

Plant Heterogeneity and Applied General Equilibrium Models of Trade: Lessons from the Canada-US Free Trade Agreement

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Abstract

Applied General Equilibrium models of trade failed to predict the sectoral changes in trade volumes following the Canada-US Free Trade Agreement. These models utilized a representative firm framework and used econometric estimates for the elasticities of substitution between home and foreign goods. I take a different approach on both fronts, modeling plants as heterogeneous and calibrating the elasticities to match estimated markups in each sector. I introduce these features by adapting a Hopenhayn (1992) model of plant entry and exit and embed this in a multisector trade model. The resulting model is very similar to Melitz (2003), but I focus on quantifying the effects of trade liberalization on trade flows and industrial structure. I calibrate the model using trade data between the United States and Canada before their Free Trade Agreement and evaluate the model's performance using later data. By successively shutting down various features of the model, I isolate the contribution of each. I find that calibrating the elasticities to markups improves the fit between model predictions and data significantly, from weighted correlations which are negative to values of 0.36. Incorporating plant heterogeneity and industrial data improves the weighted correlation to 0.77.

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1 Introduction

Trade models often fail to capture important trade facts. The most striking example is the empirical observation that small, permanent decreases in tariffs generate large increases in trade volumes. I address this puzzle by modeling plants as heterogeneous production units.¹ This differs from the usual approach in trade theory, but recent work has begun to examine these issues. Traditional applied general equilibrium (AGE) models utilize a representative firm framework.² This assumption is clearly at odds with the data, but by definition, a model is an abstraction from reality. How important is the assumption of homogeneous plants?

To answer this question, I adapt a Hopenhayn (1992) model of firm entry and exit and embed this in a static multisector trade model with monopolistically competitive plants which are heterogeneous with respect to their productivity. Hopenhayn (1992) develops a model with plant dynamics to match entry and exit rates in US manufacturing. I do not incorporate dynamics, but some plants in this model set output equal to zero, which I define as exit. This exit provides an intuitive channel for welfare gains from trade which is lacking in traditional AGE models. Increased imports displace the lowest productivity domestic plants. Heterogeneous plants also provide an additional channel for trade growth following a tariff decrease. As tariffs fall, the profitability of exporting will increase, causing more plants to enter the export market. This study demonstrates the quantitative importance of such a channel.

My model is very similar to Melitz (2003) but is embedded in a Ricardian framework and incorporates intermediate goods. Traditionally, AGE models have focused on interindustry reallocation of resources and only sparsely modeled reallocation within sectors. This paper investigates the quantitative predictions of intraindustry reallocation of resources following a change in barriers to trade. More precisely, lowering tariffs results in a larger measure of exporting plants, which displaces former domestic production through explicitly modeled exit of unproductive plants, freeing resources for more productive plants. Productivity in the sector will be influenced through this selection process.

¹I use the terms production units, plants, and establishments interchangeably.

²AGE models have also been known as Computable General Equilibrium Models or General Equilibrium Trade Models. Following Shoven and Whalley (1984), I use AGE to denote this literature.

Modeling production at the plant level provides a new dimension of data to compare to the model's predictions following a tariff decrease, such as plant size, plant productivity, and fraction of plants exporting. Empirical work shows that many of these facts are at odds with the assumption of homogeneous plants. Bernard, Eaton, Jensen, and Kortum (2003) detail these discrepancies; using a different approach, they reconcile many of the plant level facts for manufacturing as a whole. Because these industrial organization facts differ considerably across sectors, I model each two digit Standard Industrial Classification (SIC) code separately. This disaggregated approach also allows more emphasis on intermediate goods, a large component of trade between US and Canada (CA).

I examine manufacturing sectors in US and CA before and after the Canada-US Free Trade Agreement (CAUSFTA) which was signed in 1987 and implemented in early 1989. I define a sector to be a two digit SIC code in manufacturing.³ I restrict detailed analysis to manufacturing sectors primarily due to data considerations and applicability of industrial organization models. Both countries record a wide variety of data for manufacturing that is unavailable for other parts of the economy. I calibrate the model using trade data between the US and CA before their Free Trade Agreement of 1989 and evaluate the model's performance using data following the agreement.

Key inputs into AGE trade models are the elasticities of substitution between foreign and domestic goods. Typically these elasticities are drawn from econometric estimates based on trade flows and relative prices. I take a new approach and calibrate the elasticities to match estimated markups in each manufacturing sector. To highlight the contribution of this procedure, I present an AGE trade model with homogeneous plants using this technique and compare the results to the heterogeneous plant version. I find that choosing elasticities to match estimated markups significantly improves the fit between model prediction and data, especially for changes in trade flows following the CAUSFTA. The weighted correlations in earlier studies have been negative, and I find 0.36.⁴ Adding heterogeneous plants further improves the weighted correlation to 0.77.

The paper proceeds as follows. Section (2) reviews the related literature.

³All data conformed to the 1987 US SIC codes.

⁴Kehoe (2005) analyzes earlier models of the CAUSFTA and finds negative weighted correlations for trade flows.

Section (3) establishes the set of facts that motivate this study. Section (4) details the model. Section (5) outlines the calibration for the benchmark model. Section (6) describes the preliminary results. Section (7) concludes. Appendix A details all of the data used in the paper.

