Movement of Heterogeneous Goods and People

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Dedication

This thesis is dedicated to Emily. Without her support, I could not have done it.

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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. 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. 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.

After tax wages differ considerably across countries, providing strong economic incentives for individuals to migrate. Increasing political integration and regional trade agreements facilitate international labor mobility, making these economic motives more important relative to the costs of migration. I undertake an empirical analysis using economic incentives to explain the migration of college-educated Canadian workers to the United States in the 1980 to 2000 period. Young workers migrated at a rate over 10 percent during this period. I develop an overlapping generations model of migration with heterogenous agents and calibrate the model to match the total flow of young, college-educated Canadian workers to the US from 1980 to 1990. I verify the calibration by comparing migration predicted by the model to the actual migration of groups not used in the calibration. I use the calibrated model to perform two policy experiments, income tax harmonization and wage equalization. I find that tax harmonization only

reduces overall migration by 30 percent, with large reductions in the migration of workers in the middle of the income distribution. Due to the large US wage premium for highly skilled workers, the migration rate for the top quintile of workers declines only slightly. This indicates that the US premium for skilled workers contributes more to migration flows than the varying tax codes.

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Chapter 1

Introduction

Why, what, and how much countries trade has been an important question from the day national borders were established. Traditionally trade has meant the movement of goods across borders. Subsequent scholars have shown that it can be helpful to consider the movement of people as well as goods. This dissertation examines both types of movements using very different methodologies. The first essay examines the trade implications of Canada-US Free Trade Agreement. The second essay investigates the economic motives behind skilled migration from Canada to the US from 1980-2000.

1.1 Movement of Goods

Trade models often fail to capture important quantitative trade facts. The most striking example is the empirical observation that small, permanent decreases in tariffs tend to generate large increases in trade volumes. For example, trade flows between Canada and the US increased roughly 150% in the ten years following the implementation of their free trade agreement.[1] This fact has been reinforced by almost every trade agreement signed since World War II. Trade models have been largely unsuccessful in reproducing this outcome. This failure is especially pronounced for trade between advanced countries. The mechanisms that generate trade in the model have difficulty reproducing the magnitudes of the observed changes in the data.

This failure of most standard models stems from the assumptions that drive trade in

[1] Trade flows are deflated by GDP growth to avoid general economic growth biasing the results.

the various models. The Ricardian model of trade assumes differential productivity for different goods, resulting in gains from trade when countries specialized. The increasing importance of cross-hauling in the trade data invalidates this fundamental assumption of the standard Ricardian model.[2] The Ricardian model is more successful when applied to trade in primary goods rather than manufactures. Hecksher-Ohlin (HO) models of trade assume that different relative endowments of inputs drives trade flows. This model is quite successful when applied to countries that are dissimilar. Canada and the United States, however, have very similar relative endowments. This similarity makes the HO model an inappropriate tool for examining the trade relationship between Canada and the US.

Paul Krugman and others developed the New Trade Theory in part to address the inability of older models to match important trends in the trade data, primarily cross-hauling between developed countries. Krugman built on the industrial organization work of Dixit and Stiglitz to formulate a model where increasing returns and monopolistic competition fueled trade flows. New Trade Theory could qualitatively explain the enormous trade flows between developed countries. The monopolistic competition in the model mapped well to the observed trade in manufactures. Problems began to arise when the model was used to predict changes in trade flows following a trade agreement. These agreements typically lowered tariffs by a very small amount, but trade flows increased by an order of magnitude.

Trade models require several adjustments before they can be applied to the data in a serious fashion. One of the primary tools for quantitative trade analysis is the computable general equilibrium model. A computable general equilibrium model is a multi-sector, general equilibrium model whose equilibrium mimics the data. A calibrated model has parameter values chosen to exactly reproduce the benchmark data. By changing various things in the model, economists can perform policy experiments, either predicting future changes or testing the model's ability to reproduce changes we observe in the real world. Computable general equilibrium models built upon the new trade theory framework did a very poor job of matching the observed changes in trade

[2] Cross-hauling refers to bilateral trade flows within a single sector. Auto parts has traditionally been the largest source of imports and exports for many industrialized countries.

flows following a lowering of trade barriers. This failure had two dimensions, magnitude and distribution. The failure was most pronounced when examining trade in manufacturers. These models failed to match the total changes in trade flows. For the Canada-US Free Trade Agreement, models typically predicted an increase of roughly 10%. Actual trade flows increased by an order of magnitude more. This was primarily due to the small elasticity of substitution between home and foreign products. The second dimension is the distribution of increases in trade. The correlation of predicted trade changes by sector and actual trade changes by sector was negative for many models.

The reasons for this sectoral failure are more complex than the magnitudes. Several scholars worried that a simple, homogeneous firm model might be missing important aspects of the industrial organization element of international trade. Several empirical papers found a relationship between firm entry and exit into exporting that hinted at a fixed cost component of exporting. Simple summary statistics of firm level data indicated that only the most productive firms export, and that not all firms participated in the export market. These empirical insights were incorporated into the next round of trade theory by several economists. These new models included heterogeneous firms that could chose whether to participate in export based on their productivity. Aside from simply matching more aspects of the firm level data, these models introduced an important new margin contributing to increases in trade flows. As more firms enter the export market, trade flows rise. This is commonly called the extensive margin. Older models built using Krugman's New Trade Theory framework do not have an interesting extensive margin. In that setting, trade flows can only increase by each firm increasing their exports. The extensive margin certainly moved the models more in line with the observed changes in trade flows.

This thesis adapts a Melitz model of trade with heterogeneous firms to a computable general equilibrium model focusing on the Canada-US Free Trade Agreement. It is a static model with capital data bundled into labor in the model. The model is calibrated to exactly match the 1988 data for both countries, which is the year before the Canada-US Free Trade Agreement went into effect. Tariffs in the model are lowered the predicted changes in trade flows are compared to the actual changes in trade flows observed by 1998, which is the year all tariffs went to zero. This calibrated model does a good job of matching both magnitudes and sectoral accuracy of manufacturing trade flow changes. The model captures over 80% of the magnitude of changes and the weighted correlation between sectoral predicted and actual changes is 0.77. This is a marked improvement over homogeneous firm models, which captured under 10% of the magnitude and had a negative sectoral correlation.

Models that accurately reproduce observed changes in data are important for several reasons. Politicians require information on predicted winners and losers from trade agreements to accurately weigh the costs and benefits of proposed policy. Heterogenous firm models allow another dimension to identify winners and losers. Any calculation of the gains from trade also depends on the model. Gains computed in a model that does not match changes in trade flows are less likely to be correct. Continued increases in computing power and availability of data should increase the supply of complex computable general equilibrium models that include heterogeneity.

The second chapter in this thesis deals with the movement of people between Canada and the United States. Many countries complain of a brain drain, the phenomenon where skilled workers tend to leave source countries for better prospects in destination countries. The Canadian press and government have been especially worried about the flow of skilled workers to the United States. They traditionally offer the differing tax codes as the primary reason for migration. The second chapter constructs an overlapping generations model with heterogenous agents to evaluate this claim and identify other sources of migratory pressure.

1.2 Movement of People

The movement of people between countries has been studied by a variety of disciplines using a wide range of methodologies. More qualitative studies discuss reasons people migrate and put forth a myriad of explanations ranging from culture to climate Quantitative studies typically ran country level regressions with flows in one year being a single observation. The second chapter proposes a stark model where people are primarily motivated by economic forces. All other forces are wrapped up into an attachment to home country parameter that varies across individuals. This heterogeneity in individuals is necessary in a model of migration. Without it, all people of the same measurable characteristics would make the same migration decision.

This thesis focuses on the Canada-US migration patterns because the United States had little to no barriers of entry for skilled Canadians in the 1980-2000 period. This makes for a perfect natural experiment focusing on economic motives and migration. The model includes four age cohorts of agents, and twenty ability levels for every age cohort. Assuming that Canadian and American college educated workers are perfect substitutes, the model is calibrated to match flows of a single cohort in each period. The calibrated model captures much of the observed variation in migration flows by age and ability even in the non-calibrated cohorts. To test the Canadian government's ability to stem migration by adjusting taxes, the marginal tax rate in Canada is set to the marginal tax rate in the US. Migration flows fall only slightly. This indicates that the Canadian government has limited ability to stop the migration of highly skilled individual using tax policy. Most of the migration is driven by the very different wage opportunities between the two countries.

