Ricardian model of trade policy analysis.

[2] 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.

[3] Jacob Viner's (1950) work was the first to address the issue of welfare analysis of trade policy. Bhagwati, Krishna and Panagariya (1999) put together many of the major theoretical contributions since Viner's seminal

world has increased dramatically in the last 20 years (see Figure 1).[4] Also, as we observe in Figure 2, an increasing share of world trade is covered by RTAs.

Researchers have typically followed two approaches to quantifying the impact of policy changes. One approach has been the use of log-linear gravity regressions.[5] The test is performed by adding dummy variables representing the presence or absence of particular policies.[6]

Another approach has been to use applied general equilibrium models (CGE/AGE).[7] These are multi-sector general equilibrium models and can be employed to evaluate changes in trade policy ex-ante.[8] These models were used before NAFTA was active to evaluate the possible outcomes of the agreement (Brown, Deardorff and Stern 1994, Brown, Drusilla and Stern 1989, Kehoe and Kehoe 1994). Most of these models rely on the Armington (1969) "love for variety" and increasing returns to scale assumptions.[9] In general, these models tend to predict too-low gains from trade and have not been able to predict correctly the changes in trade patterns.[10] Kehoe (2003), Fox (1999) and Rolleigh (2008) compare the predictions

work.

[4] There are four types of regional trade agreements: preferential trade agreements (PTAs), free trade agreements (FTAs), custom unions (CUs) and regional economic integrations (REI). In a PTA, countries agree to have no restrictions to trade in a selected list of products. In an FTA, countries agree to have no restrictions to trade in substantially all traded goods. A CU is an FTA where the members apply a common external tariff to all non-members. An REI is a CU with a deeper economic integration that could include a common currency and free movement of factors and services. In 2009 there were 13 PTAs, 148 FTAs, and 9 CUs active in the world. An example of an FTA is NAFTA, of a CU is MERCOSUR (the Common Market of the South), and of an REI is the European Union.

[5] The gravity equation in trade relates the bilateral flow of goods between two countries according to their relative size and distance. Trade is related positively to the mass of countries (measured as GDP) and negatively to the distance between them. Tinbergen (1962) was the first to find this empirical regularity. Anderson (1979) and Bergstrand (1985) were the first to provide a theoretical foundation for the gravity model.

[6] Examples of studies employing this approach are Rose (2004), Subramanian and Wei (2007), Anderson and Wincoop (2004), and Redding and Venables (2004). Deardorff (1998) and Baier and Bergstrand (2009) present summaries of the literature on trade policy analysis under log-linear gravity regressions.

[7] Mansur and Whalley (1984) provide a review of the early literature on AGE models. More recently Kehoe and Prescott (1995) discuss the findings of several AGE studies. Examples of these models are the Michigan Brown-Deardorff-Stern model and the Purdue GTAP model (see Hertel 1997), Kehoe and Kehoe (1994), Harris (1984).

[8] Baldwin and Venables (1995) suggest that one of the main shortcomings of the AGE models is their complexity and lack of transparency, which do not allow researchers to understand what drives the results. They call them "black boxes."

[9] With the Armington "love for variety" assumption, goods are differentiated by country of origin. The assumption forces agents to always buy a positive amount of goods from all sources regardless of the price. With this assumption, the extensive margin is not adjusted when countries open to trade, only the intensive margin. Several new trade theories share the ability to capture changes on the extensive margin. Melitz (2003), Eaton, Kortum and Kramarz (2004), Ghironi and Melitz (2005), Chaney (2008), Arkolakis (2008), Helpman, Melitz and Rubinstein (2008), and Arkolakis, Klenow, Demidova and Rodriguez-Clare (2009) are notable examples. Dekle, Eaton and Kortum (2008) perform a policy trade experiment and determine how the extensive and the intensive margins of trade are affected after change in trade deficits.

[10] An exception is Kehoe, Polo and Sancho (1995). They develop an AGE model for the Spanish economy to understand the effects of a tax reform that Spain was undergoing before joining the EU. They show that their model is able to capture the change in relative prices and reallocation of resources that actually occurred.

of the CGE models with NAFTA.[11]

Other studies that have quantified the gains from trade for NAFTA are Trefler (2006), Romalis (2007), Ledermand, Maloney and Serven (2005), Shikher (2009), Krueger (1999) and the references therein. Trefler (2006) presents evidence that the Canada-United States Free Trade Agreement generated long-run aggregate welfare gains for its members.[12]

In Section 3, we develop a methodology to evaluate the trade and welfare effects of trade policies and present the key equilibrium conditions needed in order to perform any kind of policy experiment. In Section 4, we estimate the parameters of the model and show explicitly how simple it is to calibrate the model .[13] With our model, we are able to quantify and decompose the effects that a reduction or increase in a tariff in a particular sector can have over the price of intermediate inputs in that particular sector and in the rest of the economy, the general equilibrium price effects of tariff reductions at home and abroad, the impact over 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 a cheaper and more efficient technology. In Section 5 we apply the model to evaluate the trade and welfare effects of NAFTA and in Section 6 we conclude.

2 Trade Effects of NAFTA: Towards a Quantitative Model

In this section we motivate the importance of modeling trade in intermediates from different sectors and sectoral linkages for trade policy analysis. This is not only empirically relevant, but also helps to understand the trade and welfare effects of specific trade policies, like tariffs.[14] Differential trade policies affect the pattern of comparative advantage across industries and can only be captured in a model that explicitly takes into account the impact of these policies in each sector.

We first look at how tariff rates and changes in trade flows vary substantially across sectors (see Figures 3 through 6). In 1993, the year before NAFTA went into effect, sectoral tariff

[11]Concretely, these studies test the predictions of the Brown-Deardorff-Stern NAFTA model. They find that the model is not able to capture absolute aggregate changes and relative magnitudes of sectoral changes in trade flows. Also, the model does not predict large welfare gains for the member countries from signing such an agreement.

[12]The Canada-United States Free Trade Agreement (CUSFTA) became in force in 1989, before NAFTA. It became inactive in 1994 when NAFTA went into effect. Trefler (2006) studies the effect of CUSFTA together with the effect of NAFTA, focusing on Canada and the United States.

[13]We will show later that all the equilibrium variables can be solved as a function of factor prices. Therefore we are able to reduce the system of equilibrium equations and end up with one equation and one unknown per country.

[14]See section 4 for more details on the importance of multi-sector intermediate goods and input-output interrelations for welfare evaluations.

rates applied by Mexico, Canada and the United States were, on average, 12.6%, 4.2%, and 3.0% and ranged from 2.6% to 18.0%, 0% to 19.1%, and 0% to 12.3%, respectively.[15] By the year 2005 they dropped almost to zero between NAFTA members, but the tariffs that Mexico, Canada and the United States applied to the rest of the world were 7.8%, 2.1%, and 2.0% and ranged from 0.1% to 19.6%, 0% to 12.0%, and 0% to 10.2%, respectively.[16] The fact to take away is that by 2005 average tariffs had decreased considerably, 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.

Focusing on aggregate changes in trade flows, from 1993 to 2005, total exports over GDP increased by 123%, 35%, and 27%, while total imports over GDP increased by 68%, 20%, and 58% for Mexico, Canada and the United States, respectively. During the same period, changes in total exports and imports varied considerably across sectors. Larger sectors (measured according to the share of trade of a sector relative to total trade) were not necessarily the ones with fastest growth rates. For example, in the case of Mexico, the wood and plastic sectors (both with a 1% share of total exports in 1993) presented changes in exports of 7.5% and 524%, respectively.[17] In the United States, while the largest sector (auto) grew by 148%, two equally smaller sectors (minerals and textiles) presented changes of 462% and 127%, respectively. In general, the correlation between growth in exports and size of sector for the period 1993-2005 was -0.17, -0.17, and 0.18 for Mexico, Canada and the United States, respectively. With regard to imports, these correlations were -0.24, -0.25, and -0.14, respectively. These figures suggest that trade does not grow evenly across industries.[18] There is also evidence that sectors

[15] Tariff measures are weighted by imports. There are substantial problems when weighting tariffs. For a thorough discussion, see Anderson and Neary (2005). Weighting by imports leads to the import volume equivalent or the Mercantilist uniform tariff as defined by Anderson and Neary (2003). Alternatively, Leamer (1974, 1988) discusses using free trade equivalent weights. The data used for the calculations is described in the data appendix at the end of the document.

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

[17] The name of the sectors is presented at the end of the document in Table 1.

[18] One possible explanation could be adjustment in both the intensive and the extensive margins. Kehoe and Kehoe (1994) and Kehoe (2003) highlight the importance of changes in the extensive margin after trade liberalization episodes. Hummels and Klenow (2005), using disaggregated trade data, find that the extensive margin accounts for two thirds of the new goods exported and one third of the new goods imported from large economies. Kehoe and Ruhl (2003) suggest a new methodology to measure the new goods margin and study how the extensive margin changes after countries undergo periods of trade liberalization. They find that the set of least traded goods increased from 10% to 30% of total trade after the reduction of trade barriers. They also document that small tariff reductions can have large impacts on the extensive margin.

that had larger reductions in tariffs were not necessarily those with the largest increase in trade.

We capture this in our model by using an input-output structure of the economy, allowing sector-specific trade cost elasticities and introducing trade in intermediates. These elements are not a new insight by us—researchers have already recognized their empirical relevance[19]. We incorporate all these features in a simple unified framework and develop a quantitative model for trade policy analysis with a realistic representation of the structure of production of the economy.

For example, tradable and non-tradable sectors are interrelated.[20] Figure 7 is a contour plot of the I-O table for a construct rest of the world with 20 countries.[21] [22] 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. In Figure 7, a salient characteristic is that the I-O matrix presents a strong diagonal.[23] However, shares are far from 1. For example, in the case of Figure 7, the mean diagonal share is 27% and has a standard deviation of 11%. This means that industries purchase mostly intermediate inputs from other industries. If we focus only on the tradable goods, the mean share of the diagonal elements is 32%. (See Figure 8.) Without taking into account the purchases from the same sector (without the diagonal), the average share of intermediates that tradables purchase from the tradable sectors is 41%. This figure is slightly higher than the share of intermediates that they purchase from the non-tradable sectors, 22%. See Figure 9. On the other hand, the mean share of the diagonal elements of the non-tradables is 22%. The average share of intermediates that these sectors purchase from the tradable sectors is 25%, while the share of intermediates that they purchase from the non-tradable sectors is 59%. This casual inspection of the I-O table shows that sectors are strongly interrelated and that non-tradable sectors are an important input in the production of tradables. It is also worth nothing that households consume mostly services (what we label as non-tradables). Therefore, not taking into account the effects of price changes of tradables over non-tradables could produce misleading implications of policies

[19] For instance Jones (2009) and Yi, Key-Miu (2003).

[20] When we refer to tradable sectors, we mean merchandise tradable sectors. For the type of analysis that we are conducting there is no data available on bilateral trade in services; therefore, we will treat services as non-tradable sectors in this paper.

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

[22] The idea of presenting the I-O table in this way was borrowed from Jones (2007).

[23] 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).

for welfare. We show this more formally below.

3 A Model of Intermediate Goods for Trade Policy Analysis

3.1 Environment

We develop a static model with N countries. Each country is endowed with only one factor of production L_n for all $n \in N$, which we call labor.[24] In each country there are J sectors of production. Sectors are of two types, either tradable or non-tradable. Households have Cobb-Douglas preferences with shares α_n^j over final goods C_n^j produced in all sectors $j \in J$, tradable and non-tradable. We assume that $\sum_{j=1}^{J} \alpha_n^j = 1$.

3.2 Technology

Within each sector $j \in J$, a continuum of intermediate goods are produced. Each intermediate good is produced using labor and intermediate goods from all sectors according to the input-output structure of the economy. In particular, we assume that in each sector a "composite intermediate good aggregate" is produced using only intermediate goods from that particular sector. This composite intermediate aggregate is then used for two purposes: to produce intermediate goods in all sectors and to produce a sector-specific final good. We assume that there is no value added in the production of final goods; therefore, a unit of final good is produced with a unit of composite intermediate aggregate. Labor is not mobile across countries but it can be costlessly allocated across sectors, therefore $\sum_{j=1}^{J} L_n^j = L_n$ for all $n \in N$.

Ricardian motives to trade are introduced by assuming that countries have different access to technology such that the efficiency of production of intermediate goods differs across sectors and countries. Following Eaton and Kortum (2002), each intermediate good in sector j and country n is produced with an efficiency level x_n^j. As in Alvarez and Lucas (2007), x_n^j represents a "cost draw" or the inverse of the total factor productivity level that comes from an exponential distribution with parameter λ_n^j ($x_n^j \sim \exp(\lambda_n^j)$). We assume that draws are independent across goods, sectors and countries[25]. The parameter $\lambda_n^j \geqslant 0$ governs the location

[24] This is the primary input (non-produced) in each country. We refer to it as labor; however, it can be thought of as equipped labor as in Alvarez and Lucas (2007). For instance L_i can be a function of capital, land, labor and other factors, resources, used in production ($L_i = f(K_i; T_i; labor_i)$). We will not model this explicitly in this model and will refer to L_i as labor, however it is important to bear in mind that it captures more than only employment of labor factors (value added) and that its factor payment is not only wages.

[25] Eaton and Kortum (2002) work with efficiencies instead of costs. They assume that efficiencies are drawn from a Fréchet distribution. For a description of the properties of the Fréchet distribution refer to Eaton and Kortum (2002). Donaldson (2009) relates this assumption to other standard assumptions used in models of

of the distribution. In the context of this model, a higher λ_n^j (which we allow to be sector and country specific) makes lower cost draws more likely, a notion of absolute advantage.

Therefore, we denote $q_n^j(x_n^j)$ the quantity of an intermediate good q in sector j, country n, produced with an efficiency level x_n^j. The production function of $q_n^j(x_n^j)$ is given by:

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

The production function of each intermediate good only differs because of its efficiency level. Therefore, from now on we will call simply good x_n^j the intermediate good produced with efficiency level x_n^j. $q_{mn}^k(x_n^j)$ is the quantity of the composite intermediate good from sector k used to produced good x_n^j. $\gamma_n^{k,j} \geqslant 0$ is the share of sector k goods used in the production of intermediate good x_n^j, and the parameter $\beta_n^j \geqslant 0$ is the share of value added. We also have that $\sum_k^J \gamma_n^{k,j} = 1$. Notice that this production function reflects the input-output structure of the economy. In particular, $\gamma_n^{k,j}$ are the shares from the input-output tables as we described before. We also allow the share parameters to differ across countries to capture the heretogeneity in the input-output structure of different countries observed in the data[26]. It is important to note that when $\beta_n^j = 1$ the model colapses to a multi sector version of the Eaton and Kortum (2002) model as in Donaldson (2009) with non-tradable sectors.

Costs draws are amplified by the parameter θ^j; thus, a larger value of θ^j implies larger dispersion of costs across intermediate goods. Therefore, we will refer to θ^j as the dispersion of productivity, a notion of comparative advantage[27]. Different from Eaton and Kortum (2002), Alvarez and Lucas (2007) and Dekle, Eaton and Kortum (2008), we allow θ^j to be sector specific. We would expect that θ^j is lower in more homogenous sectors and higher in more heterogenous sectors. With heterogeneity in the dispersion of productivity across sectors, homogeneous tariff changes have a differential impact across sectors. For example, sectors with higher θ^j are less sensitive to a change in tariffs than sectors with lower θ^j. The intuition is that goods are less substitutes from the point of view of producers. Our estimations in section 4.1 confirm that the dispersion of productivity is heterogenous across sectors, and that is lower in more homogeneous sectors.