2 Related Literature

For recent trade negotiations, government policymakers have increasingly turned to AGE models to predict the economic effects of trade liberalizations. AGE models are typically multisector, to better address the concerns of individual industries caused by lowering trade barriers. Policymakers rely on economists to provide guidance concerning the probable outcomes of policy changes. AGE models represent the best tool for modeling the effects of lowering trade barriers. Effects of interest include sectoral changes in trade flows, employment, output per worker, and plant size, as well as the economy-wide welfare effects. AGE models are especially suitable for tracing the effects of a policy change through the economy as a whole, as well as providing estimates of welfare changes.

AGE models aim to translate the Walrasian general equilibrium structure from abstract representations of economies into realistic quantitative models. Arrow and Debreu (1954) provided the formal structure necessary for this approach, while Scarf (1967) developed an algorithm for solving such models. First designed to answer various policy questions within a single country, subsequent work used these models to evaluate various trade policies. Armington (1969) greatly simplified this application by assuming that goods were differentiated by the country of origin. This model innovation allowed trade models to match the strong evidence of cross-hauling, i.e. trade flows in both directions, even within disaggregated product classes. Traditional trade models predicted complete specialization based on comparative advantage. Another troubling fact for older models was that most trade occurred between similar, developed countries. Krugman (1979) incorporated the industrial organization theory of monopolistic competition developed by Dixit and Stiglitz (1977) into trade theory as a way of generating this fact in addition to cross-hauling. This ‘New Trade Theory’ differentiates goods by production unit rather than by the country of production.

These models typically use as inputs econometric estimates of the elasticity of substitution between home and foreign goods. For North America,

these estimates are usually low, lying in the interval $(0, 2)$, with many clustering near one. Reinert and Roland-Holst (1992a) and Shiells and Reinert (1993) are representative of North American estimates. Recent work by Erkel-Rousse and Mirza (2002) and others has cast doubt on these low elasticity estimates. I take a different approach by using industrial organization estimates of markups. Given the modeling framework I use, there is a one-to-one mapping between elasticity and markups. Elasticities of one imply an infinite markup, an implication strongly at odds with the markup literature. Markup estimates for US manufacturing range from 5, as in Hall (1988), to 1.05, as in Martins, Scarpetta, and Pilat (1996). These markups imply elasticities of substitution between varieties of 1.2 and 20, respectively. The estimates of Martins, Scarpetta, and Pilat (1996) are similar for 12 OECD countries.

3 Facts

Recent work has established a set of facts that quantitative models must address. I document these facts and briefly discuss the model's implications regarding each of these facts.

CA-US trade in manufacturing increased following the implementation of the CAUSFTA. Table 1 shows changes in US exports to CA and US imports from CA for each two-digit SIC code. The last two columns of Table 1 detail the prevailing tariffs on imports in each country. These tariffs have been computed as the average across the 8 digit Harmonized System in each country; the US and CA have identical wording for each 8 digit category. Table 1 demonstrates that even small changes in the prevailing tariffs can cause large changes in trade flows.

The literature provides multiple ways of expressing tariff barriers. Trade weighted measures of tariffs understate the barriers caused by tariffs because the highest tariffs discourage trade and thus receive small weights. Another measure commonly found in the literature is that of effective protection.⁵ Trefler (2001) documents this reduction in effective protection from 12% to 4% for Canadian imports after the implementation of the CAUSFTA. Due to the high variance among tariffs, Trefler (2001) stresses the need to study

⁵Following Basevi (1966), effective protection summarizes all of the tariff rates that affect the final product by summing the products of tariff rates and intermediate usage across other sectors.

Table 1: CAUSFTA Trade and Tariff Changes

Sector	US Exports	US Imports	US tariff	CA tariff
Foods	93.0	46.0	11.5	13.2
Tobacco	41.4	-15.5	10.7	16.0
Textiles	120.8	254.9	7.7	8.9
Clothing	244.8	138.3	17.2	11.1
Wood	50.0	69.6	14.3	2.7
Furniture	671.3	203.9	3.8	12.6
Paper	63.7	47.0	2.5	4.0
Printing	60.9	49.6	0.7	2.2
Chemicals	106.1	115.1	3.4	5.6
Petroleum and Coal	14.0	16.1	0.4	0.5
Rubber and Plastics	199.1	100.9	8.8	8.9
Leather	16.9	102.7	7.9	16.2
Non-metallic Minerals	80.5	115.5	0.5	0.5
Primary Metals	127.9	57.5	6.4	5.3
Fabricated Metals	109.0	125.2	4.2	7.7
Industrial Machinery	45.5	63.4	5.5	5.6
Electronics	124.3	219.6	4.7	7.0
Transportation	23.5	47.1	0.5	2.3
Miscellaneous	59.8	68.3	3.7	7.1

Table 1: Percentage changes in US exports to CA and US imports from CA as a fraction of GDP, for the years 1987-1996. Tariffs adapted from Magun, Rao, and Lodh (1988). Includes tariffs and tariff equivalents of non-tariff barriers.

manufacturing at a disaggregated level to avoid obscuring the effects of the FTA. This study specifically addresses this issue.

There has been a general trend towards lowering world trade barriers over the last half century. Regional trading agreements have played a large role in this decrease. The CAUSFTA lowered tariff barriers as well as non-tariff barriers (NTB's). The reduction in NTB's is more difficult to quantify. Several authors provide estimated tariff equivalents for various NTB's; Lester and Morehen (1988) conclude that NTB's raised prices by 1.6% in CA and by 1.9% in US in the mid 1980's. Table 1 incorporates NTB's by sector, as estimated by Magun, Rao, and Lodh (1988). CAUSFTA eliminated tariffs in 3 ways. Some of the 8 digit Harmonized System codes had tariffs immediately removed; other codes had their tariffs slowly removed in equal steps over five or ten years. The majority of codes had tariffs removed over time; those codes with the higher tariffs were predominantly removed in steps. I examine trade data from 1987 and 1996, allowing all tariffs to reach zero.