These results have important implications for several countries interested in migration. The European Union faces strong political pressures concerning migration. Removing barriers to the movement of labor within the European Union matches the assumptions of this model perfectly. Predicting the levels of migration from new members to existing members would be an important contribution to the discussion on enlargement.

The two chapters of this thesis focus on the movement of goods and people across national boundaries. These important questions have been addressed by a multitude of scholars. This thesis brings the power of cheaper computing and new theory to bear on these questions through the use of heterogenous agent models. The world is a heterogeneous place, and often treating it as such can greatly improve the value of the model.

Chapter 2

Heterogeneous Models of Manufacturing Trade

2.1 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

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

[2] AGE 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.

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.

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. For computational simplicity, I run the model for each sector separately, calibrating the model to each

[3] All data concorded to the 1987 US SIC codes.

individual sector. 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.

A key input to an AGE trade model is the elasticity 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 elasticity to match estimated markups in each manufacturing sector of interest. 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 (2.2) reviews the related literature. Section (2.3) establishes the set of facts that motivate this study. Section (2.4) details the model. Section (2.5) outlines the calibration for the benchmark model. Section (2.6) describes the preliminary results. Section (2.7) concludes. Appendix A.1 details all of the data used in the paper.

2.2 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

[4] **?** analyzes earlier models of the CAUSFTA and finds negative weighted correlations for trade flows.

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 (1992) 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.

2.3 Facts

Recent work has established a set of facts that quantitative models must address. I establish 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 2.1 shows changes in US exports to CA and US imports from CA for each two-digit SIC code. The last two columns of Table 2.1 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 2.1 demonstrates that even small changes in the prevailing tariffs are associated with 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 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 removing 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 2.1 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. Weighted by trade values, the three categories of reductions represented 15%, 35%, and 50% respectively. The majority of codes had tariffs removed over time; those codes with the

[5] Following 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 2.1: CAUSFTA Trade and Tariff Data. Percentage changes in US exports to CA and US imports from CA as a fraction of GDP, for the years 1988-1998. Tariffs adapted from Magun, Rao, and Lodh (1988). Includes tariffs and tariff equivalents of non-tariff barriers.

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

higher tariffs were predominantly removed in steps. The first of January, 1989, marks the first date of tariff reduction from the CAUSFTA. The first of January, 1998, was the day all tariffs were set to zero. I examine trade data from 1988 and 1998, allowing all tariffs to move from initial levels to 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 heterogenous 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 to which calibrated model with these features can match the plant level and trade data.

2.4 Model

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

2.4.2 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:

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

$$\left. (1 - \alpha_{US_j}) \int_{\omega \in \Omega_{CA_j}} c_{CA,j}(\omega)^{\frac{\sigma_j - 1}{\sigma_j}} \mu_{CA}(\omega) d\omega \right)^{\frac{\sigma_j}{\sigma_j - 1}} + \left(1 - \sum_j \theta_j \right) \log C_A \quad (2.1)$$

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

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

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 (2.1) subject to the following budget constraint:

$$\sum_j \left(\int_{\omega \in \Omega_{US,j}} p^{US}_{US,j}(\omega) c_{US,j}(\omega) \mu_{US,j} d\omega \right) + \sum_j \left(\int_{\omega \in \Omega_{CA,j}} p^{US}_{CA,j}(\omega) c_{CA,j}(\omega) \mu_{CA,j} d\omega \right) + p_A C_A \leq wL + g + \Pi \quad (2.2)$$

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.

$$P_{US,j} = \left[\left(\frac{1}{\alpha_{US,j}} \right)^{-\sigma_j} \int_{\omega \in \Omega_{US,j}} p^{US}_{US,j}(\omega)^{1-\sigma_j} \mu_{US,j}(\omega) d\omega + \left(\frac{1}{1-\alpha_{US,j}} \right)^{-\sigma_j} \int_{\omega \in \Omega_{CA,j}} p^{US}_{CA,j}(\omega)^{1-\sigma_j} \mu_{CA,j}(\omega) d\omega \right]^{\frac{1}{1-\sigma_j}} \quad (2.3)$$

[7] Due 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.

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

$$\left. (1 - \alpha_{US,j}) \int_{\omega \in \Omega_{CA,j}} c_{CA,j}(\omega)^{\frac{\sigma_j - 1}{\sigma_j}} \mu_{CA,j} d\omega \right)^{\frac{\sigma_j}{\sigma_j - 1}} \quad (2.4)$$

Note that

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

by construction.

2.4.3 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 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]

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:

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

[8] The 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.

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.

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. There is also little theoretical support that a firm owning several plants would choose a different production plan than those chosen by individual plant owners. Clausing (2000) provides empirical support for this abstraction. Production in the Ω sectors 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

$$m_{\Omega,j} = \min\{\frac{m_{1,j}}{a_{1,j}}, \ldots, \frac{m_{J,j}}{a_{J,j}}\}$$
$$y_d = \psi \left[(m_{A,\Omega_j}^{\eta} m_{\Omega,j}^{1-\eta})^{\beta} n_d^{1-\beta} - f - f_p \right]$$
$$p_d = \frac{\alpha P_{\Omega}^{\frac{\sigma-1}{\sigma}} E_{\Omega}^{\frac{1}{\sigma}}}{y_d^{\frac{1}{\sigma}}}$$

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

$$m_{\Omega,j} = \min\{\frac{m_{1,j}}{a_{1,j}}, \ldots, \frac{m_{J,j}}{a_{J,j}}\}$$

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

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

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

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.

2.4.4 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.

2.5 Calibration

I calibrate the model by choosing parameters such that the equilibrium of the model exactly reproduces the data from 1988, 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 2.2 details the elasticities and implied markups by sector. The value for the iceberg tariffs is taken from Table 2.1, 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 without a convenient algebraic relationship to the data. The literature provides little to no guidance on calibrating the various fixed costs. I chose to match facts that will be governed by these parameters in the model. To select values for these eight parameters, I exactly match the following facts for both countries: total exports, the number of establishments, the fraction of establishments exporting, and the size ratio of the top quintile to bottom quintile of plants by sales. The relationship between these facts and these parameters should be clear. The home bias parameters directly govern the size of exports. The fixed cost of a draw determines the minimum plant size, which in turn governs the size ratio of top to bottom quintiles. The fixed cost of production determines how many plants choose to operate. The fixed cost of exporting governs which plants will choose to export, determining the fraction of plants exporting. To compute the number of establishments in a sector, I divide the total resources spent on the fixed cost of production by the value for the fixed cost of production. This gives me the number of plants choosing to operate in that sector. 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.

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

Table 2.2: Markups and Implied Constant Elasticity of Substitution (CES). Markups from Martins, Scarpetta, and Pilat (1996). CES utility function implies $\sigma = \frac{\mu}{\mu-1}$, where μ is the markup.

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

2.6 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 (2003), I evaluate the fit between model prediction and data by reporting the weighted correlation between actual changes in trade flows from 1988 to 1998 and the model's predicted changes in trade flows for complete tariff elimination. The correlation is weighted by sector shipments in the base year, 1988. 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

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

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

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

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 (2003), 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.

2.6.1 Standard AGE Model

For the first two experiments, 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 (1988) or Fox (2000), as plants are homogeneous and all make identical export decisions. The first experiment follows Brown and Stern (1988) or Fox (2000) and sets elasticity of substitution to 15 for all sectors.[10] The results do not perfectly replicate Brown and Stern (1988) or Fox (2000). I attribute this to different treatment of non-manufacturers and different calibration of the base year.

Table 2.3 shows the results for tariff elimination in the homogeneous plant model with the elasticity of substitution constant across sectors at 15. For ease of reference,

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

Table 2.3 reproduces the trade data outlined in Table 2.1. Figure 2.1 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 0.12. This is a similar figure to the weighted correlations found in other studies of the CAUSFTA. Kehoe (2003) finds a value near zero for the weighted correlation, while Fox (2000) finds higher values. Regressing actual trade changes on the model's predicted trade changes yields an intercept of 91.3 and a slope of .19.

The second experiment incorporates additional sectoral data through the elasticity of substitution estimates. I use the econometrically estimated markups from Martins, Scarpetta, and Pilat (1996) to determine the elasticity of substitution in each sector. Table 2.4 shows the results for tariff elimination in the homogeneous plant model with the elasticity of substitution determined by markups. For ease of reference, Table 2.4 reproduces the trade data outlined in Table 2.1. Figure 2.2 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. 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 (2003) 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.