It is also important to note that we are assuming the same structure of production for tradable and non-tradable goods. Note that tradables and non-tradable goods enter as inputs in the production of non-tradables. This is different compared to Eaton and Kortum (2002)

international trade with heterogeneous firms, like those in Melitz (2003), Chaney (2008), and others. Costinot and Komunjer (2008) consider the case of more general distributions.

[26] For instance, see Jones (2007).

[27] We are following the notation in Alvarez and Lucas (2007). Eaton and Kortum use $1/\theta$ instead. In their case, θ is inversely related to the dispersion of the Fréchet distribution.

and Alvarez and Lucas (2007). In our model, a change in a tariff will also impact non-tradable goods sectors via the interrelation that they have with the tradable goods. We will show later that this interrelation plays an important role in order to evaluate welfare.

The production of the composite intermediate good form sector j and country n is[28]:

$$q_n^j = \left[\int q_n^j (x^j)^{1-1/\eta^j} \phi^j \left(x^j\right) dx^j \right]^{\eta^j / \left(\eta^j - 1\right)} \tag{2}$$

where the relevant density $\phi^j \left(x^j\right)$ is $\lambda_n^j \exp \left\{ -\lambda_n^j x_n^j \right\}$ for the case of non-tradable sectors and $(\prod_{n=1}^N \lambda_n^j) \exp \left\{ -\sum_{n=1}^N \lambda_n^j x_n^j \right\}$ for tradable goods.

The resource constraints in each country n are:

$$\sum_j \int_0^\infty l_n^j (x_n^j) \phi^j \left(x_n^j\right) dx_n^j = L_n, \text{ for all } n \in N \tag{3}$$

$$C_n^j + \sum_k \int_0^\infty q_{mn}^j (x_n^k) \phi^j \left(x_n^j\right) dx_n^j = q_n^j, \text{ for all } j \in J \text{ and } n \in N \tag{4}$$

The first equation is the labor market clearing condition, total labor demand by firms is equal to total labor supply; and the second equation is the goods market clearing condition, total goods demanded by household plus the demand of goods by firms is equal to the total supply of goods.

3.3 Prices and trade costs

We denote by $p_n^j(x^j)$ the effective price paid for intermediate good x^j in country n and by p_n^j to the price of a unit of the composite intermediate aggregate. Then:

$$p_n^j = \left[\int p_n^j (x^j)^{1-\eta^j} \phi^j \left(x^j\right) dx^j \right]^{\frac{1}{1-\eta^j}} \tag{5}$$

Since we assume all production is at constant returns to scale and that all markets are perfectly competitive, then firms price at unit cost.

Therefore, the price of non-tradable intermediate goods in country n is given by $p_n^j(x_n^j) = B_n^j [x_n^j]^{\theta^j} c_n^j$ where $B_n^j = \prod_{k=1}^J [\gamma_n^{k,j}]^{-\gamma_n^{k,j} \left(1-\beta_n^j\right)} \big/ \beta_n^{j\,\beta_n^j} \left(1 - \beta_n^j\right)^{\left(1-\beta_n^j\right)}$ is a constant. c_n^j can be defined as the cost of a bundle of inputs used for the production of intermediate goods in

[28] Note that this is Ethier's (1982) production function. It is also known as the Dixit and Stiglitz (1977) aggregator. Refer to Alvarez and Lucas (2007) for further details on the role of the intermediate good aggregator.

sector j and country n. The input bundle is given by

$$c_n^j = {w_n}^{\beta_n^j} \underbrace{\left(\prod_{k=1}^{J} \left(p_n^k\right)^{\gamma_n^{k,j}}\right)}_{\textbf{inputs from all sectors}}^{\left(1-\beta_n^j\right)} \tag{6}$$

As we can see, the cost of this input bundle is identical within a sector[29]. However, it varies across sectors since we allow them to have different input shares. The key difference with the one-sector model or the multi-sector model without sectors being interrelated is equation (6). As we can see, the price of this input bundle depends on the price of all the composite intermediate goods in the economy, tradable and non tradable. This is the sense in which a change in policy that affects the price in any single sector will affect indirectly all the sectors in the economy.

Trade is at a cost. We consider two types of costs, those that entail a physical loss of resources (iceberg) and costs that impact relative prices of goods (tariffs). The former are defined in physical units, "icebergs" costs. 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 $d_{nn} = 1$. We also assume that the triangular inequality holds; therefore, $d_{nh}^j d_{hi}^j \geqslant d_{ni}^j$ for all n, h, i. Intermediate goods imported to country n from country i have to pay an ad valorem flat-rate tariff τ_{ni}^j applicable over unit prices. Proceeds are lump-sum transferred to the consumers in n. We combine both costs and represent them by $\kappa_{ni}^j = (1+\tau_{ni}^j)d_{ni}^j$. Taking into account these costs, intermediate tradable goods $x^j = (x_1^j, ..., x_N^j)$ are available in country n from any location i at unit prices $B_i^j c_i^j [x_i^j]^{\theta^j} \kappa_{ni}^j$.

All producers in each tradable sector j and country n buy from the same lowest-cost supplier since they face the same price; however, the lowest-cost supplier can vary from country by country because of trade costs,[30]:

$$p_n^j\left(x^j\right) = \min_i \left\{p_i^j(x_i^j)\right\} \tag{7}$$

[29] The idea of having input bundles cost the same for each tradable good in each country goes back to Ricardo. Eaton and Kortum (2002) make the same assumption for the case of one sector. For the case of multi-sectors and one country, Donaldson (2009) makes the same assumption.

[30] 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 policy changes. 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 model. See footnote 19 in Eaton and Kortum (2002) and the study by Anderson and Wincoop (2004) for a dicussion.

Given the assumptions over the distribution of costs (x_i^j) we can solve for the distribution of prices.[31] After solving for the distribution of prices, the price index of the composite intermediate aggregate tradable sectors is given by:

$$p_n^j = A_n^j \left[\sum\nolimits_i \left[B_i^j \kappa_{ni}^j c_i^j \right]^{-1/\theta^j} \lambda_i^j \right]^{-\theta^j} \tag{8}$$

for all tradable goods j and countries $n \in N$. Where $A_n^j = \left[\int_0^\infty e^{-z_n^j} \left[z_n^j \right]^{\theta^j \left(1-\eta^j\right)} dz^j \right]^{\frac{1}{1-\eta^j}}$, $z_n^j = \mu_n^j x^j$, $\mu_n^j = \sum\limits_i \left[B_n^j \right]^{-1/\theta^j} \psi_{ni}^j$ and $\psi_{ni}^j = \left[\kappa_{ni}^j c_i^j \right]^{-1/\theta_j} \lambda_i^j$.

The price index of non-tradable composite aggregate in any non-tradable sector is given by:

$$p_n^j = A_n^j B_n^j (\lambda_n^j)^{-\theta^j} c_n^j \tag{9}$$

If λ_n^j is fixed, as we will assume in this paper, θ^j plays no role in the non-tradable goods sector.[32]

Note that given a vector of wages $w = (w_1, ..., w_N)$, (8) and (9) are JxN equations in JxN unknowns. This is important in order to solve for the equilibrium prices.

3.4 Gravity equation and trade balance

Let π_{ni}^j be the expenditure share (measure) of sector j goods that country n purchases from country i. Therefore $\pi_{ni}^j = \Pr \left[p_i^j \left(x^j \right) \leq \min_{k \neq i} p_k^j \left(x^j \right) \right]$. In our model, the expression is given by:

$$\pi_{ni}^j = \left(A_n^j B_i^j \right)^{-1/\theta^j} \left(\frac{c_i^j}{p_n^j} \kappa_{ni}^j \right)^{-1/\theta^j} \lambda_i^j, \tag{10}$$

where $j = 1, ..., J$ and $i = 1, ..., N$. Note that in non-tradable sectors, $\pi_{ii}^j = 1$. The bilateral trade share π_{ni}^j takes the form of a multi-sector version of a gravity equation. Changes in tariffs have a direct effect in trade shares through κ_{ni}^j and an indirect effect through the input bundle c_i^j since it incorporates all the information contained in the input-output tables.

[31] The distribution of prices and how to compute the price of the composite intermediate aggregate are explained in great detail in Eaton and Kortum (2002) and Alvarez and Lucas (2007). These results hold for the multi-sector good as presented in Donaldson (2009). Therefore, we refer the interested reader to these papers.

[32] The reason why we model it in this way is to allow for the alternative that λ_n^j might change. For instance, one could introduce technological spillover where the level of Total Factor of Productivity from the non-tradable goods sector might be a function of the technology of tradable goods imported for the production of non tradables from countries with frontier technology, as in Rodríguez-Clare (2007). One can think about how these spillovers might be affected by changes in trade policies. This is an extension that can be incorporated in this model and that we leave to explore in a different paper.

We allow trade to be unbalanced as in Dekle, Eaton and Kortum (2008). Sector-by-sector trade does not have to be balanced, nor country-by-country; however, it will be balanced in the world. Define S_n as the trade surplus of country n. Therefore:

$$\underbrace{\sum_j \sum_i \frac{\pi_{ni}^j}{(1+\tau_{ni}^j)} X_n^j}_{\text{Imports}} + S_n = \underbrace{\sum_j \sum_i \frac{\pi_{in}^j}{(1+\tau_{in}^j)} X_i^j}_{\text{Exports}} \tag{11}$$

where X_n^j is total expenditure on composite intermediate goods j in country n. We also have that $S_n = \sum_k^J S_n^k$, and $\sum_n S_n = 0$. This condition reflects that the effective total expenditure (excluding tariff payments) in country n plus net exports has to be equal to the sum of each country's effective total expenditure on tradable goods from n. We are adding over all the sectors, regardless of whether a sector is a tradable or a non-tradable sector. The non-tradable sectors will appear in both sides of the equation and cancel out.

3.5 Total expenditure and sectoral deficits

Although the aggregate deficit in each country is exogenous in our model, sectoral deficits are endogenously determined. This represents a departure from other Ricardian quantitative models in the literature. Eaton and Kortum (2002) and Alvarez and Lucas (2007) develop a one sector model where trade is balanced, and Dekle, Eaton and Kortum (2008) present a two sector model where sectoral deficit are exogenous. The endogeneity of sectoral deficit is important because it allows to completely endogenize total expenditure in each sector and each country. In the rest of this subsection, we explain how to solve for total expenditure in each country and sector when sectoral deficit are endogenously determined.

Total expenditure in sector j and country n is given by:

$$X_n^j = \sum_k^J \gamma_n^{j,k}(1-\beta_n^k)\left(\sum_i \frac{\pi_{ni}^j}{(1+\tau_{ni}^j)} X_n^k + S_n^k\right) + \alpha_n^j I_n \tag{12}$$

where I_n represents final absorption in country n, with $I_n = w_n L_n + \sum_k^J X_n^k[1 - \sum_i \frac{\pi_{ni}^j}{(1+\tau_{ni}^j)}]$ - S_n. Total final absorption is the sum of labor income ($w_n L_n$), tariff revenues ($\sum_k^J X_n^k[1 - \sum_i \frac{\pi_{ni}^j}{(1+\tau_{ni}^j)}]$) and the aggregate deficit ($-S_n$)[33]. The term $\sum_i \frac{\pi_{ni}^j}{(1+\tau_{ni}^j)} X_n^k + S_n^k$ is gross production in sector k. Therefore, total expenditure on goods j, by a simple accounting identity is equal to the expenditure on composite intermediates by all intermediate good firms plus the expenditure by households.

[33] As explained above, we are assuming that revenues are lump-sum transfered to the agents.

Trade surplus in sector k and country n, S_n^k, by definition is given by:

$$S_n^k = \left(\sum\nolimits_i \frac{\pi_{in}^j}{(1+\tau_{in}^j)} X_i^k - \sum\nolimits_i \frac{\pi_{ni}^j}{(1+\tau_{ni}^j)} X_n^k \right) \tag{13}$$

Plugging (13) into (12) we get

$$X_n^j = \sum\nolimits_k^J \gamma_n^{j,k} (1-\beta_n^k) \left(\sum\nolimits_i \frac{\pi_{in}^j}{(1+\tau_{in}^j)} X_i^k \right) + \alpha_n^j I_n \tag{14}$$

Note that this is a system of $J \times N$ equations. Given a vector of wages w_n, we could solve for X_n^j as a function of w_n and primitives.

It is convinient to write the system of equations in matrix form in the following way:

$$\mathbf{\Omega X} = \mathbf{\Delta} \tag{15}$$

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

$$\mathbf{X} = \begin{pmatrix} X_1^1 \\ \vdots \\ X_1^J \\ \vdots \\ X_n^1 \\ \vdots \\ X_N^J \end{pmatrix}; \quad \mathbf{\Delta} = \begin{pmatrix} \alpha_1^1 (w_1 L_1 - S_1) \\ \vdots \\ \alpha_1^J (w_1 L_1 - S_1) \\ \vdots \\ \alpha_N^1 (w_N L_N - S_N) \\ \vdots \\ \alpha_N^J (w_N L_N - S_N) \end{pmatrix} \tag{16}$$

$\mathbf{\Omega}$ is a matrix JNxJN that depends on the technology parameters β_n^j and $\gamma_n^{j,k}$, the shares of each sector and country in final demand α_n^j, tariffs τ_{ni}^j, and bilateral trade shares π_{ni}^j . The $\mathbf{\Omega}$ matrix is construted by adding three matrices, $\mathbf{\Omega} = I - F - \tilde{B}$.

The matrix I is the identity matrix. The matrix F is

$$F = \begin{pmatrix} A_1 \otimes \tilde{F}_1 & 0_{J\times J} & \cdots & 0_{J\times J} & 0_{J\times J} \\ 0_{J\times J} & A_1 \otimes \tilde{F}_2 & \cdots & \vdots & \vdots \\ 0_{J\times J} & 0_{J\times J} & \ddots & 0_{J\times J} & 0_{J\times J} \\ \vdots & \vdots & \cdots & A_{N-1} \otimes \tilde{F}_{N-1} & 0_{J\times J} \\ 0_{J\times J} & 0_{J\times J} & \cdots & 0_{J\times J} & A_N \otimes \tilde{F}_N \end{pmatrix}$$

where

$$A_n = \begin{pmatrix} \alpha_n^1 \\ \vdots \\ \alpha_n^J \end{pmatrix}, \tilde{F}_n = \begin{pmatrix} (1 - F_n^1) & \cdots & (1 - F_n^J) \end{pmatrix}$$

where $F_n^j = \sum_i \frac{\pi_{ni}^j}{(1+\tau_{ni}^j)}$. The matrix $\tilde{B}$ is given by:

$$\tilde{B} = \begin{pmatrix} \gamma_1^{1,1}(1-\beta_1^1)\tilde{\pi}_{1,1}^1 & \cdots & \gamma_1^{1,J}(1-\beta_1^J)\tilde{\pi}_{1,1}^J & \cdots & \gamma_1^{1,1}(1-\beta_1^1)\tilde{\pi}_{N,1}^1 & \cdots & \gamma_1^{1,J}(1-\beta_1^1)\tilde{\pi}_{N,1}^1 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ \gamma_1^{J,1}(1-\beta_1^1)\tilde{\pi}_{1,1}^1 & \cdots & \gamma_1^{J,J}(1-\beta_1^J)\tilde{\pi}_{1,1}^J & \cdots & \gamma_1^{J,1}(1-\beta_1^1)\tilde{\pi}_{N,1}^1 & \cdots & \gamma_1^{J,J}(1-\beta_1^J)\tilde{\pi}_{N,1}^J \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ \gamma_N^{1,1}(1-\beta_N^1)\tilde{\pi}_{1,N}^1 & \cdots & \gamma_N^{1,J}(1-\beta_N^J)\tilde{\pi}_{1,N}^J & \cdots & \gamma_N^{1,1}(1-\beta_N^1)\tilde{\pi}_{N,N}^1 & \cdots & \gamma_N^{1,J}(1-\beta_N^1)\tilde{\pi}_{N,N}^1 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ \gamma_N^{J,1}(1-\beta_N^1)\tilde{\pi}_{1,N}^1 & \cdots & \gamma_N^{J,J}(1-\beta_N^J)\tilde{\pi}_{1,N}^J & \cdots & \gamma_N^{J,1}(1-\beta_N^1)\tilde{\pi}_{N,N}^1 & \cdots & \gamma_N^{J,J}(1-\beta_N^J)\tilde{\pi}_{N,N}^J \end{pmatrix}$$

The matrix $\mathbf{\Omega}$ captures how changes in tariffs from one sector and one country impacts the expenditure in all other sectors of the economy and the world. This is the key general equilibirum effect difference compared to a one-sector model and a multi-sector model without interrelations. For example, in the special case in which $\gamma^{j,j} = 1$ there are no tariffs and trade is balanced, expenditures in each country can be solved independently of the expenditures from other countries. We can solve for a diagonal matrix $\mathbf{\Omega}$ without sectoral linkages country by country as in Donaldson (2009). For the case in which there is only one sector, $\mathbf{\Omega}$ is 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), $\mathbf{\Omega}$ only depends on the technology and preference parameters.