Using restricted plant-level data, numerous recent studies have established a set of facts for US manufacturing. Several studies have demonstrated that higher productivity plants are more likely to export than lower productivity plants. Bernard and Jensen (1999a) examine US manufacturing data and conclude that more productive plants self select into exporting. Girma, Greenaway, and Kneller (2002) find similar evidence for the United Kingdom. This fact is clearly at odds with the representative firm framework typical in AGE models. A second important fact, well documented by Bernard, Eaton, Jensen, and Kortum (2003), concerns prevalence of exporting. Few plants export, and most exporters export only a small fraction of their shipments, though this fraction does vary considerably across plants and industries. While econometric studies often incorporate this in some way, most AGE models typically ignore these facts by using a representative firm framework. Explicitly modeling heterogeneous production units is important for matching the evidence from trade liberalizations. Bernard, Jensen, and Schott (2003) provide ample evidence that lowering trade barriers in a sector increases the probability that plants in that sector exit or become exporters, as well as existing exporters increasing their exports. These are precisely the predictions of heterogeneous plant models.

Homogeneous plant models predict that every plant exports the same fraction of output. This model abstraction obscures an important margin, the reallocation of resources within manufacturing. This reallocation is important for several reasons. Productivity within the sector will increase when

more productive plants absorb labor that was previously used by less productive plants. This rationalization of production will also increase exporting as countries lower trade barriers. Bernard and Jensen (1999b) argue that 40% of the total factor productivity growth in manufacturing is due to this reallocation within manufacturing sectors. Exporting plants receive a disproportionate amount of this reallocation. Furthermore, policymakers are often interested in employment outcomes. The representative firm framework obscures intraindustry reallocations, as documented in Levinsohn (1996) for Chilean manufacturing. I capture these important dimensions of the data by explicitly modeling heterogeneous plants. Roberts and Tybout (1997) find strong econometric evidence of a sunk cost related to exporting for Columbian plants. Melitz (2003) demonstrates that uncertainty concerning a plant's productivity moves towards capturing these facts. I aim to quantitatively assess the extent a calibrated model with these features can match the plant level and trade data.

4 Model

4.1 Model overview

I develop a static two-country, US and CA, model with multiple sectors in each country. There is a non-manufacturing sector, A , and multiple manufacturing sectors, indexed by j . The former is competitive and exhibits constant returns to scale. The manufacturing sectors are monopolistically competitive and exhibit increasing returns to scale. The fundamental unit of production in the model is the plant, which acts as a profit maximizer. Plants in each manufacturing sector j produce differentiated varieties, indexed by ω , engage in Cournot competition, and are heterogeneous in their productivity. These differentiated goods appeal to the consumers' taste for variety, as well as providing monopoly power to each plant. Plants in the manufacturing sector must pay fixed costs to operate. Following Samuelson (1954), tariffs are modeled as iceberg transport costs which are rebated to consumers as lump sum transfers.⁶ The non-manufacturing sector serves primarily to balance trade flows and pin down wages between the two countries, as in Helpman, Melitz, and Yeaple (2002). I suppress subscripts when possible for clarity of

⁶Iceberg transportation costs imply that some fraction τ of the good is collected by the government.

presentation. All of the Ω sector characteristics vary by sector.

4.2 Consumers

Below we detail the consumer's problem for a US consumer. The CA consumer's problem is analogous. US consumers rank consumption bundles using the following utility function:

$$(1) \quad U(c_{US,j}(\cdot), c_{CA,j}(\cdot), C_A, \Omega_{US,j}, \Omega_{CA,j}) = \sum_j \theta_j \log \left(\alpha_{US,j} \int_{\omega \in \Omega_{US,j}} c_{US,j}(\omega)^{\frac{\sigma_j-1}{\sigma_j}} \mu_{US,j}(\omega) d\omega + \right. \\ \left. (1 - \alpha_{US,j}) \int_{\omega \in \Omega_{CA,j}} c_{CA,j}(\omega)^{\frac{\sigma_j-1}{\sigma_j}} \mu_{CA,j}(\omega) d\omega \right)^{\frac{\sigma_j}{\sigma_j-1}} + \left(1 - \sum_j \theta_j \right) \log C_A$$

where σ_j is the elasticity of substitution between different varieties ω in sector j . The set of goods produced by sector j in country i is represented by $\Omega_{i,j}$. The measure of plants producing varieties in country i , sector j , is $\mu_{i,j}(\omega, j)$. $c_{i,j}(\omega)$ represents the quantity of variety ω produced in country i by sector j consumed by a US agent. The home bias parameter varies by sector and is denoted by $\alpha_{i,j}$. The home bias parameter is a common feature in AGE models; values larger than 0.5 imply that consumers have a preference for goods produced in their home country. In this framework, the home bias parameters are isomorphic to increased transportation costs. The non-manufacturing sectors are captured by the aggregate good C_A .