2.6.2 Heterogeneous Plant Model

Table 2.5 reports the results for eliminating tariffs for the heterogeneous plant model. Figure 2.3 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

Table 2.3: Results for complete tariff removal with homogeneous firms and CES=15 for all sectors. Data changes represent percentage changes in trade as a fraction of GDP between 1988 and 1998. Weighted correlation between model and data is 0.12. Regression intercept a is 91.5; regression slope b is .18.

Sector	**US Exports Data**	**US Exports Model**	**US Import Data**	**US Imports Model**
Foods	93.0	161.1	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	235.0	138.3	218.6
Wood	50.0	210.0	62.0	28.1
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	117.0
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

heterogeneity to AGE trade models improves their performance.

2.7 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

Table 2.4: Results for complete tariff removal with homogeneous firms and CES set by markups. Data changes represent percentage changes in trade as a fraction of GDP between 1988 and 1998. Weighted correlation between model and data is 0.36. Regression intercept a is 61.3; regression slope b is .56.

Sector	**US Exports**	**US Exports**	**US Import**	**US Imports**
	Data	**Model**	**Data**	**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

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

Table 2.5: Heterogeneous Plant Model Results Compared to Data Results for complete tariff removal. Data changes represent percentage changes in trade as a fraction of GDP between 1988 and 1998. Weighted correlation between model and data is 0.77. Regression intercept, a is 2.6; regression slope, b, is 1.21.

Sector	**US Exports Data**	**US Exports Model**	**US Import Data**	**US Imports 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

a trade liberalization. Further work will investigate how the model performs on other industrial organization facts.

Figure 2.1: Model Results vs Data for Standard AGE Model with CES=15

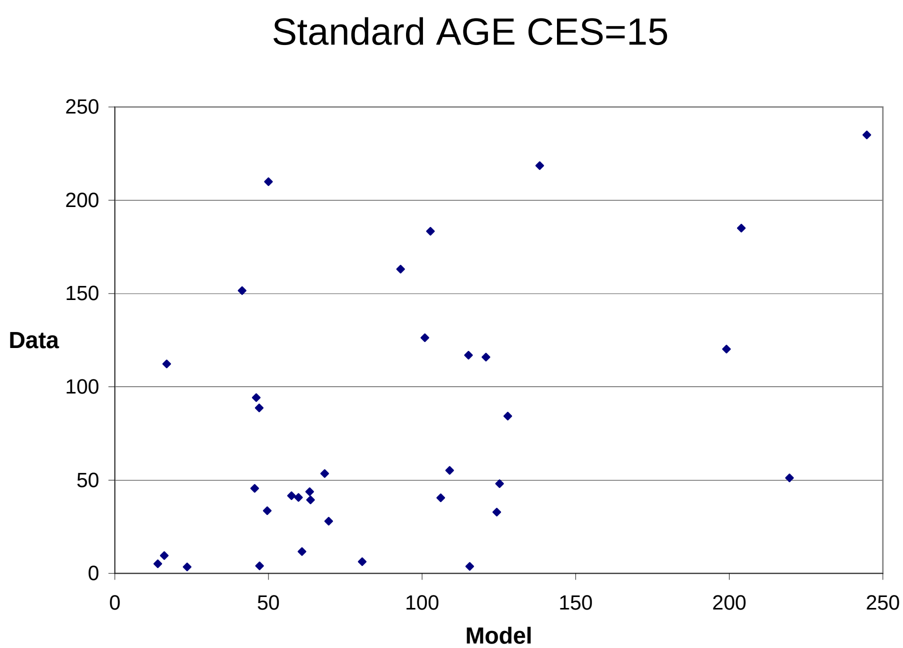


Figure 2.2: Model Results vs Data for Standard AGE Model with CES set by markups

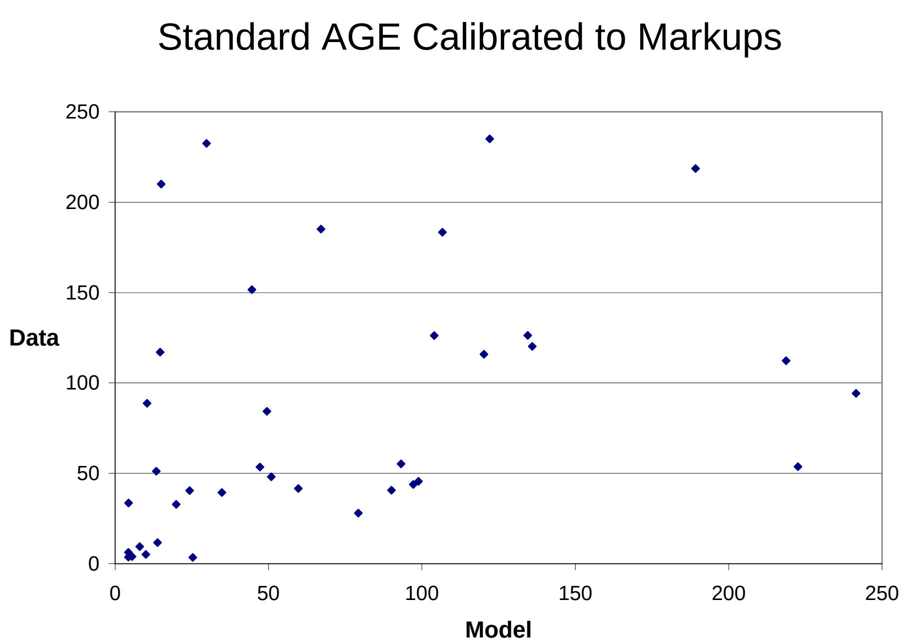
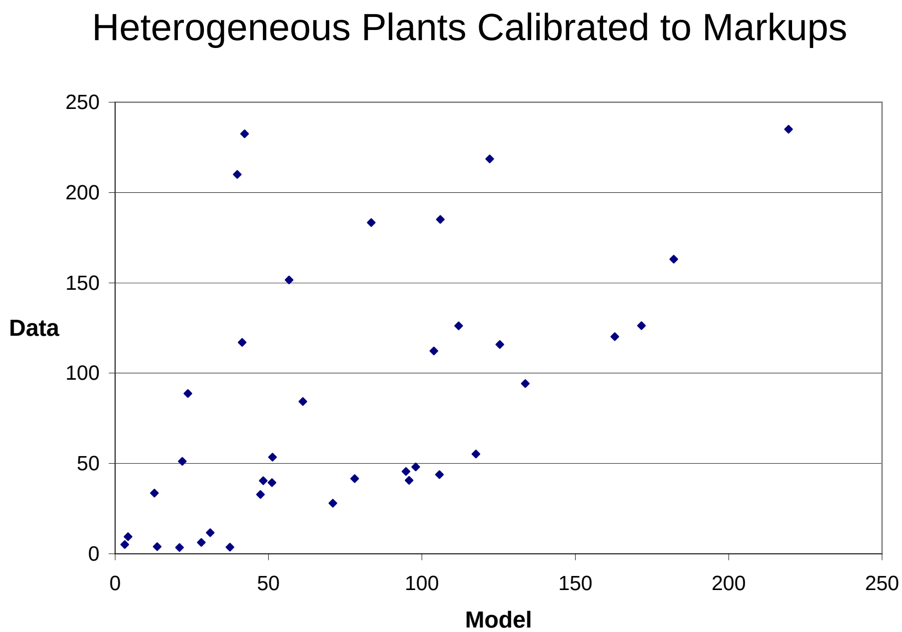


Figure 2.3: Model Results vs Data for Heterogeneous Firm Model



Chapter 3

Migration of Heterogeneous Workers

3.1 Introduction

What role do economic motives play in the observed migration patterns among OECD countries? Tax policies, average wages, and wage distributions differ considerably across countries, creating very different after-tax wage opportunities for economic agents. These differing wage distributions provide strong economic incentives for individuals to migrate. This story is typically emphasized when discussing the migration of workers from less developed nations to more developed nations. This study focuses instead on the migration of similarly educated Canadian workers to the US from 1980-2000. In the 1980-2000 period, migration of college-educated workers from Canada to the US consisted of a disproportionate fraction of high wage workers. At the same time, Canadian taxes were higher on these high wage workers than taxes in the US. At purchasing price parity, the US average wage was approximately 15% higher than Canada's during the 1980's. Furthermore, the US exhibited much greater wage dispersion than Canada. How much of the observed migration can be explained using only these economic motives? How will migration patterns change if Canada adopts the US tax system? How would migration patterns change if Canada exhibited the same wage opportunities as the US? I develop an overlapping generations model of migration with heterogeneous agents to answer the above questions.