Inverting $\mathbf{\Omega}$ we can solve for the vector $\mathbf{X}$.

$$\mathbf{\Omega X} = \mathbf{A} \cdot (\mathbf{w} - \mathbf{S}) \tag{17}$$

Let us denote by $X_n^j(\mathbf{w})$ the entry j of the vector $\mathbf{X}$ (the expenditure in sector j and country n). In this way, we have solved for total expenditure of each sector as a function of parameters, tariffs, bilateral trade shares, aggregate deficit and wages. This expression is crucial in order to solve for the equilibrium since it will allow us to express all the equilibrium conditions as a function of one vector of unknowns ($\mathbf{w}$), the vector of factor prices, w_n. We can re-express market clearing as

$$\sum_j \sum_i \frac{\pi_{ni}^j}{(1+\tau_{ni}^j)} X_n^j(\mathbf{w}) + S_n = \sum_j \sum_i \frac{\pi_{in}^j}{(1+\tau_{in}^j)} X_i^j(\mathbf{w}) \tag{18}$$

3.6 Equilibrium

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

Definition: Given L_n and S_n, an *equilibrium* under tariff structure τ is a wage vector $\mathbf{w} \in \mathbb{R}_{++}^N$ and prices p_n^j that solve equilibrium conditions (6), (8), (9), (10) and (18) for all J and N.

In order to solve for this equilibrium we need estimates on λ_n^j and d_{ni}^j, both difficult to estimate in the data. Recall that λ_n^j is a country and sector-specific measure of total factor productivity, while d_{ni}^j are trade costs (in physical units). We are not going to construct this equilibrium we are going to do something else. Instead of solving for an equilibrium under policy τ we will solve for changes in prices and wages from moving from policy τ to policy τ'. There are two advantages of doing so: first, by assuming that λ_n^j and d_{ni}^j remain constant from one equilibrium to the other we will not need to rely on estimates of these parameters; and second, this will allow us to identify the effect on changes in equilibrium prices from a pure change in tariffs, which is what we are after[34].

We now define an the equilibrium of the model in relative terms, relative to a policy under tariff structure τ:

Proposition: Let (w, p, π, c, X) be an *equilibrium* under tariff structure τ and let (w', p', π', c', X') be an equilibrium under tariff structure τ'. Define $\left(\hat{w}, \hat{p}, \hat{\pi}, \hat{c}, \hat{X}\right)$ as an equilibrium under τ' relative to τ[35]. Then using (8), (9), (10) and (18) the equilibrium conditions in relative changes solves:

Change in the cost of the input bundles:

$$\hat{c}_n^j(\hat{\mathbf{w}}) = \hat{w}_n^{\beta_n^j} \left(\prod_{k=1}^J \hat{p}_n^k(\hat{\mathbf{w}})^{\gamma_n^{k,j}}\right)^{\left(1-\beta_n^j\right)} \tag{19}$$

Change in the price index of tradables:

$$\hat{p}_n^j(\hat{\mathbf{w}}) = \left(\sum_i \pi_{ni}^j \left(\hat{\kappa}_{ni}^j \hat{c}_i^j(\hat{\mathbf{w}})\right)^{-1/\theta^j}\right)^{-\theta^j} \tag{20}$$

[34] Note that we can also evaluate the impact of an exogenous change in deficits. Dekle, Eaton and Kortum (2008) describe how to construct the equilibrium in relative changes in order to do so.

[35] $\widehat{x}$ represents the relative change of the variable x (x'/x).

Change in the price index of non tradables:

$$\hat{p}_n^j(\hat{\mathbf{w}}) = \hat{c}_n^j(\hat{\mathbf{w}}) \tag{21}$$

Changes in bilateral trade shares:

$$\hat{\pi}_{ni}^j(\hat{\mathbf{w}}) = \left(\frac{\hat{c}_i^j(\hat{\mathbf{w}})}{\hat{p}_n^j(\hat{\mathbf{w}})}\hat{\kappa}_{ni}^j\right)^{-1/\theta^j} \tag{22}$$

Change in trade balance:

$$\sum\nolimits_j \sum\nolimits_i \frac{\pi_{ni}^{j\prime}}{(1+\tau_{ni}^{j\prime})} X_n^{j\prime}(\mathbf{w}) + S_n = \sum\nolimits_j \sum\nolimits_i \frac{\pi_{in}^{j\prime}}{(1+\tau_{in}^{j\prime})} X_i^{j\prime}(\mathbf{w}) \tag{23}$$

for all J and N where $\hat{\kappa}_{ni}^j = (1+\tau_{ni}^{j\prime})/(1+\tau_{ni}^j)$.

From inspecting equilibrium conditions (19 through 23) 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.[36] 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), the share of intermediate consumption ($\gamma_n^{k,j}$), and sectoral dispersion of productivity (θ^j). Therefore, the only parameter to estimate is the sectoral dispersion of productivity θ^j; all the rest are easily available in national account and trade data. We will show in the next section how to calibrate the model and estimate the dispersion of productivity (θ^j) in order to perform policy experiments.

Finally, it is important to note that we can reduce the system of equilibrium conditions to N equations, one per country, with N unknowns, w_n. This can be done by substituting (19 through 22) into (23).

After solving for the variables we can evaluate how welfare changed from moving from tariff structure τ to tariff structure τ' in each country. This is measured as the change in real income:

$$\widehat{W_n} = \frac{\widehat{I_n}}{(\prod_j^J \hat{p}_n^j)^{\alpha_n^j}} \tag{24}$$

We now proceed to build some intuition of why adding more sectors and the interrelation across them is important for welfare comparisons.

[36] The aggregate trade deficit could change as a consequence of the change in policy. We are not modeling this and this is the reason why we fixed S_n. However, we can also change the value of total net exports in each country and solve for a relative equilibrium under policy τ' and S_n'. In the Technical Appendix we show how to derive the equilibrium conditions (19) to (23) from (8), (9), (10) and (18).

3.7 What Are the Sources of Gains From Tariff Reductions?

Let us assume that trade is balanced and that the only source of trade costs are iceberg costs (d^j_{in} according to our notation above). With these assumptions, the relative changes in real income are equal to changes in real wages:[37]

$$\widehat{W_n} = \frac{\widehat{w_n}}{(\prod_j^J \hat{p}^j_n)^{\alpha^j_n}}$$

From equation (10) we can solve for w_n/p^j_n in each sector j as a function of the share of expenditure on domestic j goods. Then, the percentage change in real income is given by:

$$\begin{aligned}\widehat{w_n} \quad = \quad & \Phi_n - \underbrace{\sum\nolimits_j^J \alpha^j_n \theta^j \log \hat{\pi}^j_{nn}}_{\text{Trade in final goods}} - \underbrace{\sum\nolimits_j^J \alpha^j_n \theta^j \widetilde{\beta}^j_n \log \hat{\pi}^j_{nn}}_{\text{Trade in intermediate goods}} + \\ & - \underbrace{\sum\nolimits_j^J \alpha^j_n \widetilde{\beta}^j_n \sum\nolimits_k^J \gamma^{k,j}_n \log \hat{p}^k_n}_{\text{Sectoral Interrelations}} + \underbrace{\sum\nolimits_j^J \alpha^j_n \widetilde{\beta}^j_n \log \hat{p}^j_n}_{\text{Price effect}}\end{aligned}$$

with $\widetilde{\beta}^j_n = \frac{(1-\beta^j_n)}{\beta^j_n}$. If we allow changes in technology $\Phi = \sum_j^J \frac{\alpha^j_n}{\beta^j_n/\theta^j} \log\left(\hat{\lambda}^j_n\right)$, otherwise $\Phi_n = 0$.

Where are the gains from trade coming from? This result shows that there are five sources of welfare gains in our model. The first source is improvements in sectoral TFP (Φ_n). This effect is amplified in a multi sector model with intermediates, and this is captured by β^j_n[38]. Note that the way in which sectors are interrelated does not play any role in the way sectoral TFP affects welfare. The second and third terms reflect the gains from openness ($\hat{\pi}^j_{nn}$). Moreover, the gains from openness come from two different sources. First, there are gains from trade in final goods. As the economies become open ($\hat{\pi}^j_{nn} > 1$) households have access to cheaper final goods from abroad which increase real income. The magnitude of the change in welfare depends on the trade cost elasticity and the share of each sector in final demand. Second, there are also gains from trade in intermediate goods. Openness allows country to have access to cheaper intermediate goods, thus they will start substituting high-cost domestic goods for low-cost foreign goods. These gains depend on the share of intermediate goods used to produce in each sector $(1 - \beta^j_n)$. When $\beta^j_n = 1$, sector j goods are only produced with labor, thus there are no gains from trade in intermediate goods. The

[37] Note that by setting $\tau^j_{nm} = 0$ then $F^k_i = 1$; and by setting $S^i = 0$, the income of the household is only labor income: $w_i L_i$.

[38] This is related to the input-output multiplier idea of Jones (2007). In his model, a positive technological shock can have magnifying effects according to how connected the sectors of production are.

interrelation across sectors affects indirectly the changes in $\hat{\pi}_{nn}^{j}$ through its effect on the cost of the input bundles at different sectors (see (10) and (6)). The fourth term shows an extra channel through which the interrelation affects welfare, the one we call sectoral interrelations. It states that real wages will depend on the change in the price of the intermediate goods from all sectors used in production. Note that this term also includes price changes of non-tradable goods. If we do not allow tradable intermediates to enter into the production of non-tradables, then the sectoral interrelation will not change for all j non-tradables. As we showed before, by inspecting the I-O tables, tradables are particularly important for the production of non-tradables, and viceversa. Note that if we set $\beta_n^j = 1$ the model collapses to a multi-sector model with no interrelation, like Donaldson's (2009). Also, note that the term sectoral interrelation will not be present if we set $\gamma_n^{j,j} = 1$, and it will collapse to a model in which sectors are not interrelated and they use only intermediates from their own sector. As we showed before, $\gamma_n^{j,j}$ is far from 1 in the data, and the share of value added in production, β_n^j, is far from 1 in the data[39]. Finally, the last term shows a price effect. The best way to understand this effect is by looking at the price equation (8) for the tradable sectors and (9) non-tradable sectors. In the case of tradable sectors, p_n^j represents the world's price of sector j goods faced by consumers in country n. Another interpretation is that p_n^j reflects how competitive is the market. Therefore, if the p_n^j decreases, country n becomes relatively more expensive with respect to the world, thus expenditure in country n and labor demand decrease. As a consequence, real wages also decrease. For the case of non-tradable sectors, we can clearly see in equation (9) that when p_n^j decreases, and given the cost of intermediate goods, factor payments decrease. That is why there is a positive sign effect over the change in real wages.

4 Quantifying the Trade Effects of NAFTA

In this section, we evaluate the trade and welfare effects from the change in the tariff structure caused by NAFTA. To do this, 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 tradeable and 20 non-tradeable).[40] Our base year is 1993, the year before the agreement became in force.

[39] In a recent study Arkolakis, Costinot and Rodríguez-Clare (2009) show that within a variety of macro-level trade models there are two sufficient statistics to evaluate welfare gains: the share of expenditure on domestic goods and trade elasticities. Our model is not in the class of models presented in Arkolakis et al. (2009). It shares similar properties to the Donaldson (2009) model in which sectoral elasticities and shares of expenditure at the sector level are needed to evaluate welfare, plus there is an additional term which captures the gains from the interrelation across sectors.

[40] Tables 1 and 2, at the end of the document, present the list of tradableand non-tradable goods sectors. The Data Appendix describes the data.

Therefore, the data on trade and production we use is for the year 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. By 2005, tariff reduction between NAFTA members were essentially complete We solve for the equilibrium in relative changes from the tariff structure in 1993 to the tariff structure in 2005. Note that the observed tariff structure in 2005 incorporates changes in policy other than NAFTA. We will control for that in our model, but before we do so, we compare the changes in trade flows from the model to the actual changes in the data. This exercise analyzes the trade effects of the 14-year process of liberalization of NAFTA members.[41]

We also 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 and we neutralize the effect of other agreements signed during the sample period. We proceed now to estimate the only parameters needed to perform policy experiments, the dispersion-of-productivity parameter (θ^j) at a sectoral level and then show how to calibrate the model to evaluate the change in policy.

4.1 Dispersion of Productivity Estimation

Recall that X_{ni}^j is the expenditure of sector j and country n goods from country i. Let the total expenditure of j goods in country n be given by $X_n^j = \sum_i^N X_{ni}^j$. From (10):

$$\frac{X_{ni}^j}{X_n^j} = \left(A^j B^j\right)^{-1/\theta^j} \left(\frac{c_i^j}{p_n^j}\kappa_{ni}^j\right)^{-1/\theta^j} \lambda_i^j \tag{25}$$

From (25) we can see how this dispersion parameter can also be thought of a trade elasticity since it will determine how trade flows react to changes in tariffs. If productivity are more dispersed, as indicated by larger values 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 in terms of the efficiency with which they are produced. 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 efficiencies are more substitutable. The change in the measure of goods traded is the adjustment at the extensive margin in this

[41] 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.

model.[42] In the model, this means that it will only impact the quantity of goods bought from the same source. The lower bound of the dispersion of productivity is the elasticity of demand from the intermediate good aggregate producers.

We propose a new method to estimate the dispersion parameter. Consider three countries indexed by i, n, and m. Now consider the cross-product of goods from sector j shipped in one direction between the three countries, from n to m, from m to i, and from i to n, and then the cross-product of the same goods shipped in the other direction, from n to i, from i to m, and from m to n. Using equation (10) we can calculate each expression and then take the ratio:

$$\frac{X_{ni}^j X_{im}^j X_{mn}^j}{X_{nm}^j X_{mi}^j X_{in}^j} = \left(\frac{\kappa_{ni}^j}{\kappa_{in}^j}\frac{\kappa_{im}^j}{\kappa_{mi}^j}\frac{\kappa_{mn}^j}{\kappa_{nm}^j}\right)^{-\frac{1}{\theta^j}}, \tag{26}$$

where all the terms involving prices and parameters $((A^j B^j c_i^j / p_n^j)^{-1/\theta^j} \lambda_i^j)$ are canceled out and we end up with a relation between bilateral trade and trade costs.[43] This method is similar to the odds ratio method developed by Head and Ries (2001) and also presented in Head and Mayer (2001).[44] Our method is also similar to the one Head, Mayer and Ries (2009) denote as "tetrads".[45] However, they require a set of four trading partners instead of three,

[42] 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. Note that 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 the Eaton and Kortum (2002) model, there are production-side gains from trade, while in a standard Armington model, like Anderson's (1979), gains are from the consumption side only.