US consumers maximize equation (1) subject to the following budget constraint:

$$(2) \quad \sum_j \left(\int_{\omega \in \Omega_{US,j}} p_{US,j}^{US}(\omega) c_{US,j}(\omega) \mu_{US,j} d\omega \right) + \\ \sum_j \left(\int_{\omega \in \Omega_{CA,j}} p_{CA,j}^{US}(\omega) c_{CA,j}(\omega) \mu_{CA,j} d\omega \right) + p_A C_A \leq wL + g + \Pi$$

where p_A , g , Π , w , and L refer to the price of the aggregate good, government

transfers, profits, wage rate, and inelastically supplied labor respectively.⁷ Subscripts on prices refer to country of origin, while superscripts refer to country of consumption. The government transfers will be the rebated iceberg transportation costs. The Canadian consumer's problem is analogous.

The US price and quantity indexes for a single manufacturing sector j , $P_{US,j}$, $C_{US,j}$ corresponding to the above problem are below.

$$(3) \quad P_{US,j} = \left[\left(\frac{1}{\alpha_{US,j}} \right)^{-\sigma_j} \int_{\omega \in \Omega_{US,j}} p_{US,j}^{US}(\omega)^{1-\sigma_j} \mu_{US,j}(\omega) d\omega + \left(\frac{1}{1 - \alpha_{US,j}} \right)^{-\sigma_j} \int_{\omega \in \Omega_{CA,j}} p_{CA,j}^{US}(\omega)^{1-\sigma_j} \mu_{CA,j}(\omega) d\omega \right]^{\frac{1}{1-\sigma_j}}$$

$$(4) \quad C_{US,j} = \left(\alpha_{US,j} \int_{\omega \in \Omega_{US,j}} c_{US,j}(\omega)^{\frac{\sigma_j-1}{\sigma_j}} \mu_{US,j}(\omega) d\omega + (1 - \alpha_{US,j}) \int_{\omega \in \Omega_{CA,j}} c_{CA,j}(\omega)^{\frac{\sigma_j-1}{\sigma_j}} \mu_{CA,j}(\omega) d\omega \right)^{\frac{\sigma_j}{\sigma_j-1}}$$

Note that

$$P_{US,j} C_{US,j} = \int_{\omega \in \Omega_{US,j}} p_{US,j}^{US}(\omega) c_{US,j}(\omega) \mu_{US,j}(\omega) d\omega + \int_{\omega \in \Omega_{CA,j}} p_{CA,j}^{US}(\omega) c_{CA,j}(\omega) \mu_{CA,j}(\omega) d\omega$$

by construction.

4.3 Technology

Careful modeling of plant level characteristics constitutes the innovation of this study. There are J manufacturing sectors, populated by heterogeneous plants which exhibit increasing returns to scale. There is a non-manufacturing sector, which exhibits constant returns to scale. Due to the

⁷Due to free entry, Π will be zero in equilibrium. Ownership of plants is equally distributed across consumers. Profits at operating firms will be positive and balanced by the fixed costs of paid by non-operating firms. This simplifying assumption corresponds to perfect capital markets.

importance of intermediate goods in international trade, this is a gross shipments model. Part of output goes to consumers for consumption, while the remaining output is used as intermediate goods in the production of all sectors. Consumers gain utility from the final goods produced by plants. All sectors combine labor and materials to make output. Materials are a composite of other sectors' output. I first detail the technology for producing the aggregate good, A . A description of production in the manufacturing sectors follows.⁸

4.3.1 Aggregate Good A

The A sector is constant returns to scale and perfectly competitive. A plant in the aggregate good sector combines materials and labor to produce output in the following fashion:

$$y_A = A m^\zeta n_A^{1-\zeta}$$

where materials are in turn made up of a composite of other sector outputs as follows:

$$m = m_{A,A}^{1-\sum_j \lambda_j} \prod_j m_{j,A}^{\lambda_j}$$

Materials produced in sector j and destined for sector A are denoted by $m_{j,A}$. In a slight abuse of notation, A refers to the aggregate good sector as well as productivity in that sector, but the meaning should be clear from the context. The aggregate good is freely traded, making it a natural choice for the numeraire good. When taken to the data, the A sector will represent all non-manufacturing economic activity.

4.3.2 Manufacturing Sectors Ω_j

There are J manufacturing sectors indexed by j . Although the parameters specific to the Ω_j sector differ by country, I suppress that notation when possible to simplify the exposition. I will also suppress the j subscript whenever possible, but all parameters will vary by sector. I model production decisions at the plant level rather than the firm level. This is primarily because of data limitations. Clausing (2000) provides empirical support for this abstraction.

⁸The standard AGE trade model is a special case of the heterogeneous plant model. If the fixed cost of exporting, f_e , is zero and the productivity distribution is degenerate, then all plants make identical decisions to export a fixed fraction of output and produce differentiated varieties.

Production in the Ω sectors generally exhibits increasing returns to scale and market power over varieties specific to each plant. Plants differ by their productivities, denoted by ψ .

The model incorporates increasing returns technology by offering plants a menu of fixed costs they may choose to pay. Plants pay a fixed cost f to receive a productivity draw, ψ from the distribution $F(\psi)$, which determines the plant's marginal cost of production. Plants must also pay a fixed cost to produce output, f_p and another fixed cost to export, f_e . Within a sector j , I order plants by their productivities, as ψ completely characterizes a plant. All plants with the same productivity ψ have the same input demands, outputs, and make the same exporting decisions; although they produce distinct varieties ω . The cost of the draw is a sunk cost. I use the term variable profits to denote the profits earned before the fixed cost of a draw is added to the plant's costs.