While the actual number of migrants might appear small, the composition of migrants is highly skewed towards those Canadians with higher wages.[1] Among Canadian workers working more than 1000 hours a year, only 4% were living and working in the US; it is over 10 percent for those who are college educated workers. In 1990 among workers earning over $US 75,000, the percent living in the US rises to over 20% for all workers.[2] Canadian migrants not only tend to make more than non-migrants, but also tend to make more than their US counterparts with a similar level of education and experience. For example, the percentage of US natives earning $90,000 (1990 US) or more is 4.5%, while the figure for Canadian migrants is 8.1%. Figure 3.1 documents this fact by illustrating the distribution of annual wages of Canadians living in the US relative to the wage distribution of US natives for those who were 35 to 44 years old in 1990.[3] The distributions for other age groups are similar. The data indicates that migrants are not randomly drawn from the Canadian population. The purpose of this study is to demonstrate that migration is closely related to the economic incentives facing potential migrants and to quantify each incentive's contribution to observed flows.

The most obvious of these economic incentives is the tax system. Canadian newspaper headlines routinely cite the tax differential between Canada and the US on high wage workers as the primary cause of the 'brain drain', which they define as the migration of skilled professionals from Canada to the US.[4] At first glance, this analysis seems sound. Canadian taxes are higher at all income levels exceeding a few thousand dollars throughout the period of interest. Furthermore, conventional wisdom holds that Canadian taxes are more progressive than US taxes, suggesting high earners have more to gain by migrating.

Thoughtful examination reveals two holes in this argument. College educated Canadians earning incomes with the largest tax differential are not the same Canadians that

[1] I define a "migrant" as a Canadian-born person living and working in the US, regardless of their citizenship status. Operationally, a migrant is a Canadian-born person who appears in the US census as a worker in the US. Support for this definition can be found in Section 2.1.

[2] All dollar amounts are in 1990 US dollars. I translate Canadian wages into US dollars using purchasing price parity from the OECD. Adjustments for public services provided in each country are included in the wage comparisons.

[3] Annual wage income from the 1990 US Census and the 1991 Census of Canada.

[4] I define tax differential as the difference between US and Canadian effective tax rates for a given income.

are migrating in the largest numbers. Figures 3.2 and 3.3 document the effective income tax schedules for both countries in 1985 and 1990. The largest tax gap occurs at approximately at $30,000 (constant 1990 US$) in the middle of the nineteen eighties, 1985, and at the end of the period, 1990. In 1985, the effective US tax rate at $30,000 was 6.6 percent lower than Canada's. Depending on the age group, this peak occurs at the 40th to 65th percentile of the wage distribution. However, the highest rate of migration occurs at the top quintile of the wage distribution. Among college graduates, this pattern of migration holds across all age groups. Moreover, the difference between the US tax rates and Canadian tax rates is decreasing above $30,000. This suggests that the differences in tax systems alone cannot explain the observed migration patterns.

Differences in pre-tax wage rates provide another economic incentive to migrate. To investigate this motive for migration, I specify a version of the model where all workers experience the same proportional increase in wages upon migration to the US; after calibration, this specification fails to capture the observed flows. I thus conclude that differences in average wages explain little of the migration patterns. I find that the inclusion of the different wage distributions between Canada and the US crucial to explaining the observed migration rates from Canada to the US.

Work practices differ across countries. Aside from generating differences in average wages, work practices affect the distribution of wages across workers within the same country.[5] Canada and the US have very different earnings distributions, even within age and education cohorts. Assuming that workers are ex-ante identical across countries, skilled Canadians face large wage gains from migrating to the US. Hendricks (2002) finds that immigrants to the US benefit from wage increases that are unexplained by differences in physical capital and human capital accumulation, indicating that migrants to the US benefit from country specific work practices.[6] Figure 3.4 exhibits the differences in labor earnings between the US and Canada in 1990 within each age group among college graduates. The figure plots the average wage in Canada and in the US for each 5 percentile group in the wage distribution for each age group. In particular, note that for all age groups, a positive US wage difference becomes evident at about the 50th percentile and increases thereafter as one moves up the wage distribution. The large

[5] Examples include degree of unionization, safety laws, and governments' industrial and labor policies.

[6] Hendricks (2002) calls this country specific total factor productivity or TFP.

differences suggest there exists large potential wage gains for highly skilled Canadian migrants. Finnie (2001) reaches a similar conclusion. I find this economic motive to be the most important for explaining observed migration patterns.

To determine which economic motives best explain the observed flows, I develop an overlapping generations model carefully modeling the economic incentives outlined above. Agents differ in ability and in terms of their attachment to Canada. This delivers a rich set of predictions about the pattern of migration by wage and by age over time. Careful modeling of tax policies and the overlapping generations structure is crucial in estimating the effects of tax and transfer policies on migration. Furthermore, the analysis highlights the limited effects of Canada harmonizing her tax code.

Migration has always been an important source of factor movements. More recently, attention has focused on the migration of the highly skilled. Borjas (1987) argues that migration rates can be explained by economic motives. In other words, individuals rationally make migration decisions based on income differentials net of moving costs. However, the empirical strategy in Borjas (1987) is silent on the timing and pattern of migration. One of the contributions of this paper is the development of a migration model where the pattern and timing of migration is determined by tax policies and wage differences across countries. Another lies in providing an explicit mechanism for the self-selection of migrants identified in numerous empirical studies of migrants.[7]

A number of papers study the relation between a government's tax and transfer policies and migration. Most investigate simple environments that yield qualitative results. This includes Bucovetsky (2003), Razin and Swagel (2002), Hassler, Mora, Storesletten, and Zilibotti (2005) and Wong and Yip (1999). These studies share our interest in economic motives and migration. However, these models abstract from the complexity of actual tax schedules and wage differentials across regions. They analyze the consequences of differences in tax policies in non-quantitative, simple theoretical settings. Their approach generates numerous analytic results, but provides little guidance to answering concrete policy questions.

Less common are the papers that study migration and carefully model relevant institutions. Storesletten (2000) investigates a related question; he asks whether the fiscal problems associated with social security can be resolved with the selective immigration

[7] See, e.g., the literature surveyed in **?**

of high-skilled workers. Storesletten (2000) does not, however, model the migration decision of agents. This study aims to unite the two approaches to quantitatively answer important questions concerning migration and economic motives.

The remainder of this paper is organized as follows: In section 3.2, I provide an overview of the main features of the data and the institutions that motivate the model. These include migration and tax policies as well as stylized facts on labor markets and productivity. The model is introduced in section 3.3. Section 3.4 summarizes the data on migration, income and taxes that are used in the calibration and describes the calibration strategy. It also presents the results of the calibration. Section 3.5 describes the policy experiment of harmonizing Canadian tax institutions with those of the US and reports on the results. Section 3.6 concludes.

3.2 Migration, Taxes and Income

In this section, I highlight the main institutions that motivate the modeling choices. In particular, the emphasis is on the selection of a sample of workers who do not face binding migration quotas. Second, I describe the main differences in the economic environments in which workers can locate, including the tax systems, the distribution of wages and the provision of public goods and services.

3.2.1 Canadian Migration to the US

For the past 50 years, skilled Canadians could freely migrate to the US to live and work. US immigration policy distinguishes between immigrants and nonimmigrant workers. The former are permanent legal residents while the latter have the right to live and work in the US for a limited amount of time. However, nonimmigrant visas can be renewed indefinitely by the same worker. Because the economic incentives and constraints that motivate the model are identical for both immigrants and nonimmigrant workers, I make no operational distinction between them.

US migration policy towards Canadians since 1952 has allowed open immigration for college-educated Canadians. Policy in this period consists of 3 distinct policy regimes which cover the periods: (1) 1952-65, (2) 1966-88, (3) 1989-present. On a per capita basis, Canadian migration to the US was highest during the first period, with over 30,000

Canadians becoming a legal permanent resident of the US annually during this period. The US did not limit the level of Canadian immigration until 1965. Canadians becoming legal permanent residents fell by over 50% from period (1) to period (2). However, beginning in the 1970s and increasingly throughout the 1980s, many Canadians came to work and live in the US as nonimmigrants under H1 and L1 visas.[8]

The H1 class was created in 1952 to assist US employers who needed skilled workers temporarily. The L1 class's intent is similar, except its target is the set of international firms operating in the US. The law governing these nonimmigrant classes was vague, and the INS interpreted it broadly. Unlike employment-based immigration, no US labor market certification was required to demonstrate that (1) qualified US workers were not available, and (2) the wages and working conditions attached to the job will not adversely affect similarly employed US workers. Moreover, both classes of nonimmigrants could generally remain in the US for up to 6 years. In practice, a baccalaureate degree was sufficient to obtain approval (GAO, 1992). This allowed a broad range of skilled Canadians to live and work in the US.