[43] The number of cross product terms in our method is given by

$$\text{Number of cross terms} = \sum_{n=1}^{N-2} d_n$$

where $d_n = n(n+1)/2$ and N is the number of countries in the sample. Therefore, for a sample of 5 countries there will be 11 observations per good.

[44] Using the notation in our model, the odds ratio is given by

$$\frac{X_{ni}^j X_{in}^j}{X_{nn}^j X_{ii}^j} = \left(\kappa_{ni}^j \kappa_{in}^j\right)^{-\frac{1}{\theta^j}}$$

where X_{nn}^j are home sales. The empirical strategy is to take time differences and in this way eliminate the exporter and importer fixed effects. In the Alternative Estimation Appendix we also estimate the dispersion of productivity using this method. We do so for robustness check of our results.

[45] The tetrad is given by

$$\frac{X_{ni}^j X_{ml}^j}{X_{nl}^j X_{mi}^j} = \left(\frac{\kappa_{ml}^j}{\kappa_{nl}^j}\frac{\kappa_{ni}^j}{\kappa_{mi}^j}\right)^{-\frac{1}{\theta^j}}$$

The terms X_{ml}^j / X_{mi}^j, X_{ni}^j / X_{nl}^j eliminates the importer fixed effects. This is the method that Martin, Mayer and Thoenig (2008) apply. The terms X_{ml}^j / X_{nl}^j, X_{ni}^j / X_{mi}^j eliminate the exporter fixed effects. This is method and this reduces the sample size considerably.[46]

The advantage of using (26) is that unobservable trade costs will cancel out. For example, consider the following model of asymmetric trade costs.[47] From the definition of κ^j_{ni}, trade costs are divided between tariffs (non-symmetric) and iceberg (also non-symmetric) trade costs:

$$\log \kappa^j_{ni} = \log \tilde{\tau}^j_{ni} - \log d^j_{ni} \tag{27}$$

where $\tilde{\tau}^j_{ni}$ is equal to $(1+\tau^j_{ni})$. Iceberg trade costs, $\log d^j_{ni}$, can be modeled quite generally as linear functions of cross-country characteristics:

$$\log d^j_{ni} = \phi^j_{ni} + \mu^j_n + \omega^j_i + \varepsilon^j_{ni} \tag{28}$$

where $\phi^j_{ni} = \phi^j_{in}$ captures symmetric bilateral trade costs like distance, language, common border, and belonging to an FTA or not. The parameter μ^j_n captures an importer sectoral fixed effect, for example, non-tariff barriers, and it is assumed common to all trading partners of country n. The parameter ω^j_i is an exporter sectoral fixed effect that can also capture non-tariff barriers, and it is assumed common to all trading partners of country i. ε^j_{ni} is a random disturbance term (unobserved determinants of trade costs, for example) and is assumed orthogonal to tariffs. Introducing these trade costs into (26) we get:

$$\log\left(\frac{X^j_{ni}X^j_{im}X^j_{mn}}{X^j_{in}X^j_{mi}X^j_{nm}}\right) = -\frac{1}{\theta^j}\log\left(\frac{\tilde{\tau}^j_{ni}}{\tilde{\tau}^j_{in}}\frac{\tilde{\tau}^j_{im}}{\tilde{\tau}^j_{mi}}\frac{\tilde{\tau}^j_{mn}}{\tilde{\tau}^j_{nm}}\right) + \tilde{\varepsilon}^j \tag{29}$$

where $\tilde{\varepsilon}^j = \varepsilon^j_{in} - \varepsilon^j_{ni} + \varepsilon^j_{mi} - \varepsilon^j_{im} + \varepsilon^j_{nm} - \varepsilon^j_{mn}$. Note that all the symmetric and a-symmetric components of the iceberg trade costs cancel out. The terms $\kappa^j_{ni}/\kappa^j_{in}$, $\kappa^j_{im}/\kappa^j_{mi}$, and $\kappa^j_{mn}/\kappa^j_{nm}$ will cancel the symmetric bilateral trade costs (ϕ^j_{ni}, ϕ^j_{im}, and ϕ^j_{mn}). The terms $\kappa^j_{ni}/\kappa^j_{nm}$, $\kappa^j_{im}/\kappa^j_{in}$, and $\kappa^j_{mn}/\kappa^j_{mi}$ cancel the importer fixed effects (μ^j_n, μ^j_i, and μ^j_m); and the terms $\kappa^j_{ni}/\kappa^j_{mi}$, $\kappa^j_{im}/\kappa^j_{nm}$, and $\kappa^j_{mn}/\kappa^j_{in}$ cancel the exporter fixed effects (ω^j_i, ω^j_m, and ω^j_n). The only identification restriction is that $\tilde{\varepsilon}^j$ is assumed orthogonal to tariffs[48].

that Anderson and Marcouiller, (2002) apply. By taking ratios of these ratios you can eliminate the exporter and the importer fixed effect. However, in order to apply the method they need a reference country.

[46] Head, Mayer and Reis (2009) use the tetrad method to estimate trade costs. In orther to do so, they need a reference importer and exporter country to identify the parameters. Hallak (2006) and Romalis (2007) apply this method. In the case of Romalis (2007) he uses as a reference importer country the European Union and as reference exporter country a construct rest of the world.

[47] 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 neet to assume symmetry in order to get identification.

[48] We estimate (29) by OLS. Under the presence of zeros, there is a problem with this approach since the dependent variable is not defined. A solution to this problem is to use the PPML estimator suggested on Santos-Silva and Tenreyro (2010).

We estimate the dispersion of productivity parameter sector by sector using the proposed specification (29) for 1993, the year before NAFTA was active.[49] Table 3 presents the results.

We present 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 whose the result is presented at the bottom of Table 3).[50] Our priors over the relative magnitudes were that sectors with goods which are less differentiated (more substitutable) should have a smaller value of the dispersion parameter (larger values for $1/\theta^j$). By inspecting the list of sectors, this prior is confirmed. For example, petroleum is the sector with most homogenous products has the largest estimated coefficient of 51.08. Other homogeneous sectors like minerals and wood have an estimated value of 15.76 and 10.83 respectively. For the case of more differentiated goods sectors like auto or machinery the values are 1.01 and 1.52 respectively. To check for the robustness of our estimates we dropped observations with small trade flows. Table 3 shows the estimates for the the 99% of the sample and the 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 lowest 1% and re-estimated the productivity parameter. Then we dropped the lowest 2.5%. Note how the number of observations changes when we drop the smallest 1%. On average there are 3 countries in the sector whose cumulative weight is smaller than 1%. Taking one country from the full sample implies potentially loosing 105 observations, if

[49]Bilateral trade data for the year 1993 is 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 (29)) 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 world trade in each sector. This countries are: Argentina, Australia, Brazil, Canada, Chile, China, the Czech Republic, the European Union, India, Indonesia, Japan, Korea, New Zealand, Norway, Thailand and the United States. All the data for the estimation is described in the Data Appendix at the end of the document.

[50]Several studies have estimated trade elasticities. For example: Anderson, Balistreri, Fox, and Hillberry (2005) find the average elasticity to be 17. Broda and Weinstein (2006) find that the simple average of the elasticities are 17 at a seven-digit (TSUSA), 7 at the three-digit (TSUSA), 12 at a ten-digit (HTS) and 4 at a three-digit (HTS) goods desagregation. 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 -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 (2009) make the point that the "true" elasticity of substitution is more than twice the elasticity implied by aggregate data. Hertel, T.W., D. Hummels, M. Ivanic, and R. Keeney (2003) estimate sectoral trade elasticities with values between 3 and 30.

Table 3

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
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
Com	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	8.22	(1.07)		9.29	(1.00)				
Test equal parameters			F(17, 7294) = 7.52				Prob > F = 0.00		

Notes: The dependent variable is $\ln(X^j_{ni}X^j_{im}X^j_{mn}\ /\ (X^j_{in}X^j_{mi}X^j_{nm}))$ where X^j_{ni} are trade flows from n to i. The independent variable is $\ln(\tau^j_{ni}\tau^j_{im}\tau^j_{mn}\ /\ (\tau^j_{in}\tau^j_{mi}\tau^j_{nm}))$ where $\tau's$ are tariffs. $1/\theta^j$ is the negative of the estimated coefficient. We use only data from 1993 or before. Heteroskedasticity-robust standard errors are reported. The estimate for manufacturing is the mean of the sector estimations. The test for equal parameters between manufacturing sectors is a Wald test. All the data is described in the Data Appendix.

it had bilateral trade with all others. There are three sectors which we find not robust since they changed sign as we restricted the sample.[51] This are: Basic metals, Machinery n.e.c., and Auto.[52] We also re-estimated the dispersion parameters including importer and exporters fixed effects to check for the stability of the estimates. Table 4 presents the estimates

Table 3 also presents the mean estimate of the 18 manufacturing sectors. The magnitude of the sector estimated coefficient is similar to 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 using different methods of estimation.[53] Ours is 8.22. More recently Fieler (2009) estimates a value of 12.09. Our final estimates are the estimates presented in Table 3 for the 99% sample, since they take care of the small trading countries (outliers). For the sectors Basic metals, Machinery n.e.c., and Auto we replace them by the mean estimate for the manufacturing sector.

4.2 Calibration

One of the advantages of working with relative changes is that we do not need estimates of total factor productivity nor of transport costs. The only parameter that needs to be estimated is the sectoral dispersion of productivity. This is a key advantage of our methodology since it simplifies considerably the way the model is calibrated and used to evaluate policy changes.

The data needed is sectoral data on bilateral trade flows (Z_{in}^j− imports of i from n), value added (VA_n^j), gross production (Y_n^j), and the I-O tables H_n. We will show how to calculate country and sector parameters to include in the model.

To obtain the bilateral trade share π_{in}^j, we first calculate domestic sales in each country, Z_{ii}^j. This is is the difference between gross production in i and total exports from i; $Z_{ii}^j = Y_i^j - \sum_{n=1, n\neq i}^N Z_{ni}^j$. Then, we calculate net exports in each sector j and country i, $S_i^j = \sum_{n=1}^N Z_{ni}^j - \sum_{n=1}^N Z_{in}^j$. We obtain π_{in}^j for each sector j and pair of countries i, n in the following way:

$$\pi_{in}^j = Z_{in}^j / \left(Y_i^j - S_i^j \right) \tag{30}$$

[51] 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% of the sample. Without China the numbers are presented in the table. China represented 5% of the share of trade in that sector.

[52] Machinery n.e.c. corresponds to manufacture of electrical machinery and apparatus n.e.c.. This is a "residual" sector which includes a variety of electrical machineries not elsewhere classified.

[53] The estimate from Eaton and Kortum (2002), $1/\theta = 8.28$, has been the reference value in the literature. For instance, Alvarez and Lucas (2008), Fieler (2009), Waugh (2009) and Deckle, Eaton and Kortum (2008) among others, use this value.

Table 4

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
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
Com	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	9.04	(1.14)		9.33	(1.19)				

Notes: The dependent variable is $\ln(X^j_{ni}X^j_{im}X^j_{mn} \;/\; (X^j_{in}X^j_{mi}X^j_{nm}))$ where X^j_{ni} are trade flows from n to i. The independent variable is $\ln(\tau^j_{ni}\tau^j_{im}\tau^j_{mn} \;/\; (\tau^j_{in}\tau^j_{mi}\tau^j_{nm}))$ where $\tau' s$ are tariffs and we also included importer and exporter fixed effects. $1/\theta^j$ is the negative of the estimated coefficient. We use only data from 1993 or before. Heteroskedasticity-robust standard errors are reported. The estimate for manufacturing is the mean of the sector estimations. All the data is described in the Data Appendix.

The share of value added in each sector and country (β_n^j) is given by:

$$\beta_n^j = VA_n^j / Y_n^j \tag{31}$$

The share of sector k's spending on sector j's goods is $\gamma^{j,k}$. This is calculated in the following way. From the I-O matrix H_n, denote the element j (row) k (column) of the matrix by $h_n^{j,k}$. This is then the intermediate consumption of sector j in sector k;

$$\gamma_n^{j,k} = \frac{h_n^{j,k}}{\sum_j h_n^{j,k}} = \frac{\text{intermediate consumption of sector } j \text{ in sector } k}{\text{Total intermediate consumption of sector } k} \tag{32}$$

Finally, calculate α^j in the following way:

$$\alpha_n^j = \frac{Y_n^j - S_n^j - \sum_k^J \gamma_n^{j,k}(1-\beta_n^k)\left(Y_n^k\right)}{I_n} \tag{33}$$

where I_n is total final absorption in the data.

4.3 Solving the Model

Solving the model in relative changes allows us to use information under policy τ to construct the new equilibrium under policy τ'. In order to determine the effect of a new policy, proceed as follows. First, construct the elements of $\hat{\kappa}_n^j$ using the information of policy τ and the new policy τ'. Then calculate π_{in}^j, as shown in (30). After that, calculate γ_n^j, β_n^j, and α_n^j as shown in $(31-33)$. Finally, θ^j comes from the estimation presented in table 3 column 5. Now guess a vector of wages $\hat{\mathbf{w}}$. Given this guess, use $\hat{\kappa}_i^j$, γ_n^j, and, β_n^j in $(19-21)$ and solve for $\hat{p}_i^j(\hat{\mathbf{w}})$ and $\hat{c}_i^j(\hat{\mathbf{w}})$ consitent with $\hat{\mathbf{w}}$. Then use π_{in}^j and θ^j together with the calculated $\hat{p}_i^j(\hat{\mathbf{w}})$ and $\hat{c}_i^j(\hat{\mathbf{w}})$ and solve for $\pi_{in}^{j\prime}(\hat{\mathbf{w}})$ using (22). Given $\pi_{in}^{j\prime}(\hat{\mathbf{w}})$, τ',and with γ_n^j, β_n^j, and α_n^j construct $\mathbf{\Omega}$, and $\mathbf{\Delta}$. Then solve for $\mathbf{X}_n'$ by inverting $\mathbf{\Omega}$ and postmultiplying it by $\mathbf{\Delta}$. Introduce $\pi_{in}^{j\prime}(\hat{\mathbf{w}})$, $\mathbf{X}_n'$, τ', S_n, and L_n into (23) and verify that it holds. If not, adjust your guess of $\hat{\mathbf{w}}$ until it does[54].

4.4 Results

We now use the estimated parameters and incorporate the change in tariffs from 1993 to 2005, both between NAFTA members and with the rest of the world, to quantify the trade effects

[54]The algorithm that we employ to solve for the equilibrium is multidimensional version (increasing the dimensions to J sectors) of the one proposed by Alvarez and Lucas (2008). This variables are solved up to a normalization, in our case $\sum_n^N w_n' L_n = \sum_n^N w_n L_n$.