A plant which has purchased a draw has three options: produce zero output because variable profits do not exceed the fixed cost of producing output, operate only in the domestic market because variable profits from exporting will not cover the fixed cost of exporting, or operate in both domestic and foreign markets because the variable profits from exporting exceed the fixed cost of exporting. The three options refer to plants with the lower, mid-range, and higher productivity draws respectively. More formally, a plant which has purchased a draw solves:

$$\max\{0, \pi_d(\psi), \pi_e(\psi)\}$$

where π_d and π_e refer to profits from domestic only production and profits from exporting respectively.

I present the various maximization problems facing a US plant. The Canadian plants face a similar problem. A firm in sector j with productivity ψ will solve the following problem to determine profits from domestic operations:

$$\pi_d(\psi) = \max_{(y_d, n_{d,j}, m_{A,\Omega_j}, m_{\Omega,j}, p_d)} p_d y_d - w n_{d,j} - p_A m_{A,\Omega_j} - p_{\Omega_j} m_{\Omega,j}$$

subject to

$$m_{\Omega,j} = \min\left\{\frac{m_{1,j}}{a_{1,j}}, \dots, \frac{m_{J,j}}{a_{J,j}}\right\}$$

$$y_d = \psi \left[(m_{A,\Omega_j}^\eta m_{\Omega,j}^{1-\eta})^\beta n_d^{1-\beta} - f - f_p \right]$$

$$p_d = \frac{\alpha P_{\Omega}^{\frac{\sigma-1}{\sigma}} E_{\Omega}^{\frac{1}{\sigma}}}{y_d^{\frac{1}{\sigma}}}$$

where $y_d(\psi)$ and $n_d(\psi)$ are the outputs and labor inputs for this good, σ is the elasticity of substitution between varieties, and f_p is a fixed production cost. The subscript d denotes that the quantities apply to domestic only producers. The materials purchased from other manufacturing sectors are aggregated into $m_{\Omega,j}$ using a Leontif production function with unit input requirements $a_{i,j}$. As above, materials produced in sector i and destined for sector j are denoted by $m_{i,j}$. Solving the consumer's problem yields the inverse demand function, p_d .

In addition to the fixed cost of operating, f_p , a plant in sector j may choose to pay f_e to enter the export market if its productivity draw is sufficiently large. Thus after purchasing a productivity draw, a plant that chooses to export solves the following problem:

$$\pi_e(\psi) = \max_{\{n_e, m_{A,\Omega_j}, m_{\Omega,j}, y_{US}^{US}, y_{US}^{CA}, p_{US}^{US}, p_{US}^{CA}\}} p_{US}^{US} y_{US}^{US} + p_{US}^{CA} y_{US}^{CA} - w_{US} n_e - p_A m_{A,\Omega_j} - p_{\Omega,j} m_{\Omega,j}$$

subject to

$$m_{\Omega,j} = \min \left\{ \frac{m_{1,j}}{a_{1,j}}, \dots, \frac{m_{J,j}}{a_{J,j}} \right\}$$

$$y_{US}^{US} + \frac{y_{US}^{CA}}{1 - \tau_{US}} = \psi \left[(m_{A,\Omega}^\eta m_{\Omega,\Omega}^{1-\eta})^\beta n_e^{1-\beta} - f_e - f_p - f \right]$$

$$p_{US}^{US} = \frac{\alpha_{US} P_{\Omega,US}^{\frac{\sigma-1}{\sigma}} E_{\Omega,US}^{\frac{1}{\sigma}}}{(y_{US}^{US})^{\frac{1}{\sigma}}}$$

$$p_{US}^{CA} = \frac{(1 - \alpha_{CA}) P_{\Omega,CA}^{\frac{\sigma-1}{\sigma}} E_{\Omega,CA}^{\frac{1}{\sigma}}}{(y_{US}^{CA})^{\frac{1}{\sigma}}}$$

where y_i^j and p_i^j denote the output and price of a good produced in country i and consumed in country j . The subscript e indicates that the functions apply to exporting plants. The materials purchased from other manufacturing sectors are aggregated into $m_{\Omega,j}$ using a Leontif production function with unit input requirements $a_{i,j}$. Again, the solution to the consumer's problem

yields the inverse demand functions for each country. Traded goods in this sector face iceberg transportation costs, which are rebated to the consumer as a lump sum.

4.4 Equilibrium

The definition of equilibrium requires extensive notation. Subscripts refer to the country of production, while superscripts refer to the country of consumption. I begin with the necessary objects in each Ω_j sector, followed by the objects for the A sector. An equilibrium is defined as a set of functions mapping varieties ω into quantities consumed in the two countries, $\{c_{US}^{US}, c_{CA}^{US}, c_{US}^{CA}, c_{CA}^{CA}\}$, a set of functions mapping varieties into quantities produced, $\{y_{US}^{US}, y_{US}^{CA}, y_{CA}^{US}, y_{CA}^{CA}\}$, a set of functions mapping varieties to labor and materials purchased by domestic only plants, d , and exporting plants, e , for each country i and sector j , $\{n_{i,j}^d, n_{i,j}^e, m_{\Omega,j,i}^d, m_{A,\Omega_j,i}^d, m_{\Omega,j,i}^e, m_{A,\Omega_j,i}^e\}_{i=US,CA}$, a set of functions mapping varieties to prices for each country i and each type of plant, $\{p_i^d, p_i^e\}_{i=US,CA}$, relevant quantities for the A sector for each country i , $\{y_{A,i}, m_{A,A,i}, m_{\Omega,A,i}, n_{A,i}\}_{i=US,CA}$ such that:

1. Given prices, the functions above solve the consumers' problem
2. Given prices, the functions above solve the plants' problems
3. Labor and product markets clear
4. Zero expected profits for entrants in each sector in each country

Melitz (2003) provides a uniqueness and existence proof for a single sector version of this economy.