The 1990 Immigration Act greatly restricted admissions under the H1 class, imposing quotas and a labor market certification requirement. The labor market certification required the employers of potential migrants to establish that their migration would not harm US workers.[9] However, the Canada-US Free Trade Agreement (FTA) was implemented in 1989. One of its effects was increased labor mobility between Canada and the US. In particular, it facilitated the movement of high-skilled workers which is operationally defined as a baccalaureate degree. This policy regime continued under the implementation of the North American Free Trade Agreement (NAFTA) in 1994.[10]

In summary, US migration policy towards Canadians can be characterized as freely allowing Canadians with bachelor's degrees or similar professional accreditation[11] to

[8] In 1989, 480,000 nonimmigrant visas were issued to aliens who were authorized to live and work in the US. In contrast, the annual quota for immigration to the US through the employment-based class was 54,000 in 1989; spouses and children count towards this quota. The employment-based class is intended to attract skilled immigrants to the US but clearly accounted for a small fraction of the total number of skilled migrants to the US.

[9] The definition states that US workers in comparable situations would not be adversely affected in terms of the employment opportunities, working conditions and wages

[10] In 1999, almost 70,000 TN visas were issued to Canadians wishing to move to the US as NAFTA workers.

[11] e.g. M.D.'s, registered nurses, L.L.B.'s

migrate. I model this policy by focusing on college graduates. The model universe consists of all full-time Canadian workers with college degrees in 1990. This eliminates the need to explicitly model policy constraints on migration for the economic agents. This simplifying assumption restricts the model's application to countries with relatively open borders. I use the migrant to describe anyone born in Canada living and working in the US, as recorded by the US census. Many of these migrants in the model are technically not immigrants to the US, as they are in the US on non-immigrant visas, such as the H-1B and TN. Based on the visa records, over 90% of Canadians moving to the US from 1990-1999 are using those types of visas. These visas are often renewed indefinitely, making those workers into immigrants for economic modeling purposes.

3.2.2 US-Canada Tax Treaties

Income tax differentials can drive migration only if Canadian migrants have the option of filing under the US tax system. Like most OECD countries, Canada taxes personal income based on residency. An individual's residency status is a legal distinction that differs from her address. Prior to the US-Canada tax treaty of 1983, Canadians living in the US could only file taxes in the US if they sold their property in Canada and lived with their families in the US. Comparing US census data to tax forms collected suggests that many Canadians living in the US did not file as Canadians. After 1983, Canadians living in the US could easily file taxes under the US system.

The US-Canada tax treaty allows Canadian migrants to file under the US tax system. Although the US-Canada tax treaties allow for Canadians in the US to file a Canadian tax return, the vast majority do not. Revenue Canada data on the total number of non-resident filings (including non-US residents) is less than 10% of the number of all Canadian workers in the US. Moreover, the average income among those who file a Canadian tax return is lower than average income in Canada. This suggests that the high wage Canadian workers in the US are not filing as Canadians. I model this by forcing migrants to participate in the US tax system.

3.2.3 US and Canada Personal Income Taxes

Beginning in the 1970's and continuing through the 1980's, personal income taxes increased in both the US and Canada. Personal income taxes underwent a steady increase along several important dimensions in Canada. Personal income taxes increased as a fraction of national income, from 13.8% of GDP in 1980 to 19.7% in 1990. The average tax rates faced by the upper quintile of income earners increased from 12.5% in 1970 to 19.1% in 1980.[12] It further increased to 24.4% in 1990. The marginal tax rate faced by a high income Canadian taxpayer increased significantly. For example, the marginal rates at the 80th percentile increased by one-third, from 24.5% in 1980 to 32.4% in 1990. In contrast, the evolution of US tax policy is one characterized by a smaller increase in the 1970's, followed by a slight decrease in the 1980's.

The growing importance of the personal income tax implies that the richest Canadians became increasingly important for government revenues. Historically, the top quintile of Canadian taxpayers represented about 45% of personal income and two-thirds of the total income tax. This group of wage earners is an important source of tax revenues. Significant migration of workers from this group will impair the Canadian governments' ability to sustain the existing level of transfers and provision of tax-financed goods and services. This study focuses on college educated Canadians. College graduates represented about one-fifth of the full-time Canadian labor force in 1990. However, they accounted for 34% of total personal income taxes paid among full-time Canadian-born workers in Canada. Among Canadian-born college graduates who migrated to the US, I estimate that the taxes they would have paid represents 7.9% of total personal income taxes paid by full-time Canadian-born workers in Canada. Canadian policy makers are alarmed by the increasing number of Canadians migrating to the US and its implications for the Canadian economy and welfare state.[13] I thus pay careful attention to modeling the upper portion of the income distribution.

I employ effective tax rates in modeling the US and Canadian tax policies. I model

[12] In this section, both the marginal and average tax rates are the effective tax rates based on the US Internal Revenue Services's Statistics of Income and Revenue Canada's Taxation Statistics. I compute the effective average tax rates as the total taxes paid divided by total taxable income for each income group. The effective marginal tax rates are equal to the changes in taxes paid divided by the change in total taxable income.

[13] e.g., **?**, and the Sept-1999 issue of Policy Options.

the tax policies in the US and Canada as mappings $\{\tau_{US}(), \tau_{CA}()\}$ from total income into taxes. Statutory rates do not reflect changes to the tax codes that are important to the taxpayer, such as deduction size and scope. Evidence suggests that these differences are important. A series of recent studies by the US General Accounting Office found that over 99% of US filers in 1999 correctly choose the larger of the standard versus itemized deduction in computing their taxable income (GAO, 2001, 2002). As I abstract from the labor/leisure margin, the actual marginal tax rate faced by the workers on additional income is less interesting. Workers choose where to locate based their after tax income in each country. I thus use effective tax rates, calculated from IRS and Revenue Canada data. For model simplification, I abstract from intranational regional location when computing these effective tax rates.

3.2.4 US and Canadian Consumption and Corporate Taxes

I abstract from the explicit modeling of consumption and corporate taxes. I justify this decision by using purchasing price parities (PPP) from the OECD to obtain the relative price of consumption between the US and Canada. In the computation of PPP, consumption taxes have been included to arrive at the final price of the consumption basket.

For a similar reason, I abstract from corporate taxes. Economic theory suggests that corporate taxes have two effects relevant to this study. One effect is the impact on the capital stock and the second is the impact on the price of goods. Higher corporate taxes means that the cost of capital is higher relative to consumption. This implies that the capital stock and output will be lower than they would be in an identical economy with lower corporate taxes. This would lead to lower wages in the economy with higher taxes. In the calibration, I use actual wages from both countries' censuses to determine the wages facing potential migrants. Assuming that workers are paid their marginal product, this procedure incorporates both differences in capital per worker and aggregate productivity differences between the two countries. The second effect of corporate taxes, its impact on prices, has already been taken into account in the calculation of international prices, PPP. Corporate taxes and consumption taxes are thus included through the PPP adjustments and require no explicit modeling.

3.2.5 Labor Supply

The average hours of labor supplied by a worker varies by over 20 percent over his life cycle. The typical life cycle profile is humped shaped. In 1990, average hours of Canadian workers in working in Canada increased by 2.5 hours a week between the ages of 25 and 45. Between 45 and 60, average hours worked decreases by over 5 hours a week. However these changes in the labor supply cannot be explained by changes in wages which increased by 45 percent in the early part of the life cycle (25–45) and decreased by approximately 20 percent over the latter part of the life cycle (45–60). The increase in average wages from 25 to 35 is comparable to the wage decrease for older workers. However the subsequent decline in wages did not elicit a comparable decrease in labor supply. This pattern also holds for US workers. Moreover, this pattern persists when I disaggregate workers according to their position in the wage distribution and by their educational attainment. For example, average wages for the bottom quintile of the US college graduates increased by about one-third in the early part of their life cycle while their average weekly hours increased by one. However, their average weekly hours declined by the same amount as average wages fall by about 10 percent in the latter part of their life cycle. I reach a conclusion similar to that expressed in McGrattan and Rogerson (1998), that "the effect of wage changes on the desired hours of work is still unknown." I do not attempt to explain the worker's labor supply decision and assume that workers in the model economy are endowed with a unit of time which they supply inelastically throughout their working life.