Table 5

Changes in trade flows relative to GDP (Manufacturing sector)				
	Data	Model		
Country	1993-2005	Tariff	$\beta^j = 1$	No I-O
Canada exports	24.4 %	34.4%	11.0%	17.1%
Canada imports	16.0 %	23.8%	7.3%	10.3%
Mexico exports	130.6 %	131.9%	52.3%	59.6%
Mexico imports	68.3 %	56.4%	19.9%	23.2%
U.S. exports	28.6 %	51.4%	26.7%	29.4%
U.S. imports	49.4 %	24.8%	12.5%	14.6%

Note: This table compares the observed changes in exports and imports over GDP and the simulated changes. The column "Tariff" are the simulated results from a change in the tariff structure from 1993 to 2005. "$\beta^j = 1$" refers to no Intermediates and "No I-O" to no interrelation across sectors, no input-output matrix. The data used is described in the Data Appendix.

from tariff eliminations. Table 5 presents the models and the observed changes in exports and imports over GDP for the manufacturing

Looking at Table 5, the relative and absolute magnitudes simulated from the model resamble the observed changes except for the United States (column Tariff). The trade responses from tariff reductions seem to explain a large fraction of the changes in trade flows observed for Mexico and Canada. This is not the case for the United States. From the period 1993 to 2005 there were substantial changes in the United States trade deficit due to reasons that are not related to tariff policy. The simulations of the model are conditional on fixing certain variables; like technology, geographic trade costs, and trade deficits. When we incorporated the exogenous change in trade deficit observed from 1993 to 2005 to the model, the model simulates a large response on imports relative to exports compared to the case of no trade deficit adjustment. Specifically, the simulated changes in manufacturing imports over GDP for the United States change to 49.6% and exports to 31.1%.

We also quantify the role of intermediates and sectoral linkages in order to correctly access trade policy. We compare 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 between the sectors. By setting $\beta^j = 1$, the production function of tradable goods collapses to a multi sector Dornbush, Fisher and Samuelson (1977) model with a continuum of goods and countries (like in Donaldson(2009)). Note that it will also rule out the interconnection across sectors. In this simplified model, tradable goods are only consumption goods. We re-calibrate the model taking into account that there are no intermediate goods in production and compare the results of this model to the intermediates good model we had before.

The third column in table 5 presents the results. As we can see, the trade effects from a tariff reduction are lower in the case of no intermediate goods in production. The reason of this result is that goods are traded only for consumption and not for production. With trade in intermediates, a reduction in tariffs will result in an increase of importing intermediate goods for production. This will not only allow producers to produce at lower costs and increase their sales domestically, but it will also increase the efficiency of exporting sectors and therefore export more. This result suggests that intermediates played an important role in the case NAFTA, in particular for Mexico and Canada.

We also compare the implied changes in trade flows with a model where there is trade in intermediate however there is no sectoral linkages. In this case we are not using the off diagonal elements of the I-O matrix. The fourth column in table 5 presents the results. As in the case of no intermediates, the trade effects from tariff reductions are lower when sectors are not interrelated. The intuition of this result 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, domestic and international.

Figures 10-12 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.[55] A 45 degree line is included in each figure to guide the comparison. As we can see, most of the sectors are located close to the 45 degrees 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 of these sectors, such as petroleum, chemicals, and mining. We also compare the average change in trade and absolute magnitudes of changes in trade from the model and the data. We run a linear regression between the implied changes in trade flows from the model against the observed changes in the data.[56] The intercept of the regression evaluates how similar are the average changes in the data while the slope of the regression evaluates how well the model matches the sign and the absolute magnitude of changes. We did this for the case of changes in imports and changes in exports separately. The results are presented in Figures 10-12. As we can see, the

[55] Concretely, what we are comparing is the difference between $x^j_{i,t+1}/\ y_{i,t+1}$ - $x^j_{i,t}/\ y_{i,t}$ from the model and the data; 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. 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.: $((x^j_{i,t+1}/y_{i,t+1})/(x^j_{i,t}/y_{i,t})$ $-1)(x^j_{i,t}/\sum_{j=1}^{J} x^j_{i,t})$. This is what Kehoe, Polo and Sancho (1995), Kehoe (2003), and Rolleigh (2004) do. We also used this measure and the results are the same as the ones presented with our measure.

[56] What we do is a weighted least square regression. Details on this measure of goodness of fit are presented in Kehoe et.al (1995), Kehoe (2003), Rolleigh (2004) and Fox (1999).

Table 6

Simulated values					
Change in real wages - NAFTA case					
	Total effect	Final	Intermediates	Interrelations	Price effect
Mexico	2.0%	0.7%	1.6%	3.5%	-3.8%
Canada	0.8%	0.2%	0.3%	1.5%	-1.2%
USA	0.2%	0.1%	0.1%	-0.3%	0.3%

Note: This table presents the decomposition of the change in real wages as derived in section 3.7. The total effect refers to the total effects from NAFTA tariff reductions. Final refers to the contribution of final goods traded. Intermediates to the contribution from Intermediate goods traded. Interrelations, to the contribution from sectoral interrelations.

intercept and the slope coefficients are positive; therefore the direction of trade from tariff reductions are aligned with the data. Regarding the magnitudes, we can observed that most of the observed trade changes for Mexico are a consequence of the tariff reductions. This is not the case for the United States and Canada.

We now turn into the welfare analysis. Table 6 shows that as a consequence of the tariff reductions, real wages increased in all NAFTA countries and Mexico had the largest gains.

We also present the decomposition of the change in real wages derived in section 3.7. We can see that in Mexico and Canada the change in real wages is mainly explained by the access to cheaper intermediate inputs and sectoral interrelations. This results confirm the importance of trade in intermediate goods and I-O linkages to correctly evaluate the welfare gains from trade. For the case of the United States, trade in intermediate goods plays a less important role and the sectoral interrelations contributed negatively to the change in real wages. The negative contribution of sectoral linkages is explained because in most sectors the increase in nominal wages has a stronger effect on prices than the reduction in tariffs. Figure 5 showed that United States tariffs rates were already low before the NAFTA was active. Therefore, the United States was the country in the agreement that had the lowest percentage change in tariffs.

Finally, we also quantify tariff revenues. Since in our model tariff revenues are lump-sum transferred to consumers, there is a direct relationship between the change in tariffs and the size of tariff revenues. When we add the change in tariff revenues to our measure of welfare, we find that Mexico suffers the largest tariff revenue losses. Mexico had the biggest tariff reduction among NAFTA members. The change in real income in Mexico (considering the tariff revenue losses) is -0.2% .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 -0.2% in Canada and 0.1% in the United States due to NAFTA.

5 Conclusion

In this paper we build into a Ricardian model for trade policy analysis the role of trade in intermediate inputs, sectoral linkages and differing productivity levels across sectors. The model can be used for both ex-ante and ex-post trade policy evaluation. We also propose a new method to estimate sectoral trade elasticities. The estimations are performed using only trade and tariff data and not assuming bilaterally symmetric trade costs. We estimate sectoral dispersions of productivity for manufacturing and non-manufacturing sectors for the year 1993.

With our model and method of estimation we decompose the trade and welfare effects of NAFTA. We find that as a consequence of the tariff reductions, real wages increased in all NAFTA countries. Mexico had the largest gains, while Canada and the United States gained relatively more from their liberalization against the rest of the world. By decomposing the welfare effects, we conclude that tariff reductions can generate significant welfare and trade effects and that the source of these effects can differ across countries according to the importance of intermediate inputs in production and I-O linkages. This is particularly the case for the case of NAFTA.

As a final point, we show how not taking into account a realistic representation of the structure of production of the economy can lead to different conclusions about the trade and welfare effects of trade policy. Three channels explain this. First, trade cost elasticities are sector and country specific; second, intermediate inputs are traded across different sectors; and finally, tradable and non-tradable sectors are interrelated according to I-O linkages. By comparing our results to a model without sector-specific dispersion of productivity, we show that it is crucial that the dispersion parameter differ across sectors in order for the model to correctly assess trade policy (in terms of welfare and trade flows). The reason is that adjustments at the extensive margin vary sector-by-sector, and this can only be captured by sectoral dispersion parameters[57]. Trade in intermediate inputs, besides being empirically relevant, amplifies the welfare effects of tariff reductions. Changes in tariffs will have a direct effect on the costs of intermediate inputs used by firms in different countries. This is particularly relevant for sectors that rely on foreign, cost-efficient inputs, as is the case for most sectors in Mexico. Finally, understanding the interrelation across sectors is important

[57] If after a reduction in tariffs countries start trading goods that they were not trading before, this is referred to as changes on the new goods or the extensive margin of trade. When countries trade more or less of the goods that they were already trading, this is referred to as changes on the intensive margin of trade.

for correctly assessing welfare. The impact of tariffs in one sector has effects over all other sectors. This is also the case in non-tradable goods that rely on intermediate tradable inputs for their production. These non-tradable goods are consumed by agents, and if we do not consider this channel we could under-estimate the welfare gains from tariff reductions.

The model presented in this paper provides policy makers and researchers with a flexible tool that can easily be adapted to evaluate any type of tariff concessions. By focusing on changes, we show how to perform policy experiments without relying on estimates of total factor productivity or transport costs, which are both difficult to estimate. Relying only on data on bilateral trade flows, production and tariffs, some of the questions that can be answered with this model are, What are the trade and welfare effects from changing partners within a trading bloc, from moving out of a trading bloc, or from joining a new trading bloc? How might a tariff concession in an industry affect trade flows in that industry or in industries related to that industry? What tariff structure can maximize welfare? Alternatively, we could have also considered quantifying the trade effects from changes in sectoral technology or changes in non-tariff trade costs. We believe that these are important questions that should be addressed in the future. Our framework is well suited to do so.

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Table 1

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

n.e.c = Not Elsewhere Classified

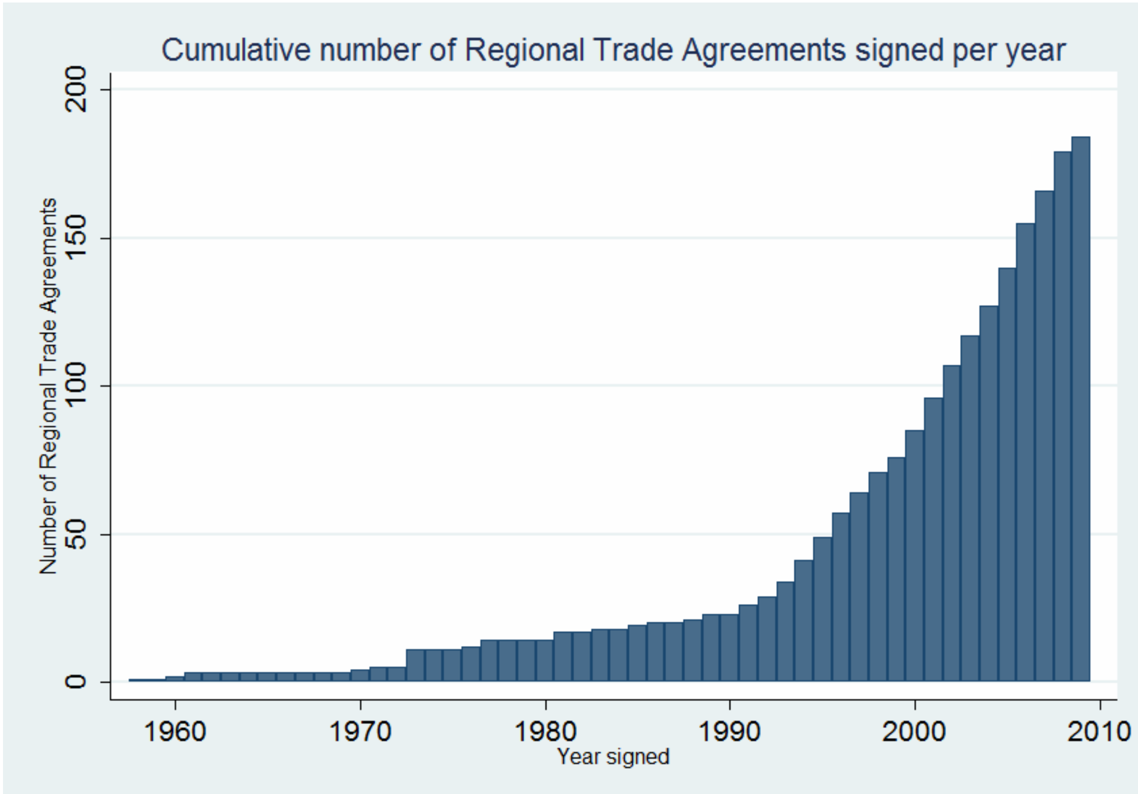
Table 2

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.	62
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 defence 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

Figure 1

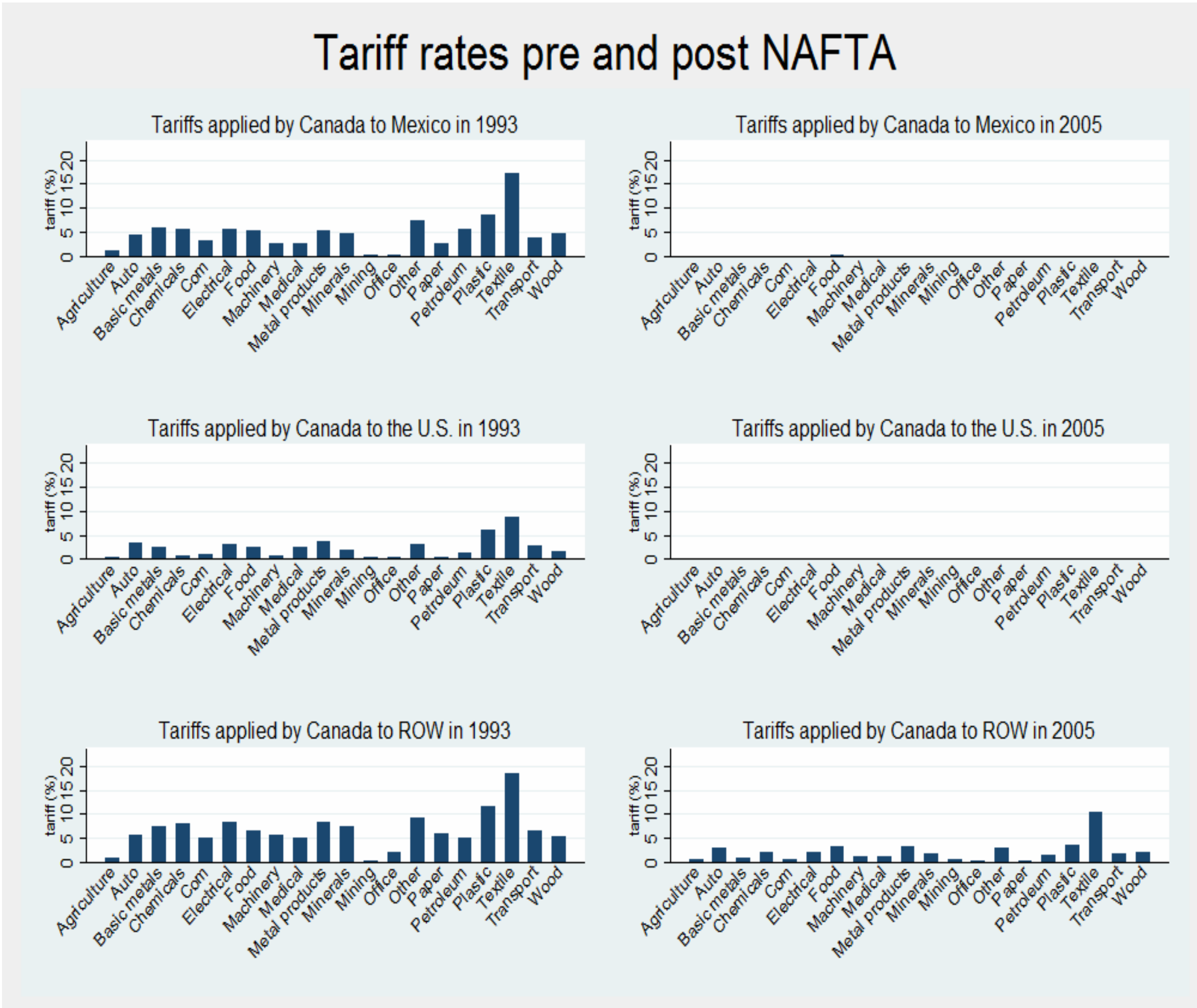


Note: This picture considers all type of Regional Trade Agreements: preferential trade agreements (PTAs), free trade agreements (FTAs), custom unions (CUs) and regional economic integrations (REI) Source: World Trade Organization.