5 Calibration

I calibrate the model by choosing parameters such that the equilibrium of the model exactly reproduces the data from 1987, which I treat as the base year. For many of the parameters, this is a straightforward process of deriving an algebraic relationship in the model and reading the parameter value from the data. This is the traditional AGE calibration process. I call calibrating these parameters the independent calibration, as values for these parameters can be found independently of each other. Because of the plant heterogeneity, some

parameters do not have simple analytic relationships with the data. For these parameters, I choose a number of facts equal to the number of parameters to match and adjust these parameters until model output matches the chosen facts. I call this process the interdependent calibration.

The following details the independent calibration. I choose the total labor in each economy to match employment in each country, because this is a static model that does not focus on the labor supply decision. The productivity in the aggregate good sector, A , is chosen to match gross shipments in each country. The utility share parameters, θ , are chosen to match the consumption share of goods. The CES between varieties, σ_j , is chosen to match the gross output markups estimated by Martins, Scarpetta, and Pilat (1996). I use US estimates for both countries, as it is a preference parameter. Martins, Scarpetta, and Pilat (1996) find similar markups for all OECD countries, providing support for using the US estimates. I also assume that plants exhibit the same elasticity of substitution between varieties as consumers when purchasing materials. It is important to note that these markups imply much higher values for elasticity than in standard in AGE models. Traditionally, AGE models have used econometric estimates of the elasticity of substitution between home and foreign goods as the CES between differentiated varieties.⁹ The estimated elasticities imply implausibly large markups, infinity for many categories. Table 2 details the elasticities and implied markups by sector. The value for the iceberg tariffs is taken from Table 1, with the estimated transportation costs taken from Hummels (1999) added. The share parameters for the various materials usage, β, η, ζ , and $a_{i,j}$, are taken from the input-output tables for each country. Given σ_j , there is a one to one mapping between plant employment and plant productivity. I model the productivity distribution as Pareto, minimizing the sum of squared differences between the implied and actual employment distribution for the each country in each sector.

Interdependent calibration is required for the home bias parameters, the fixed cost of a draw, the fixed cost of production, and the fixed cost of exporting. This gives us eight parameters per sector. To select these eight parameters, I exactly match the following facts for both countries: total exports, the number of establishments, the fraction of establishments exporting,

⁹By substituting $C = \int_{\omega \in \Omega_{US}} c_{US}(\omega)^{\frac{\sigma-1}{\sigma}} \mu_{US}(\omega) d\omega$ and $C^* = \int_{\omega \in \Omega_{CA}} c_{CA}(\omega)^{\frac{\sigma-1}{\sigma}} \mu_{CA}(\omega) d\omega$, this model becomes the traditional Armington model, where the goods C and C^* are only distinguished by country of origin.

Table 2: Markups and Implied Constant Elasticity of Substitution (CES) between Varieties

Sector	Markups	CES
Foods	1.05	21.0
Tobacco	1.56	2.8
Textiles	1.08	13.5
Clothing	1.10	11.1
Wood	1.22	5.5
Furniture	1.06	17.7
Paper	1.13	8.7
Printing	1.19	6.3
Chemicals	1.31	4.3
Petroleum and Coal	1.05	21.0
Rubber and Plastics	1.07	15.3
Leather	1.08	13.5
Non-metallic Minerals	1.13	8.7
Primary Metals	1.12	9.3
Fabricated Metals	1.09	12.1
Industrial Machinery	1.06	17.7
Electronics	1.54	2.9
Transportation	1.10	11.1
Miscellaneous	1.09	12.8

Table 2: Markups from Martins, Scarpetta, and Pilat (1996). CES utility function implies $\sigma = \frac{\mu}{\mu-1}$, where μ is the markup.

and the size ratio of the top quintile to bottom quintile of plants by sales. The literature provides little to no guidance on calibrating the various fixed costs. I provide no uniqueness proof for the calibrated parameters that I use, but I did arrive at the same calibrated parameters from hundreds of different starting values for the interdependent calibration.

6 Results

The following section reports the results for bilateral tariff removal between the two countries. I report three sets of results. The first set is a standard AGE trade model, identical to the model described above, but with the fixed costs of exporting set to zero and a degenerate productivity distribution. The second set of results maintains the homogeneous nature of plants, but I use econometric estimates on markups to calibrate the elasticities of substitution. The final set of results incorporates plant heterogeneity as described above. In all experiments, I fully eliminate tariffs and compare the model's predicted changes in trade flows to the actual changes in trade flows ten years after the CAUSFTA went into effect. Barriers to trade are not eliminated; the transportation costs cited in Hummels (1999) remain. In all experiments, the the rest of the world is aggregated into a single country with no changes to tariffs.