3.2.6 US Premium

Differing work practices lead to differing labor market outcomes. Of particular interest to this study are the differing wage distributions between Canada and the US. I call this difference the US premium. For high wage earners, the US premium is large and positive. However, it is generally negative for workers between the ages of 35-54 in the bottom half of the wage distribution.

The increase in US wage inequality has been well documented (e.g. Katz and Murphy (1992), Gottschalk and Moffit (1994)). There are two distinct dimensions to the increase. First, there has been an increase in the dispersion of wages between individuals with different observable characteristics such as gender, levels of education and experience. This is known as between-group inequality or dispersion. The second dimension of increasing wage dispersion is the growth in within-group dispersion, also called *residual inequality*. Dispersion of wages has increased between individuals with the same set of observable characteristics, including college graduates at all levels of experience. Residual inequality has increased significantly in the 1980s. In the literature, this dispersion is attributed to differences in unobserved characteristics, including ability. This motivates the modeling of the wage opportunities in which I assume the distribution of unobserved ability is the same in Canada and the US.

It is the differences in residual inequality between Canada and the US that are relevant to this investigation. While wage dispersion has grown in all OECD countries including Canada, the US is an outlier. Bar-Or, Burbidge, MaGee, and Robb (1995) Freeman and Katz (1994) have documented the increase in wage dispersion in Canada. They found that although both between-group and within-group wage dispersion has risen in Canada, it has not increased to the same extent as in the US. Moreover, this is not true for all groups. Bar-Or, Burbidge, MaGee, and Robb (1995) found that dispersion has decreased among experienced college-educated Canadian workers. This flattening of the earnings opportunities in Canada imply larger gains for more skilled workers who choose to migrate to the US.

I find significant differences in the distribution of wages among college graduates between the US and Canada. In general, the US exhibits greater wage dispersion. Within an age or experience group, the differences are increasing in wages.[14] For example, among those who were 35–44 years old in 1990, the Canadian worker at the 80th percentile of the wage distribution earned approximately $43,500 while the American at the 80th percentile earned $50,000. This suggests that the migrant at the 80th percentile faces an potential increase of almost 15% in their pre-tax wages. For the individual at the 95th percentile, the corresponding pre-tax wage gain is almost 35%. However, those workers whose wages are below the median face a wage decline in migrating to the US. This general pattern holds across 3 of the 4 age groups. The positive US premium for

[14] Following the literature, I impute experience as the difference between age and the number of years of schooling. Actual years of experience cannot be directly observed in most data sources, including the US Census, the Canadian Census and the Current Population Survey.

young workers (25-34 year-olds) at all levels of ability is the exception. The large US premium for young workers remains even when part time workers are included. Cutting the data different ways changes the size of the increase, but does not reverse the sign of the premium. The calibration section documents the US premium by age cohort.

Numerous explanations offer stories for the differing wage opportunities across countries. Most of these rely on substantial differences between the countries' endowments of human or physical capital. These explanations are unsuccessful quantitatively when presented with such similar countries. The tax and transfer systems are the most obviously different between the two countries. Within country studies of the effects of tax changes on wage distributions are generally unable to explain the distributions solely with taxes.[15] Explaining the differing wage distributions is beyond the scope of this project. I thus measure the US premium and feed it into the model exogenously.

3.3 The Model

The model is a standard overlapping generations model with three extensions: location decision, heterogeneous ability and heterogeneous attachment to Canada. I allow agents to choose their location. Work and residence will occur at the chosen location. In the calibrated model, the two locations are Canada and the US. The second extension is the introduction of agents who are heterogenous in their ability. This heterogeneity will be instrumental in matching the observed wage distributions. Agents of different ability will be able to earn a different wage in each location in each stage of their life cycle. In other words, the wage distribution depends on ability, location, and age. Third, agents differ with respect to their attachment to Canada. Any model of migration requires some heterogeneity in agents or all agents with identical observed characteristics would make the same migration decisions. Agents with high attachment to Canada will experience a greater utility loss from consumption upon locating in the US while agents with no attachment to Canada will not experience any such loss. I model this attachment as a drop in utility for a given level of consumption in the period in which the worker moves. The characteristics of each location differ in two ways. They differ in terms of their

[15] Leung (2005), which examines US tax changes and wage distributions from 1970-1990, is representative.

tax policy and in terms of their returns to ability. Each location has a tax policy that is non-linear and depends on an agent's total taxable income. I detail the agents, the policies, and the environment below.

3.3.1 Workers

I assume the economic decision making unit of interest is the individual worker. This means I abstract from potentially important household planning and gain model tractability. I would expect this abstraction to lessen the model's ability to match the migration of workers for whom the US premium is negative. Future work might exploit the detailed census data to investigate joint planning problems at the household level. Instead, this study treats male college educated Canadian workers as the sole agents.[16]

Agents are born with two unchanging characteristics, ability ψ and attachment θ. Ability determines what wage opportunities are available in each location and is public information. Attachment determines the utility cost of migrating for the worker and is private information. The attachment parameter is one of the primary innovations of this study and is detailed in the next section. The distributions of ability and attachment are public information. Workers are indexed by ability, attachment, age, location, and bond holdings. Thus a worker's state can be represented by the tuple $\zeta = (\psi, \theta, i, a, b)$ where i denotes age, a denotes the worker's current location, and b denotes their bond holdings. Workers live for T periods, working for $T - 1$ of those periods and consuming savings in period T.

Attachment

A quantitative model of migration must include some cost of migration, and this cost must vary across individuals. Without this heterogeneity, everyone of a given ability and age would make the same migration choices, which is a clear counterfactual. I introduce an attachment parameter, θ, for living in Canada to capture this fact. If a worker migrates, her effective consumption, $\hat{c}$, in that period is θc instead of c. The attachment reflects the idea that a person generally realizes higher utility from the same consumption levels in their home country due to the proximity of family and friends.

[16] Including female workers changes the results only slightly.

I abstract from explicitly modeling the one-time financial and bureaucratic costs of moving as these can be rolled into the attachment parameter.[17] I assume that the attachment to Canada disappears after 10 years in the US which is equal to one period in the calibrated model. Aside from migrating, attachment remains constant throughout an agent's life. If a worker returns to Canada, then that worker reacquires their attachment to Canada, although in the calibrated model no workers return. I impose the condition that the distribution of attachment is uniform across all age groups and all ability levels.[18]

The Worker's Problem

Workers have preferences over the stream of consumption in each period of life that can be represented by the following utility function.

$$U(\{c_i\}_{i=1}^{T}) = \frac{1}{\rho}\sum_{i=1}^{T}\beta^{i-1}\hat{c}_i^{\rho}$$

where the preference parameters β and ρ govern the worker's discount rate and intertemporal elasticity of substitution respectively. She faces a sequence of budget constraints each period i of the following form:

$$b_{i+1} + c_i \leq rb_i + w(\psi, i, a) - \tau_a(m_a(w(\psi, i, a), b_i))$$

where c_i is the quantity of current consumption, r is the gross interest rate paid on bond holdings at the beginning of the period, b_i, and the worker's current location or address is denoted by a. Wages are determined by ability, age, and location. $w(\psi, i, a)$ is the wage paid to a worker of generation i, with ability ψ working in country $a \in \{US, CA\}$. The tax schedule and taxable income differ by country and are denoted by τ_a and m_a respectively. I impose the condition that bond holdings are zero at the end of an individual's life, thus $b_{T+1} = 0$.

[17] Explicitly modeling the costs of moving would change the calibration procedure but would not change the model results as long as the cost of moving were uncorrelated with the attachment parameter.

[18] I appreciate that attachment to the home location probably changes over the life cycle. Introducing free parameters where the attachment varies over the life cycle or across ability would allow for a improved match of the model with the data. Instead, I chose discipline in the calibration over perfectly matching the data.

To solve the model, I formulate the worker's problem as a dynamic programming problem. Let each worker's state be $\zeta = (\theta, \psi, i, a, b)$, with the same notation as above. Let $S = (A(\psi, i), \tau)$ be the aggregate state. The $'$ denotes a variable's value in the next period. Agents face the following dynamic programming problem:

$$V(\zeta, S) = \max\{V_s(\zeta, S), V_m(\zeta, S)\}$$

where V_s, V_m are the continuation values associated with staying and migrating respectively.