Figure 2

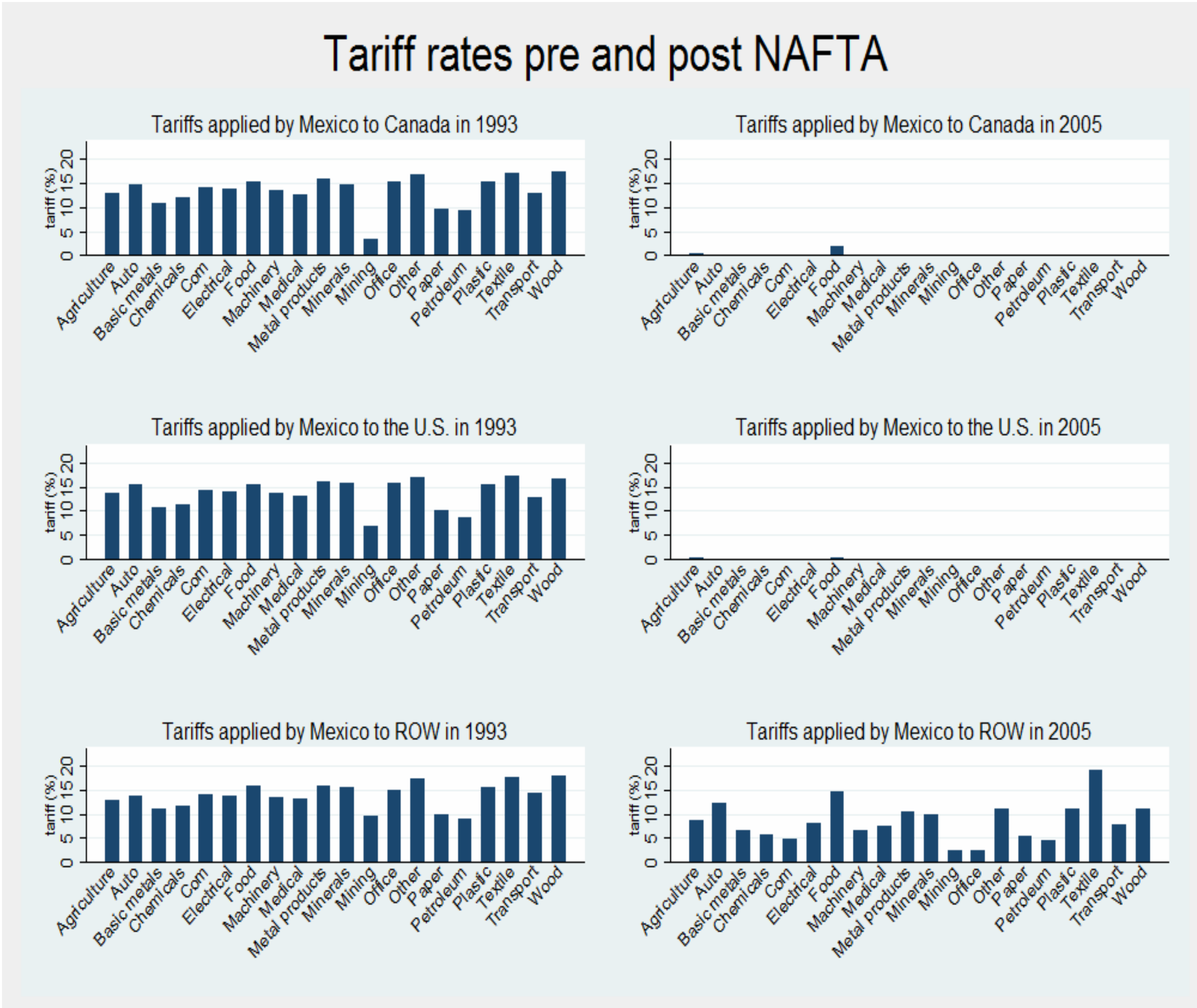
Note: The share is calculated as the total trade between members of Regional Trade Agreements over total trade in world for each year. Source: World Trade Organization.

Figure 3



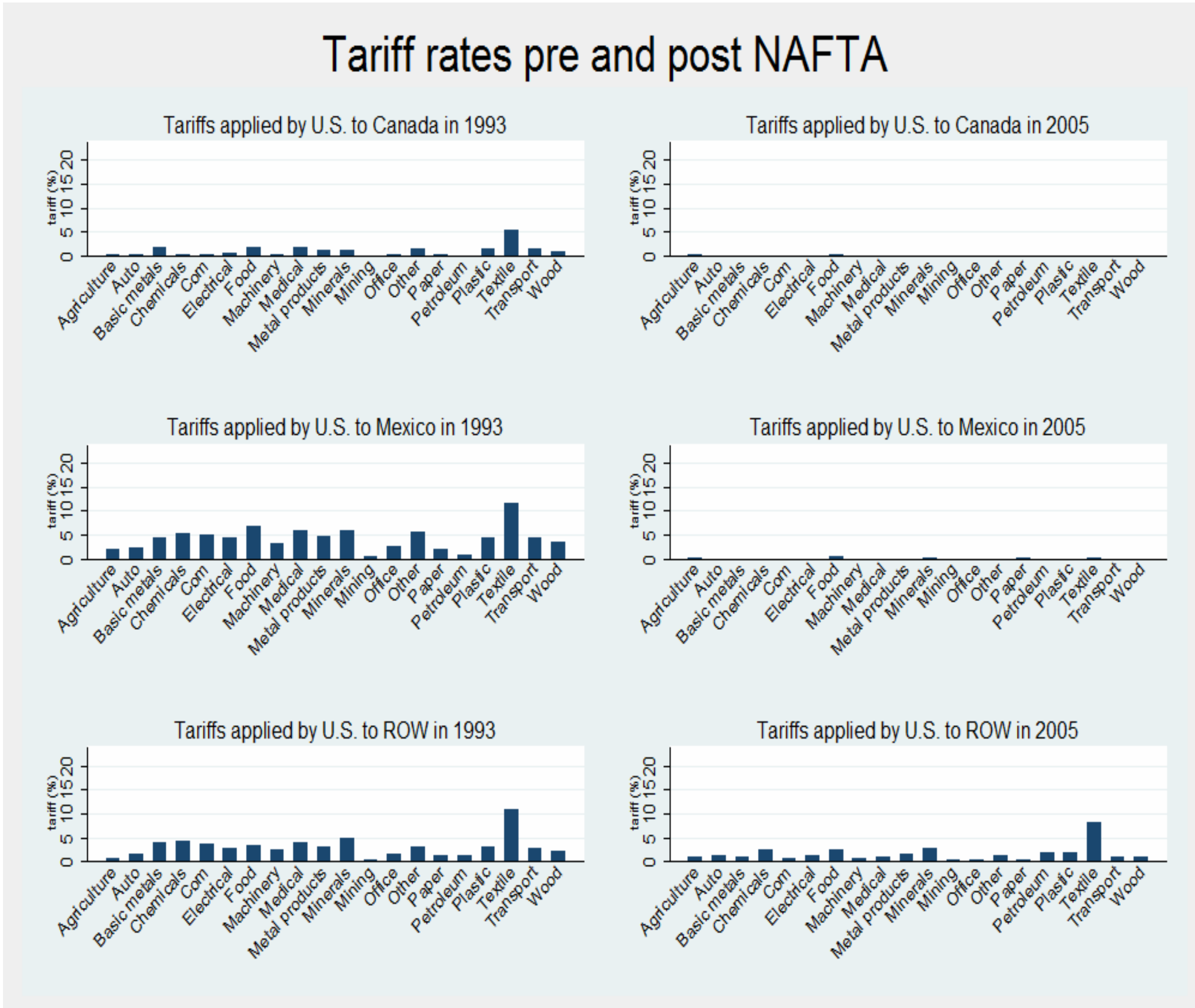
Note: Tariffs applied by sector (ISIC rev. 3). This figure presents the tariffs applied by Canada to NAFTA members and ROW (rest of the world). Figures on the left side show tariffs in 1993 and on the right side tariffs in 2005. See the Data Appendix for more details.

Figure 4



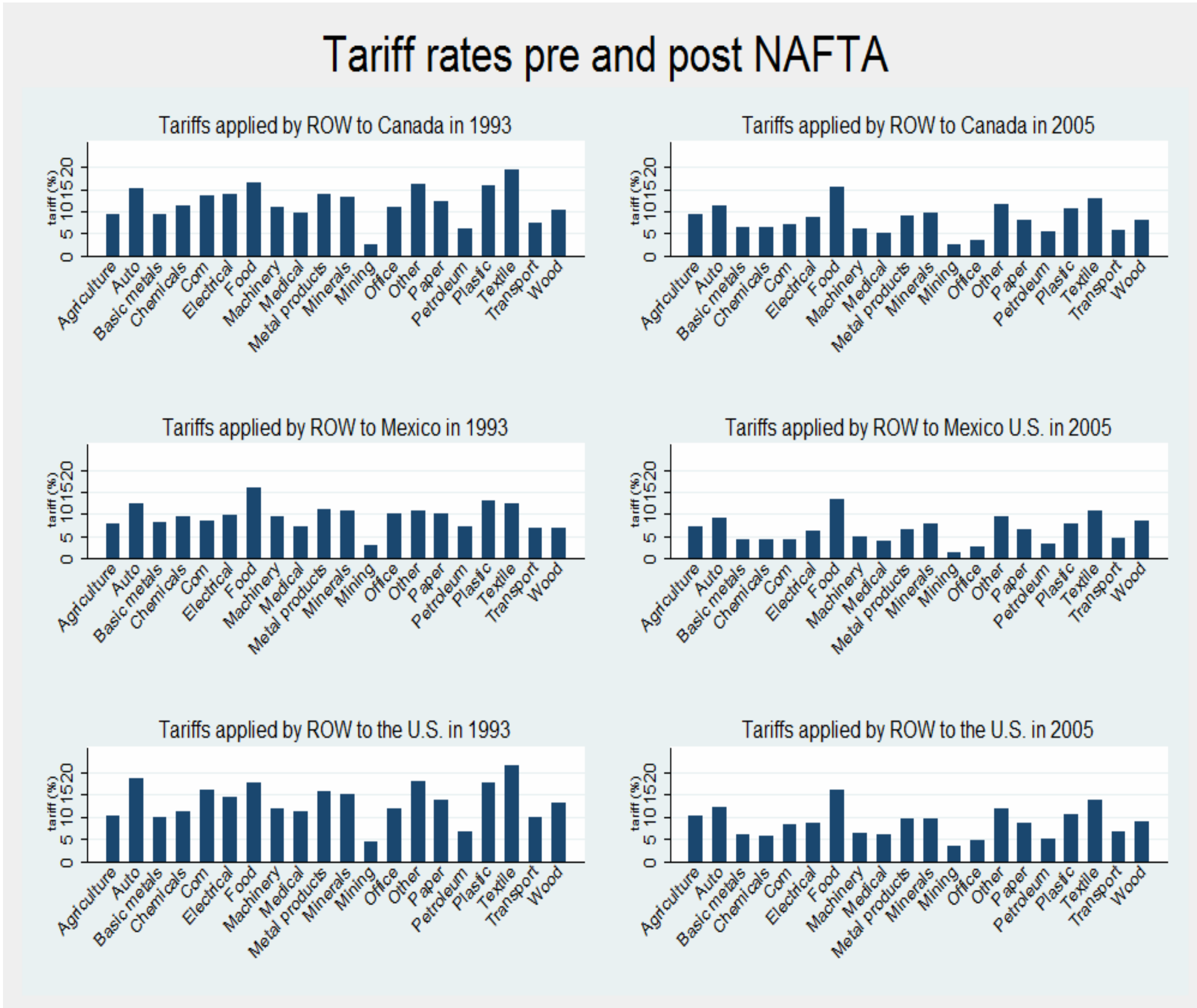
Note: Tariffs applied by sector (ISIC rev. 3). This figure presents the tariffs applied by Mexico to NAFTA members and ROW (rest of the world). Figures on the left side show tariffs in 1993 and on the right side tariffs in 2005. See the Data Appendix for more details.

Figure 5



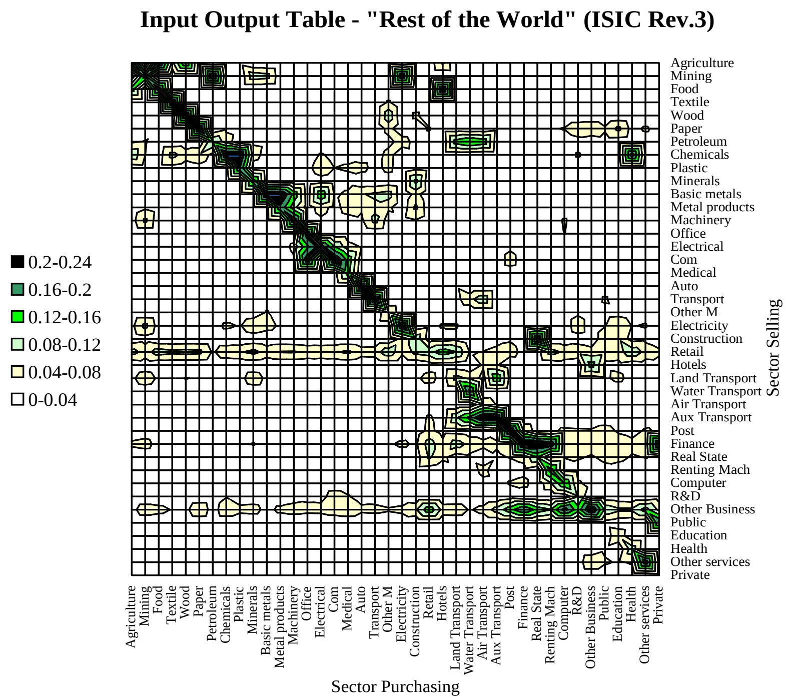
Note: Tariffs applied by sector (ISIC rev. 3). This figure presents the tariffs applied by Mexico to NAFTA members and ROW (rest of the world). Figures on the left side show tariffs in 1993 and on the right side tariffs in 2005. See the Data Appendix for more details.