There are many summary statistics which quantify goodness of fit. Following Kehoe (2005), I evaluate the fit between model prediction and data by reporting the weighted correlation between actual changes in trade flows from 1987 to 1996 and the model's predicted changes in trade flows for complete tariff elimination. The correlation is weighted by sector shipments in the base year, 1987. To compute the weighted correlation between model, y , and data, \hat{y} , with n observations, construct the following relationships: first compute the weighted mean of percentage changes for both data and model

$$\bar{y} = \sum_{i=1}^n \gamma_i y_i \quad \bar{\hat{y}} = \sum_{i=1}^n \gamma_i \hat{y}_i$$

where γ_i is sector i 's share of total shipments. Next, calculate the weighted variance of these vectors of changes, $var(y)$, as

$$var(y) = \sum_{i=1}^n \gamma_i^2 (y_i - \bar{y})^2 \quad var(\hat{y}) = \sum_{i=1}^n \gamma_i^2 (\hat{y}_i - \bar{\hat{y}})^2$$

The covariance between the model and data, $cov(\hat{y}, y)$, is

$$cov(\hat{y}, y) = \sum_{i=1}^n \gamma_i^2 (y_i - \bar{y})(\hat{y}_i - \bar{\hat{y}})$$

The weighted correlation coefficient between y and \hat{y} is

$$corr(y, \hat{y}) = \frac{cov(\hat{y}, y)}{[var(\hat{y})var(y)]^{\frac{1}{2}}}$$

The weighted correlation coefficient, $corr(y, \hat{y})$, measures to what degree the predictions were correct in direction and relative magnitudes; it does not account for absolute magnitudes.

Another measure of fit, also used by Kehoe (2005), is the slope and intercept from a weighted least-squares regression of actual changes on predicted changes:

$$\hat{y}_i = a + by_i + \epsilon_i$$

where ϵ_i is an error term. Specifically, a and b solve the following problem:

$$\min \sum_{i=1}^n \gamma_i (a + by_i - \hat{y}_i)^2$$

The deviation of the intercept, a , from zero captures the model's failure to match the average changes. The deviation of the slope, b , from 1 captures the model's failure to match the signs and absolute magnitudes of the changes. I report these three statistics for all experiments.

6.1 Standard AGE Model

For the first experiment, I build a standard AGE model of the US and Canada. I use the same aggregation as described above. All non-manufactured output is produced using constant returns to scale technology under perfect competition. Each manufacturing sector incorporates increasing returns to scale with firms engaging in monopolistic competition. Monopolistic firms set prices according to a constant markup over marginal costs. These simplifications reduce the model to something very similar to Brown and Stern (1989) or Fox (1999), as plants are homogeneous and all make identical export decisions. I follow Brown and Stern (1989) or Fox (1999) and set elasticity of

substitution to 15 for all sectors.¹⁰ The results do not exactly match Brown and Stern (1989) or Fox (1999). I attribute this to different treatment of non-manufacturers and different calibration of the base year.

6.2 Homogeneous Plant Model

Table 4 shows the results for tariff elimination in the homogeneous plant model. For ease of reference, Table 4 reproduces the trade data outlined in Table 1. Table 4 is the result of 19 separate experiments, treating each two-digit SIC code as the manufacturing sector of interest separately. Figure 1 represents the same information graphically, with the percentage changes in trade as a fraction of GDP on the vertical axis and the model's predictions on the horizontal axis. The weighted correlation between the homogeneous plant model and the data is 0.36. This is a significant improvement over other AGE models of the CAUSFTA. Kehoe (2005) finds a value of less than zero for the weighted correlation. Regressing actual trade changes on the model's predicted trade changes yields an intercept of 61.3 and a slope of .56, also a large improvement over earlier studies. Matching markups in the model to estimated markups instead of using direct econometric estimates of elasticities greatly enhances the performance of AGE trade models.

6.3 Heterogeneous Plant Model

Table 5 reports the results for eliminating tariffs for the heterogeneous plant model. Figure 2 represents the same information graphically, with the percentage changes in trade as a fraction of GDP on the vertical axis and the model's predictions on the horizontal axis. Adding plant heterogeneity improves the fit, as the weighted correlation between model prediction and data increases to 0.77. The results of regressing actual percentage changes in trade flows as a fraction of GDP on the model's predictions yields an intercept of 2.6 and a slope of 1.21. This is strong evidence that adding plant heterogeneity to AGE trade models improves their performance.

¹⁰I also ran this experiment using the elasticities from Reinert and Roland-Holst (1992b), but the results matched the data poorly.

Table 3: Standard AGE Model Results Compared to Data

Sector	US EX Data	US EX Model	US MP Data	US MP Model
Foods	93.0	163.1	46.0	94.2
Tobacco	41.4	151.6	-15.5	232.5
Textiles	120.8	115.9	254.9	126.2
Clothing	244.8	235	138.3	218.6
Wood	50.0	210	62.0	28
Furniture	671.3	53.7	203.9	185.1
Paper	63.7	39.4	47.0	88.7
Printing	60.9	11.7	49.6	33.6
Chemicals	106.1	40.5	115.1	117
Petroleum and Coal	14.0	5.1	16.1	9.5
Rubber and Plastics	199.1	120.2	100.9	126.3
Leather	16.9	112.3	7.9	183.4
Non-metallic Minerals	80.5	6.3	115.5	3.7
Primary Metals	127.9	84.3	57.5	41.6
Fabricated Metals	109.0	55.2	125.2	48.1
Industrial Machinery	45.5	45.6	63.4	43.8
Electronics	124.3	32.8	219.6	51.2
Transportation	23.5	3.5	47.1	4.0
Miscellaneous	59.8	40.7	68.3	53.5

Table 3: Results for complete tariff removal and CES set to 15 across all sectors. Data changes represent percentage changes in trade as a fraction of GDP between 1987 and 1996. Weighted correlation between model and data is 0.11. Regression intercept a is 91.6; regression slope b is 0.19.