Consider the case where the worker stays. For agents beginning the period in country $a \in \{US, CA\}$,

$$V_s(\zeta, S) = \max_c \frac{c^\rho}{\rho} + \beta V(\zeta', S)$$

subject to

$$b' + c \leq w(\psi, i, a') + rb - \tau_{a'}(m_{a'}(w, b))$$

$$i' = i + 1$$

$$a' = a$$

For the case where the individual migrates from a to a',

$$V_m(\zeta, S) = \max_c \frac{\hat{c}^\rho}{\rho} + \beta V(\zeta', S)$$

subject to

$$b' + c \leq w(\psi, i, a') + rb - \tau_{a'}(m_{a'}(w, b))$$

$$i' = i + 1$$

$$a' = \begin{cases} US, & a = CA \\ CA, & a = US \end{cases}$$

where effective consumption is

$$\hat{c} = \begin{cases} \theta c, & a = CA \\ c, & a = US \end{cases}$$

so that migrants to the US suffer from a one-time penalty in utility that is proportional to their consumption in the period in which they move, $\hat{c} = \theta c$. Return migrants to Canada do not suffer any utility loss from migrating.

3.3.2 The Environment

Workers trade non-contingent bonds at constant interest rate r.[19] I do not impose market clearing in the bond market as Canadian potential migrants do not comprise the entire set of participants in the bond market. Market clearing in the bond market would require explicit modeling of US workers. Since there is no uncertainty in the model, non-contingent bonds complete the markets. I detail two features of the worker's environment below, the tax systems and the wage systems.

Personal Income Taxes

A tax policy is a pair (τ_a, m_a) that maps wage and savings income into taxes paid. m_a maps wage and savings income into taxable income and τ_a maps taxable income into net taxes paid.[20]

There is a tax schedule that varies across each of the two locations, (τ_{US}, τ_{CA}). Workers know the tax schedule, and assume that it is permanent. I assume that workers migrate at the beginning of each period so that they pay taxes based on the location in which they currently live and work. The tax schedules potentially differ at each level of taxable income. Aside from the differing marginal rates, the most numerically significant difference is interest payments for workers living in the US can be deducted against income. This reflects the different treatment of interest payments in the two countries.

For Canada, I assume that interest payments are not tax deductible, giving the following expression for taxable income, m_{CA}.

$$m_{CA}(w,b) = \begin{cases} (r-1)b + w & b_t > 0 \\ w & b \leq 0 \end{cases}$$

For the US, I assume that interest payments are tax deductible, yielding the following expression for taxable income.

$$m_{US}(w,b) = (r-1)b + w$$

[19] Model variations allowing r to vary over time changes the calibration procedure, but only alter the migration results slightly.

[20] Taxes at some distribution levels are negative, meaning those agents receive positive net transfers from the government.

Production and the US Premium

I assume that workers are endowed with a backyard technology that differs by location, thus abstracting from firms as the basic production unit. Workers produce a homogeneous good whose price is normalized to one, hence a worker's wage is equal to output. In each country, there is a wage function that maps ability and age into wages:

$$w(\psi, i, a) = y(\psi, i, a) = A(\psi, i, a)$$

The US premium for workers of ability ψ of age i is therefore

$$\Pi(\psi, i) = \frac{A(\psi, i, \mathrm{US})}{A(\psi, i, \mathrm{CA})}$$

so that $\Pi(\psi, i) > 1$ represents a positive US premium where the worker of ability ψ and age i would earn higher current wages if she migrated. Conversely, a negative US premium for worker type (ψ, i) occurs where $\Pi(\psi, i) < 1$. I stress that a worker's output is independent of other workers' activities in the model. In particular, migration will exert neither downward pressure on the wages in the host country nor upward pressure on wages in the source country. There is no economic interaction between workers in the model. This means there is no feedback on migration decisions and the US premium.

3.3.3 Equilibrium

In the calibration, I focus on the steady state migration patterns of Canadian workers only. Since they form an insignificant fraction of the combined US and Canadian labor force, I assume that they will not affect the interest rate on bonds and do not require the bond market to clear.

Definition

A *stationary recursive migration equilibrium* is a set of consumption, savings, and migration plans $(c, b', a)(\zeta, S))$ and value functions $(V, V_s, V_m)(\zeta, S)$ such that, given tax policies and the US premium, the value functions (V, V_s, V_m) solve the worker's recursive problem and the functions (c, b', a) are the associated optimal plans.

Properties

The equilibrium is characterized by a set of cutoff migration rules. Workers with sufficiently high θ, low attachment to Canada, will migrate, while those with lower θ will not. Given a set of workers with the same ability, age, beginning-of-period-address, and bond holdings, (ψ, i, a, b), there is either (i) a cutoff level of attachment θ^* such that the worker with attachment θ^* is indifferent between migrating and not migrating, or (ii) no agent will migrate. In case (i), all workers in that set who are less attached to Canada, $\theta \geq \theta^*$, will migrate. Recall that a low θ means a higher loss in effective consumption from migrating as $\hat{c} = \theta c$ in the period of migration. I exploit this fact in the computation of the equilibrium and its associated migration rates.

For simple characterizations of the US premium (e.g. $A(\psi, i)$ = constant) and the tax differential (e.g. $\tau_{US} = \gamma\tau_{CA}$ for some constant γ), it is straightforward to establish propositions regarding the relative migration rates of individuals of differing abilities and age.[21] However, the actual environment studied does not satisfy such simple characterizations. The figures listed above document this, in both the tax rates and the US premium.

3.4 Calibration

Below I detail the calibration of the model for the 1980-1990 period. The calibration procedure for the 1990-2000 period is nearly identical, simply iterated by one time period. The model universe consists of white male college graduates who were born in the US or Canada between the ages of 25-64 and worked more than 20 hours per week in 1989 or 1990. Thus all data refers to this group.[22] I translate units in Canadian dollars from the 1991 Census of Canada into comparable units of US dollars using the purchasing price parity (PPP) of 1.30. This is the average PPP for the 1980-1989 period from the OECD. I use the 1990-1999 average PPP to convert Canadian dollars in the 2001 Census to US dollars.

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[21] Leung and Rolleigh (2001) establishes a number of theorems in a similar theoretical economy with simple wage and tax differentials.

[22] Using different groups as the model universe generally produces similar results. The exception is including both males and females with at least a high school education. This dramatically changed the calibrated attachment parameter.

The central element of the calibration strategy is the targeting of key moments of the migration rates for groups of workers differentiated by their age and wages. The parameters in the model can be divided into three sets. The first set of parameters are taken from the literature because there is an imperfect mapping between model outputs and observable data. This set of parameters consists of the preference parameters β and ρ, which govern the discount rate and intertemporal elasticity of substitution respectively. The second set of parameters are chosen to exactly match the data. This set of parameters consists of the wage distributions and tax schedules, $w = A(\psi, i, a)$ and $\tau = \{(\tau, m)_{US}, (\tau, m)_{CA}\}$. The last set of parameters are selected to best match the migration flows between 1980 and 1989. This is the set of parameters that characterize the distribution of attachment to Canada, $G(\theta)$. The parameters governing the $G(\theta)$ distribution are chosen to minimize the sum of squared differences between model predicted migration and actual migration. It is not possible to hit the migration flows exactly. In the preferred calibration, I calibrate $G(\theta)$ to best match the flow of 25-34 year olds between 1980 and 1989. I choose this calibration instead of allowing attachment to vary by age to impose discipline on the exercise. Allowing $G(\theta)$ to vary by age and take values above 1, implying a distaste for your home country, improves the fit of the model only slightly.

3.4.1 Distribution of Ability

I assume that that workers have the same underlying distribution of ability $F(\psi)$ in the US and Canada. Within each age group i, there is a one-to-one mapping between ability ψ and wages $w(\psi, i, CA)$. This means that there is also a one-to-one mapping between the distribution of ability and the distribution of wages. I discretize the distribution of wages into 5 percentile bins and set the corresponding $\psi_j, j \in \{5, 10, ..., 95, 100\}$ to be the average wage in that percentile bin. This procedure means that I do not have to calibrate F independently. All the information regarding differences in ability relevant to the model will be contained in the wage function parameter, A, where $w(\psi, i, a) = A(\psi, i, a)$.

3.4.2 Wages

Wages in the model refer to the wages for the single unit of labor supplied over on year. The wage functions could more accurately be called earned income functions, as that is the relevant category used from each country's census. The earned incomes are reported at an annual rate to make comparisons simple. In the model, one time period is a decade and wages are multiplied by 10.