Figure 6



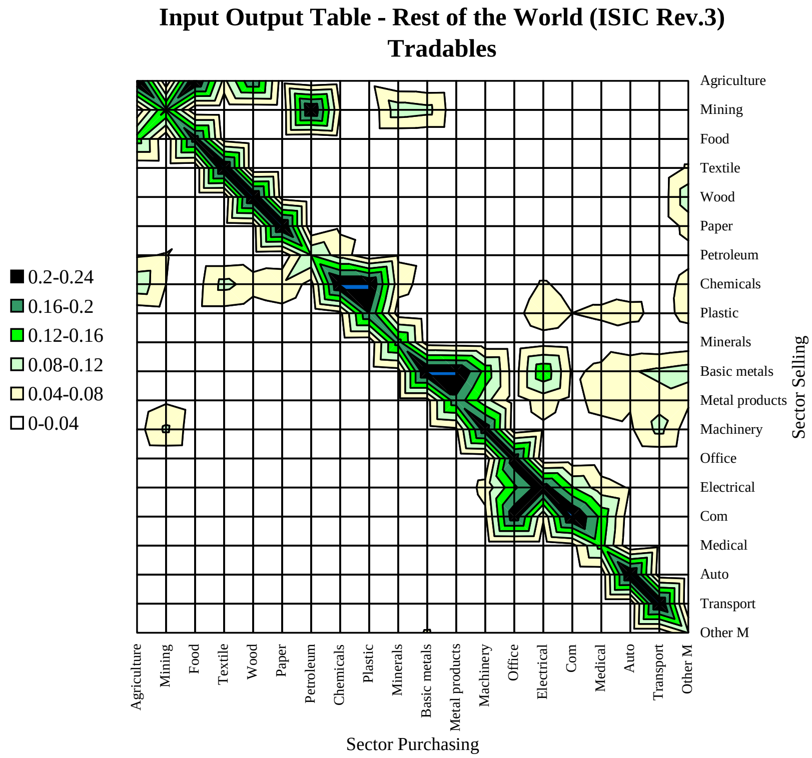
Note: Tariffs applied by sector (ISIC rev. 3). This figure presents the tariffs applied by the ROW (rest of the world) to NAFTA members. Figures on the left side show tariffs in 1993 and on the right side tariffs in 2005. See the Data Appendix for more details.

Figure 7



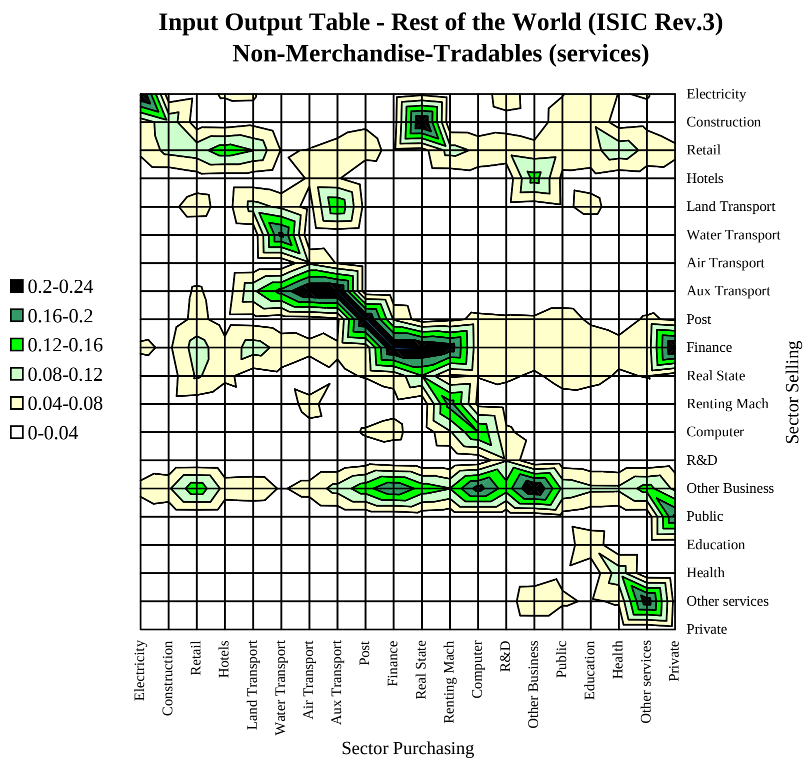
Note: I-O table for a construct rest of the world. We use the (OECD) STAN database 2002 edition (ISIC Rev.3) Input Output tables. The rest of the world was constructed with 22 countries which reported I-O tables for the year 2000. The list of countries are: Austria, Belgium, Czech Rep, Germany, Denmark,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

Figure 8



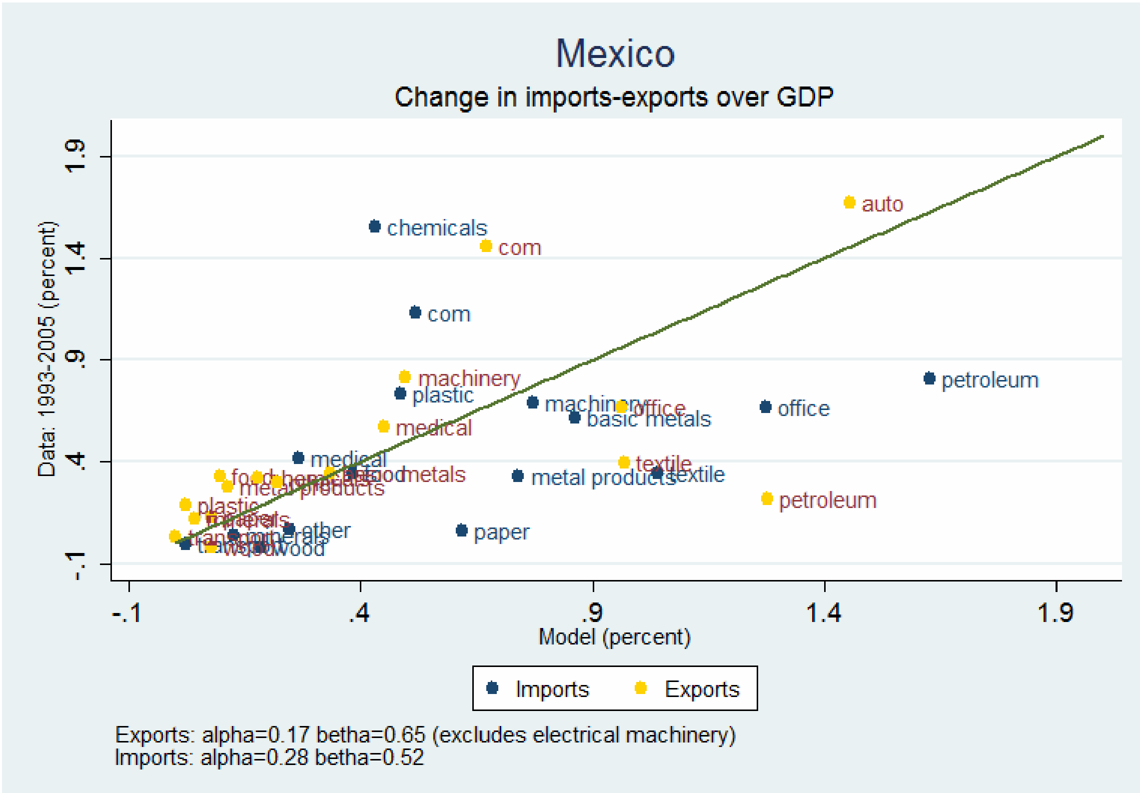
Note: I-O table for a construct rest of the world, tradable sectors. See Table 1.

Figure 9



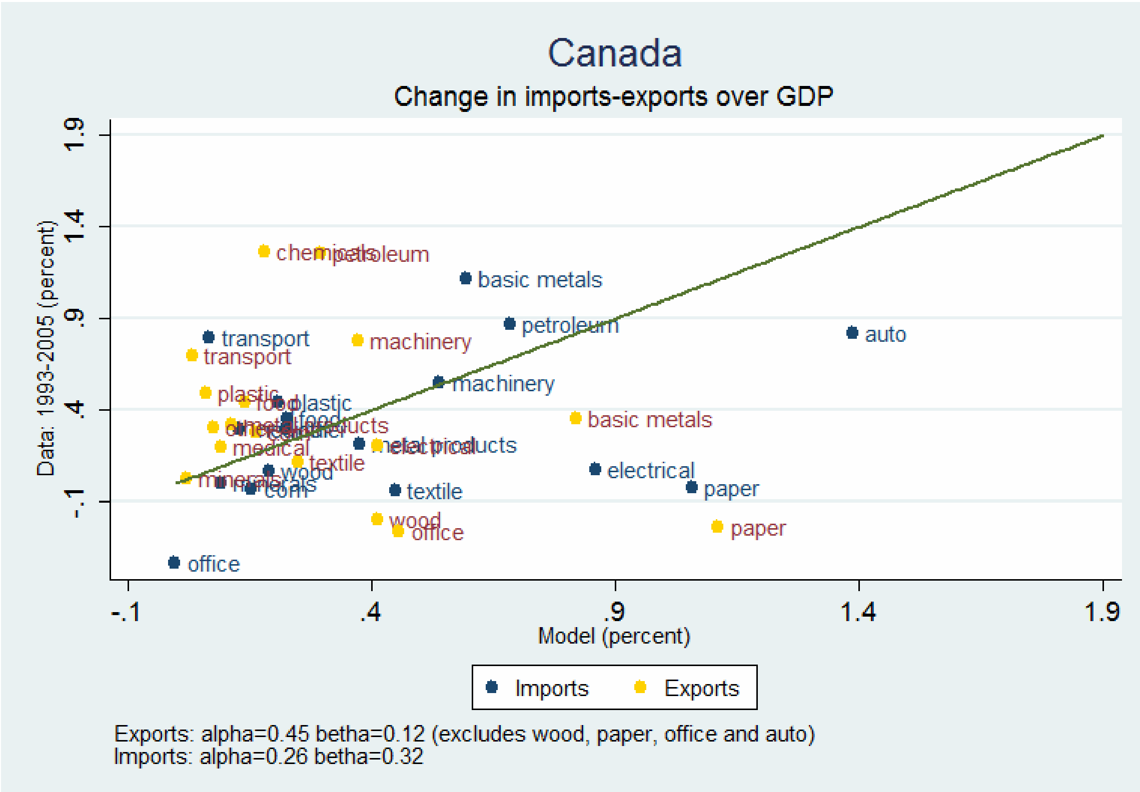
Note: I-O table for a construct rest of the world, non-tradable sectors. See Table 2.

Figure 10



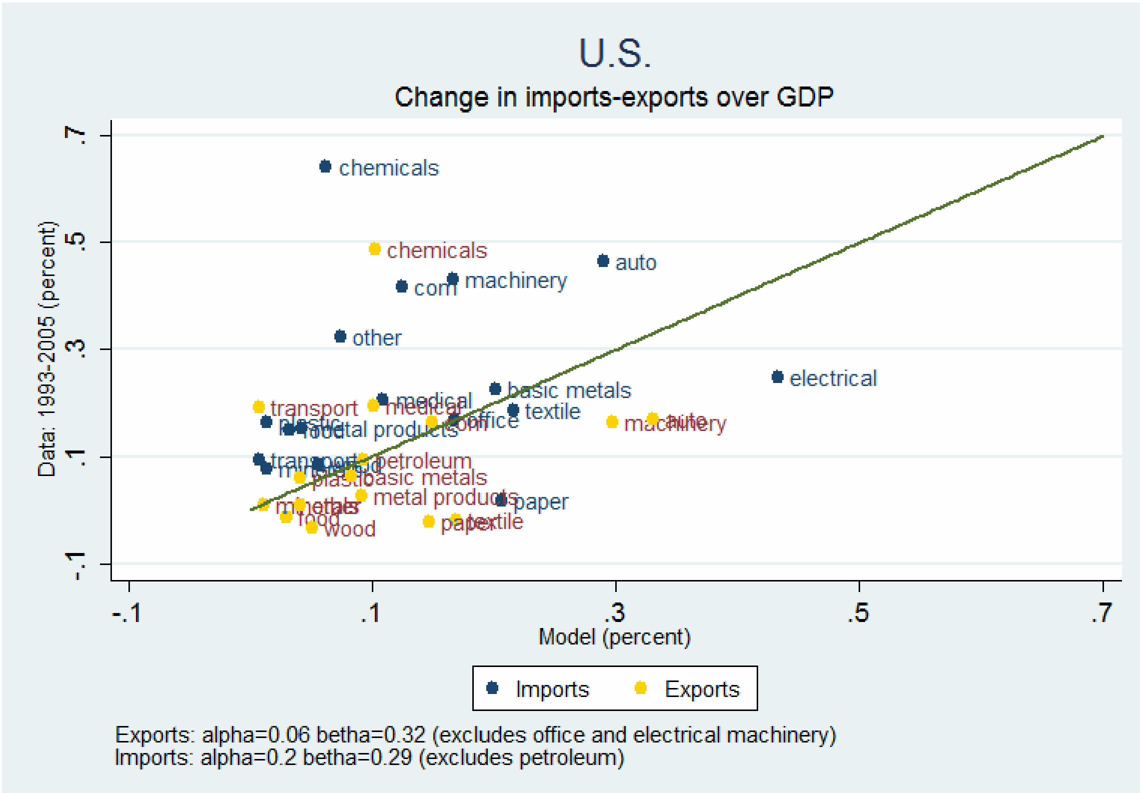
Note: In this figure we are comparing the difference between $x^j_{i,t+1}/\ y_{i,t+1}$ - $x^j_{i,t}/\ y_{i,t}$ from the model and the data; where $x^j_{i,t}$ are imports (or exports) from sector j and country i at time t and $y_{i,t}$ is GDP from country i at time t. y-axis are observed changes, x-axis model's simulations. The figure excludes electrical and auto imports.

Figure 11



Note: In this figure we are comparing the difference between $x^j_{i,t+1}/\ y_{i,t+1}$ - $x^j_{i,t}/\ y_{i,t}$ from the model and the data; 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. y-axis are observed changes, x-axis model's simulations. Figure excludes auto imports

Figure 12



Note: In this figure we are comparing the difference between $x^j_{i,t+1}/\ y_{i,t+1}$ - $x^j_{i,t}/\ y_{i,t}$ from the model and the data; 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. y-axis are observed changes, x-axis model's simulations. Figure includes all sectors

Data Appendix

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 wether 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) 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 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 which reported I-O tables for the year 2000: Austria, Belgium, the Czech Republic, Germany, Denmark, Spain, Finland, France, the United Kingdom, Hungary, Ireland, Italy, Japan, Korea, the Netherlands, Norway, New Zealand, Poland, Portugal, Russia, Slovakia, and Sweden.

Estimation Appendix

Estimation of Dispersion of Productivity

To estimate the dispersion of productivity, we collect data on trade flows and tariff rates for 17 economies: Argentina, Australia, Brazil, Canada, Chile, China, the Czech Republic, the European Union, India, Indonesia, Japan, Korea, New Zealand, Norway, Thailand and the United States. Brazil was dropped from the sample because it was experiencing a currency crisis (large devaluation, high inflation). These economies represent 82% of the world's trade in 1993 and at least 72% in each sector (see table below). Data on trade flows is from the United Nations Comtrade database for the year 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 (see table in Appendix-sectors). The reporter country is the importer, and imports are at CIF. values. Data on tariffs is from UNCTAD-TRAINS for the years 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 bilateral tariffs data is 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.

Head and Ries Index

In this section we describe an alternative way of estimating the dispersion of productivity using the methodology proposed by Head and Ries (2001). We present a detailed discussion on the estimation methodology, a description of the data used in the estimations and the problems with this methodology.