Table 4: Homogeneous Plant Model Results Compared to Data

Sector	US EX Data	US EX Model	US MP Data	US MP Model
Foods	93.0	277.2	46.0	241.5
Tobacco	41.4	44.6	-15.5	29.8
Textiles	120.8	120.2	254.9	104.0
Clothing	244.8	122.1	138.3	189.2
Wood	50.0	15.0	62.0	79.3
Furniture	671.3	222.6	203.9	67.1
Paper	63.7	34.8	47.0	10.4
Printing	60.9	13.8	49.6	4.4
Chemicals	106.1	24.3	115.1	14.7
Petroleum and Coal	14.0	10.0	16.1	8.0
Rubber and Plastics	199.1	136.0	100.9	134.5
Leather	16.9	218.7	7.9	106.7
Non-metallic Minerals	80.5	4.3	115.5	4.3
Primary Metals	127.9	49.5	57.5	59.7
Fabricated Metals	109.0	93.2	125.2	50.9
Industrial Machinery	45.5	98.9	63.4	97.2
Electronics	124.3	19.9	219.6	13.4
Transportation	23.5	25.3	47.1	5.5
Miscellaneous	59.8	90.1	68.3	47.2

Table 4: Results for complete tariff removal. Data changes represent percentage changes in trade as a fraction of GDP between 1987 and 1996. Weighted correlation between model and data is 0.36. Regression intercept a is 61.3; regression slope b is 0.56.

Table 5: Heterogeneous Plant Model Results Compared to Data

Sector	US EX Data	US EX Model	US MP Data	US MP Model
Foods	93.0	182.1	46.0	133.7
Tobacco	41.4	56.7	-15.5	42.2
Textiles	120.9	125.4	254.9	112.0
Clothing	244.8	219.5	138.3	122.1
Wood	50.0	39.8	62.0	71.0
Furniture	671.3	384.2	203.9	106.0
Paper	63.7	51.1	47.0	23.7
Printing	60.9	31.0	49.6	12.8
Chemicals	106.1	48.3	115.1	41.4
Petroleum and Coal	14.0	3.1	16.1	4.2
Rubber and Plastics	199.1	162.9	100.9	171.6
Leather	16.9	103.9	7.9	83.5
Non-metallic Minerals	80.5	28.1	115.5	37.4
Primary Metals	127.9	61.2	57.5	78.1
Fabricated Metals	109.0	117.6	125.2	98.0
Industrial Machinery	45.5	94.8	63.4	105.7
Electronics	124.3	47.4	219.6	21.9
Transportation	23.5	21.0	47.1	13.7
Miscellaneous	59.8	95.8	68.3	51.3

Table 5: Results for complete tariff removal. Data changes represent percentage changes in trade as a fraction of GDP between 1987 and 1996. Weighted correlation between model and data is 0.77. Regression intercept, a is 2.6; regression slope, b , is 1.21.

7 Conclusion

AGE trade models did not perform well in predicting the sectoral changes in trade flows between CA and US due to the CAUSFTA. Given the detailed data available for these two countries, this is problematic for standard AGE models of trade. A common issue was the large increase in trade flows, a fact that most models failed to predict. Simply increasing the elasticity of substitution is one way to generate larger trade flows. I demonstrate that calibrating the constant elasticity of substitution to match industry markups rather than using econometric estimates plays an important role in improving the model's fit. This technique is an easily implemented improvement on existing procedures. This calibration process may not be suited for all country pairs. US and CA exhibit very similar industrial organization facts, relative to US and Mexico, for example. For developed nations, calibrating a sector's elasticity of substitution between varieties to estimated markups may provide an easy way to improve the match between model and data.

Recent empirical work shows that the assumption of homogeneous production units is not consistent with plant level data. I demonstrate that adding plant heterogeneity to an AGE model improves the model's ability to predict changes in trade flows following a trade liberalization. Further work will investigate how the model performs on other industrial organization facts.

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A Data Appendix

All trade data comes from the World Bank data set Trade and Production Database available at www.worldbank.org/research/trade. The data is in International Standard Industrial Classification (ISIC), Rev. 2. Table A 1 details the mapping to two-digit SIC codes. CA has no separate 2 digit code for instruments, so I have combined them with miscellaneous manufacturing for both countries. I use the US and CA Annual Survey of Manufacturers for most of the sector specific industrial organization data. Data on fraction of plants which export comes from the Special Report on Exporters from the 1987 US Census of Manufacturers for the US and A Profile of Canadian Exporters for CA. I use the Penn World Tables version 6.1 for aggregate data for each country.

Table A 1: Data Concordance

1987 SIC	ISIC Rev. 2	Description
20	31 (excl. 314)	Food
21	314	Tobacco
22	321	Textiles
23	322	Apparel
24	331	Lumber and Wood
25	332	Furniture
26	34 (excl. 342)	Paper
27	342	Printing and Publishing
28	35 (excl. 353-4)	Chemical
29	353	Petroleum
30	355	Rubber
31	323, 324	Leather
32	36	Stone, Clay and Glass
33	36	Basic Primary Metals
34	38 (excl. 382-5)	Fabricated Metals
35	382	Non-Electrical Machinery
36	383	Electrical Machinery
37	384	Transportation and Equipment
38+39	385 + 39x	Instruments and Miscellaneous