We start from the bilateral trade share equilibrium condition:

$$\pi_{ni}^{j} = \left(A^{j} B^{j}\right)^{-1/\theta^{j}} \left(\frac{c_i^j}{p_n^j} \kappa_{ni}^{j}\right)^{-1/\theta^{j}} \lambda_i^j \tag{34}$$

Using this equation for two pairs of countries and for the same sectors we can determine a relation between bilateral trade shares and trade costs. Time differencing and taking logs of the expression delivers an equation which can be used to estimate θ^j using data on bilateral

Table A1

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

trade shares and tariffs[58]:

$$\log\left(\widehat{\frac{X_{ni}^{j}X_{in}^{j}}{X_{ii}^{j}X_{nn}^{j}}}\right)=-\frac{1}{\theta^{j}}\log\left(\widehat{\kappa_{ni}^{j}\kappa_{in}^{j}}\right) \tag{35}$$

Note that this measure is a difference in difference cross-product of equation (10) in Eaton and Kortum (2002). Head and Ries (2001) and Head and Mayer (2002) refer to it as the country-pair odds ratio and use it in their estimations. The equation measures the change over time in bilateral trade of sector-specific goods for the pair of countries i, n. The empirical strategy is to take a long difference. The reason for this is that changes in tariffs can take time to adjust, and short time differences will not capture the correct magnitudes. Therefore, we take 1993 as the initial year and 2005 as the final year. We will assume that trade costs are divided between tariffs and geographic trade costs in the following way:

$$\log\kappa_{ni}^{j}=\log(1+\tau_{ni}^{j})-\log d_{ni}^{j}$$

where $\log d_{ni}^{j}$ is modeled as a linear function of cross-country characteristics:

$$\log d_{ni}^{j}=\phi_{ni}^{j}+\mu_{n}^{j}+\varepsilon_{j}$$

where $\phi_{ni}^{j}=\phi_{in}^{j}$ captures symmetry, not sector-specific, bilateral trade costs like distance, language, border effects and belonging to a FTA or not. μ_{n}^{j} is a destination sector effect cost that captures non-tariff barriers and it is assumed unilateral and common to all trading partners of country n. ε_{j} is an error term that captures the change in unobserved determinants of trade costs and is assumed orthogonal to the change in tariffs. Note that after taking time differences the term ϕ_{ni}^{j} drops out because it is assumed to be constant. Our identification restriction is that non-tariff barriers are orthogonal to tariffs[59]. From this estimation we identify values of θ^{j} for each sector and then use them in the model.

To estimate the dispersion of productivity using this methodology, we use a sample of 25 OECD countries: Australia, Austria, Canada, the Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Korea, Luxembourg, the Netherlands,

[58]Hat variables refer to differences in time. For instance, if we time difference over a span of two periods, $log\,(\widehat{y})=log\,(y_{t+1})-log\,(y_{t})$.

[59]The United Nations Conference on Trade and Development (UNCTAD, 2005) presents the most detailed estimation of non-tariff barriers (NTB) worldwide for the period 1994-2004. They show that NTB based on quantity and price controls decreased from 44.7% of tariff lines to 15% during that period. They also show that during the same time period, other forms of NTB increased from 55.3% to 84.8%. For instance, technical barriers to trade has increased from 31.9% to 58.5%, suggesting that effective NTB might have not changed over time. Beghin (2006) presents a summary of the results.

Norway, Poland, Portugal, Slovakia, Spain, Sweden, Switzerland, the United Kingdom and the United States. We collect data on trade flows and tariffs rates from UN COMTRADE and UNCTAD-TRAINS, respectively, for the years 1993 and 2005. For estimating the dispersion of productivity using equation (35) we also need data on value added. We collect data on value added from the OECD.stats database. This dataset compiles data on value added at the industry ISIC rev.3 level for OECD countries.

One caveat regarding using this approach is that in order to determine the value of home sales, X_{ii}^{j}, or what country i consumes of country i's j goods, one needs to infer this from the data since there is no direct measure of home sales. As we showed in the calibration section, this is calculated by taking the difference between gross production and total exports. The issue is that for some industries and some countries, the value of total exports could exceed the value of gross production[60]. This is a standard problem when working with data from different sources. To avoid dropping observations when this occurs we proceed as follows: whenever domestic sales are negative in both 1993 and 2005, we drop the observation. If domestic sales are negative in either 1993 or 2005 we keep the bilateral trade share that involves that domestic sales constant, using the value where they are positive. Table below reports the estimates using this approach, with and without controlling by an importer fixed effect. The correlation between this statistic and the one calculated using our method is 0.7. However, the estimated parameters seem to be unstable when we control with country fixed effects.

[60] There are several explanations for why this might happen, according to the Documentation of the OECD STAN database, exports can exceed production because exports may include re-exports; production data are often based on industrial surveys which allocate firms according to their primary activity, while exports of the related commodities might be recorded to their secondary activity; for many countries exports are valued at purchasers prices while production is often valued at basic prices; a bias may be introduced by the standard conversion from product-based trade statistics to activity-based industry statistics for certain sectors for certain countries. One way to avoid this problems is using the value of imports, which are generally declared at CIF, purchase prices. Another alternative is to aggregate over sectors to reduce the concordance problem. However, this last suggestion is not useful in our setup since the goal is to measure a dispersion productivity parameter sector by sector.

Table A2

Sectoral Dispersion Productivity-Odds Ratio Method				
			with fixed effects	
Sector Name	$1/\theta^j$	s.e.	$1/\theta^j$	s.e.
Agriculture	7.1	(11.5)	-5.9	(8.9)
Mining	25.7	(40.7)	40.7	(32.6)
Food	0.5	(2.9)	-4.3	(5.2)
Textile	5.9	(3.1)	-21.6	(6.0)
Wood	2.2	(5.1)	-2.1	(8.5)
Paper	5.7	(2.6)	-3.1	(6.5)
Pretroleum	25.6	(12.2)	7.4	(20.8)
Chemicals	23.0	(4.7)	5.5	(4.7)
Plastic	13.0	(3.4)	6.0	(11.2)
Minerals	0.3	(3.1)	-2.6	(7.6)
Basic metals	4.9	(8.5)	-21.0	(11.0)
Metal products	3.4	(4.6)	-8.1	(15.1)
Machinery nec	18.5	(4.5)	-3.8	(7.1)
Office	23.2	(19.2)	1.1	(15.9)
Electrical	26.4	(5.6)	15.1	(7.9)
Com	7.4	(6.8)	-0.2	(8.0)
Medical	14.5	(5.2)	75.1	(31.8)
Auto	23.7	(6.9)	14.5	(16.1)
Other Transport	24.0	(9.8)	-1.5	(9.7)
Other	4.6	(3.1)	-3.9	(5.0)

Technical Appendix

In this appendix we show how to derive the equilibrium conditions in relative terms, from $\tau \to \tau'$. We also describe in further details the optimization problem of the firms.

Equilibrium in relative terms

Consider the input bundle under policy τ'

$$c_n^{j\prime}(\hat{\mathbf{w}}) = w_n^{\prime\beta^j} \left(\prod_{k=1}^{J} p_n^{\prime k}(\hat{\mathbf{w}})^{\gamma^{k,j}}\right)^{\left(1-\beta^j\right)}$$

Now divide this equilibrium condition by the input bundle under policy τ

$$\frac{c_n^{j\prime}(\hat{\mathbf{w}})}{c_n^{j}(\hat{\mathbf{w}})} = \frac{w_n^{\prime\beta^j} \left(\prod_{k=1}^{J} p_n^{\prime k}(\hat{\mathbf{w}})^{\gamma^{k,j}}\right)^{\left(1-\beta^j\right)}}{w_n^{\beta^j} \left(\prod_{k=1}^{J} p_n^{k}(\hat{\mathbf{w}})^{\gamma^{k,j}}\right)^{\left(1-\beta^j\right)}}$$

We get:

$$\hat{c}_i^j\left(\hat{\mathbf{w}}\right) = \hat{w}_i^{\beta^j} \left(\prod_{k=1}^{J} \hat{p}_i^{k}(\hat{\mathbf{w}})^{\gamma^{k,j}}\right)^{\left(1-\beta^j\right)}$$

Let us consider how the price index of tradables j changes from equilibrium $\tau \to \tau'$. From (8) under policy τ'

$$p_i^{j\prime}\left(\hat{\mathbf{w}}\right) = A^j B^j \left(\sum\nolimits_n \left(c_n^{j\prime}\left(\hat{\mathbf{w}}\right)\kappa_{in}^{\prime j}\right)^{-1/\theta^j} \lambda_n^j\right)^{-\theta^j}$$

Dividing both sides by p_i^j,

$$\frac{p_i^{j\prime}\left(\hat{\mathbf{w}}\right)}{p_i^j} = A^j B^j \left(\sum\nolimits_n \left(\frac{c_n^{j\prime}\left(\hat{\mathbf{w}}\right)\kappa_{in}^{\prime j}}{p_i^j}\right)^{-1/\theta^j} \lambda_n^j\right)^{-\theta^j}$$

Using the definition of $\hat{p}_i^j$ and $\hat{c}_n^j$,

$$\hat{p}_i^j\left(\hat{\mathbf{w}}\right) = \left(\sum\nolimits_n \left(\hat{c}_n^j\left(\hat{\mathbf{w}}\right)\hat{\kappa}_{in}^j\right)^{-1/\theta^j} A^j B^j \left(\frac{c_n^j \kappa_{in}^j}{p_i^j}\right)^{-1/\theta^j} \lambda_n^j\right)^{-\theta^j}$$

Using equilibrium (8) under policy τ,

$$\hat{p}_i^j\left(\hat{\mathbf{w}}\right) = \left(\sum\nolimits_n \left(\hat{c}_n^j\left(\hat{\mathbf{w}}\right)\hat{\kappa}_{in}^j\right)^{-1/\theta^j} \pi_{ni}^j\right)^{-\theta^j}$$

The price index of non-tradables can be solved in the same way.

To derive the equilibrium condition (20) start from (10) under policy τ' :

$$\pi^{j\prime}_{ni}\left(\hat{\mathbf{w}}\right) = \left(A^j B^j\right)^{-1/\theta^j} \left(\frac{c^{j\prime}_i\left(\hat{\mathbf{w}}\right)}{p^{j\prime}_n\left(\hat{\mathbf{w}}\right)}\kappa^{\prime j}_{ni}\right)^{-1/\theta^j} \lambda^j_i$$

use the definition of $\hat{p}^j_i$ and $\hat{c}^j_n$

$$\hat{\pi}^j_{ni}\left(\hat{\mathbf{w}}\right)\pi^j_{ni} = \left(A^j B^j\right)^{-1/\theta^j} \left(\frac{\hat{c}^j_n\left(\hat{\mathbf{w}}\right)\hat{\kappa}^j_{in}}{\hat{p}^j_n\left(\hat{\mathbf{w}}\right)}\frac{c^j_i}{p^j_n}\kappa^j_{ni}\right)^{-1/\theta^j} \lambda^j_i$$

Divide both sides by π^j_{ni} and use the definition of the equilibrium condition (10) :

$$\hat{\pi}^j_{ni}\left(\hat{\mathbf{w}}\right) = \left(\frac{\hat{c}^j_n\left(\hat{\mathbf{w}}\right)\hat{\kappa}^j_{in}}{\hat{p}^j_n\left(\hat{\mathbf{w}}\right)}\right)^{-1/\theta^j}$$

Finally (23) is the same as equilibrium condition (18) under policy τ'.

Optimization problem

Households Problem

We let p^j_i be the price of the final good j, $p^j_i(x^j_i)$ is the price of the tradable good x^j_i and w_i wages. Households have Cobb-Douglas utility function. The problem they solve is:

$$\max_{\{C^j_i\}} \prod\nolimits_j [C^j_i]^{\alpha^j} \quad s.t: \sum\nolimits_j p^j_i C^j_i = I_i \tag{36}$$

where I_i is households wealth and α^j is the share of sector j goods in total final demand. The equilibrium conditions to this problem are:

$$\begin{aligned} p_i &= \prod\nolimits_j [p^j_i]^{\alpha^j} \Big/ \prod\nolimits_j \left[\alpha^j\right]^{\alpha^j} && (37) \\ p^j_i C^j_i &= \alpha^j I_i && (38) \end{aligned}$$

Households wealth is given by labor income and lump sum transfers from the government (tariff revenue as we will see in a moment).

Composite Intermediate

The producer of the intermediate aggregate purchases tradable goods from domestic and foreign firms in order to produce a sector specific composite good. They do so in a cost efficient way, therefore:

$$p_i^j q_i^j = \min_{q_i^j(x_i^j)} \int p_i^j(x^j) q_i^j(x^j) \phi^j\left(x^j\right) dx^j \quad s.t: \left[\int q_i^j(x^j)^{1-1/\eta^j} \phi^j\left(x^j\right) dx^j\right]^{\frac{\eta^j}{\eta^j-1}} \geqslant q_i^j \tag{39}$$

Note that $p_i^j q_i^j$ is the total expenditure on tradable goods in sector j. The solution to the problem is:

$$q_i^j(x^j) = \left[\frac{p_i^j(x^j)}{p_i^j}\right]^{-\eta^j} q_i^j \tag{40}$$

which is the optimal demand of tradable good x^j. Note that this good is not indexed by country since it can be purchased from any source. The price of the good, $p_i^j(x^j)$ is the effective price in market i of the good bought from the lowest cost supplier (potentially from abroad). We will derive in a moment the share of these goods bought from each source. Aggregating over all the tradable bought in industry j to produce the intermediate good q_i^j we find that the price of the composite good p_i^j is given by:

$$p_i^j = \left[\int p_i^j(x^j)^{1-\eta^j} \phi^j\left(x^j\right) dx^j\right]^{\frac{1}{1-\eta^j}} \tag{41}$$

Note that the aggregate price index in each sector will be affected by changes in the price of tradable goods, therefore tariffs impact the price of the composite goods.

Producer of Intermediate Varieties

In each country, the producer's of the tradable goods x_i^j hire labor and buy composite goods from all sectors in order to maximize profits (or equivalently in this problem, minimize costs):

$$p_i^j(x_i^j) q_i^j(x_i^j) = \min_{l_i^j(x_i^j), \left\{q_{mi}^k(x_i^j)\right\}_{k=1}^J} \sum\nolimits_{k=1}^J p_i^k q_{mi}^k(x_i^j) + l_i^j(x_i^j) w_i \tag{42}$$

$$s.t : \left[x_i^j\right]^{-\theta^j} \left[l_i^j(x_i^j)\right]^{\beta^j} \left[\prod\nolimits_{k=1}^J q_{mi}^k(x_i^j)^{\gamma^{k,j}}\right]^{(1-\beta^j)} \geqslant q_i^j(x_i^j) \tag{43}$$

The optimal demand of labor is given by:

$$l_i^j(x_i^j) = \beta^j \frac{p_i^j(x_i^j) q_i^j(x_i^j)}{w_i} \tag{44}$$

and the demand of each composite good by

$$q_{mi}^{k}(x_i^j) = \gamma^{k,j} \left(1 - \beta^j\right) \frac{p_i^j(x_i^j) q_i^j(x_i^j)}{p_i^k} \tag{45}$$

Note that we can easily allow for some firms not to demand some composite goods of certain sectors by simply setting $\gamma^{k,j} = 0$ for that particular sectors. Also note that the case of AL and EK is the one in which $\gamma^{j,j} = 1$. As is standard for the Cobb - Douglas technology case, the marginal cost or average cost is given by a geometric mean of the input costs:

$$p_i^j(x_i^j) = \frac{B^j}{[x_i^j]^{-\theta^j}} c_i^j$$

where B^j is a constant[61] and c_i^j is the cost of the input bundle :

$$c_i^j = {w_i}^{\beta^j} \prod\nolimits_{k=1}^{J} \left(p_i^k\right)^{\gamma^{k,j}\left(1-\beta^j\right)}$$

Since sectors are interrelated, the cost of the input bundle is impacted by changes in the price of goods from different sectors[62]. This is the channel in which a change in a tariff in one sector will affect the input bundle in other sectors.

[61] Given by $B^j = \prod\nolimits_{k=1}^{J} [\gamma^{k,j}]^{-\gamma^{k,j}\left(1-\beta_j\right)} \big/ {\beta^j}^{\beta^j} \left(1-\beta^j\right)^{\left(1-\beta^j\right)}$.

[62] In the Eaton and Kortum (2002) model, $\gamma^{j,j} = 1$; therefore changes in tariffs from other sectors will not have cross sectoral implications as they do in our model.