US Wage Function

I assume that there is no US out-migration to Canada. Iqbal (2000) notes that in the 1980-2000 period, for every US managerial migrant to Canada, 59 Canadians migrate to the US. Similar numbers appear in other professional occupational categories.[23] This assumption implies that the observed wage distribution of the US-born mirrors the underlying ability distribution. Given this, it is straightforward to compute the US wage function from the observed wage distribution of US-born workers $\hat{w}(j, i, US)$ where j denotes percentile bin and i denotes age group in the data. I set the wage to be equal to the average wage of workers in each 5-percentile bin for each age group. Table 3.1 reports the US wage distribution in thousands of 1990 US dollars. Note that the wage distribution is heavily skewed towards higher wages for higher ability workers. Thus we would expect more high ability workers to migrate.

Canadian Wage Function

It is not possible to simply set the Canadian wage function to be equal to the observed Canadian wage distribution due to the skewed migration of high ability workers to the US.[24] Some fraction of workers in each 5–percentile wage bin has migrated to the US so that the underlying ability distribution is not simply equal to observed wage distribution. The fraction of each percentile group that has migrated must be determined and included in the calculation of wage opportunities in Canada. It is impossible to directly observe the wage that a migrant would have received if she had remained in Canada. This wage must be imputed from the available data using strong assumptions. I must impute

[23] Mimicking the Canadian procedure for the US changes the US wage distribution by less than .1% in each bracket.

[24] Due to lack of data, no adjustments were made for Canadian migrants to other countries.

her position in the Canadian wage distribution that would have prevailed if there were no migration. I assume that the underlying ability distribution is the same in the two countries and that Canadian workers who migrate earn the same wage as their US counterpart of the same ability and age. This allows me to infer the number of Canadians who migrated by ability and age from examining the US Census. I then incorporate these migrants into the construction of the Canadian wage function.

From the Canadian Census, I know the number of Canadians in each age group, $N(i, CA)$ and therefore the number of Canadians in each 5–percentile bin for each age group i, $N_p(i, CA) = N(i, CA)/20$. Starting at the bottom of the wage distribution one age group at a time, I subtract the number of Canadians in the US in the corresponding percentile bin, $N_{1-5}(i, US)$ from the total per percentile bin to get the number of Canadians in that bin who remained in Canada, $N_{1-5}(i, CA) = N_p(i, CA) - N_{1-5}(i, US)$. The average wage for the bottom 5-percentile is then the average wage of the $N_{1-5}(i, CA)$ workers at the bottom of the Canadian wage distribution for that age group. Then I calculate the wages of the 6–10th percentile bin based on the next $N_{6-10}(i, CA)$ workers in the wage distribution and so on. Table 3.2 reports the Canadian wage function computed by this procedure for the first time period.

Without correcting for the disproportionate number of high wage earners who migrated to the US would result in a downward bias at the upper end of the Canadian wage function and would overstate the wages of those at the bottom of the distribution. This procedure has large effects for some workers, 4% in the first period and 6% in the second period. Although small compared to the US premium at the upper tail of the wage distribution, it is significant for those at the lower end of the distribution.

3.4.3 Tax Policies

I choose the tax policies to reflect the net effective taxes paid, taking into account the value of two important public goods provided by the government, health care and education. I choose the tax schedules to replicate the effective income tax rates in each country in the midyear for the period of interest. Using the IRS' Statistics of Income and Revenue Canada's Taxation Statistics, I compute the effective tax rates for 1985 and 1995 in each country. I adjust them to 1990 US dollars using the deflator for personal consumption expenditure in each country. The tax schedules are shown in Figures 3.2

and 3.3.

Education and health care are regarded as important goods that matter to most individuals. Canada has historically devoted a larger fraction of government expenditures on these goods than the US. It is also clear that the consumption of these goods varies across the wage distribution. However, I do not have information on the distribution of such spending among college workers of differing ability. Hence, I model government spending on health care and education as equal lump sum transfers to all workers. These lump sum transfers amounted to $5,255 in Canada and $4,504 in the US. These represent total public expenditures at all levels of government as the provincial governments are responsible for the delivery of health and education services and for the adminstration of the health care and education systems. No adjustments are made for quality of good provided in either education or health care.

Let $\hat{\tau}_a(m)$ represent the effective tax rates for country a before subtracting out public expenditures on health and education. Let tr_a denote the value of public health and education expenditures in country a. Then the net effective taxes paid by an agent with taxable income m in country a is:

$$\tau(m) = \hat{\tau_a}(m)m + tr_a$$

3.4.4 Preference Parameters

The discount rate and elasticity of substitution are taken from the macro literature. I set the discount rate $\beta = 0.6$ and the elasticity of substitution $\rho = -1$ in the benchmark calibration. The discount factor chosen corresponds to an annual discount rate of 0.95. Sensitivity analysis using different discount rates or intertemporal elasticities of substitution do not quantitatively change the benchmark migration results.[25]

3.4.5 Distribution of Attachment

I choose the attachment distribution G to best match the migration pattern for each decade. In the preferred calibration, I target the flows of the cohort who were 25-34 years

[25] I recalibrated the model using annual discount rates of 0.9 and 0.98 and intertemporal elasticities of substitution equal to $\frac{3}{4}$ and $\frac{1}{4}$. Changing these parameters alters the calibrated values for attachment, but the predicted flows look similar to the benchmark calibration. Higher elasticities lead to larger predicted flows, especially in the higher ability brackets.

old at the start of each period. I do this by matching the model predicted migration rate by age and ability to the observed migration rate by age and ability. Define $\mu(\psi, i)$ to be the observed migration rate by ability and age; let the model's predicted rate by ability and age be denoted by $\hat{\mu}(\psi, i)$. I choose the parameters that govern G to minimize the sum of squared differences between observed and actual migration rates. More formally:

$$G = \arg\min_{G} \sum \left(\hat{\mu}(\psi, i_{25-34}) - \mu(\psi, i_{25-34})\right)^2, \tag{3.1}$$

I impose that the attachment follow a linear partial distribution function. I chose the slope and intercept of the partial distribution that minimizes the difference between model predicted and actual migration by age and ability as defined in (3.1). As the area under the pdf must equal one, this is effectively a single parameter distribution.

3.4.6 Results - Benchmark Calibration

The calibrated model succeeds in reproducing the the increasing rates of migration for the 25-34 year old workers as their wages increase. Despite the fact that I impose uniform attachment to Canada across all age groups, the model manages to reproduce the pattern of increasing rates for these non-calibrated workers. The fit is of course better for the youngest generation, as attachment is calibrated to match it as closely as possible. Figures 3.5 and 3.6 demonstrate the fit for the two youngest cohorts. The fit for the 35-44 year olds is still quite close, despite using the attachment calibrated to the youngest cohort. By construction, the taxes paid and wages received in the model replicate the data. The predicted and observed migration rates by ability and age are reported in Tables 3.3 and 3.4.

Table 3.3 reports the model and data migration rates by age and ability for the first time period. The model captures the increasing rate of migration for all age cohorts, despite only calibrating the attachment to the 25-34 year olds. As expected, the fit is best for the calibrated age group. The model predictions consistently fail to match the actual migration of lower ability workers in the older two cohorts. This is primarily due to the fact that the older cohorts have little to no economic incentives to migrate give their wage opportunities. Even those individuals with $\theta = 1$, no attachment to Canada, face no economic gains at the lower end of the ability distribution. The mismatch between model and data could be remedied by allowing θ to take on values above 1, representing an attachment to the US even for native born Canadians. Although this would improve the fit of the model, it would shed little light on the economic motives for migration. I thus choose to restrict θ to a maximum value of 1. Despite the disciplined calibration of the attachment parameter, the model performs relatively well for the other age cohorts.

Table 3.4 reports the actual and predicted migration by age and ability cohorts for 1990-2000. The most striking feature of the second period is the large increase in migration rates. This is most likely due to two independent developments towards the close of the millennium. The implementation of NAFTA and subsequent easing of temporary visa requirements combined with a relatively stronger performance of the US economy drove migration rates up significantly. Both of these developments are captured by the model. The stronger US economic performance shows up directly in the calculation of the 1990-2000 US premium. The easing of travel requirements is indirectly captured by recalibrating the attachment parameter for the second period. The model captures this increased migration rate quite well for the calibrated cohort, the 25-34 year olds. The quality of fit declined slightly relative to the earlier decade, but still captures the trend of increasing rates by ability for all cohorts. The model again fails to replicate the high migration rates of lower skilled older workers. For the oldest cohort of workers, the lowest ability workers face no economic gains from migrating, and thus model prediction will always be zero for them. The model does capture some of the migration rates for the oldest cohort, but consistently under predicts them. The story is similar for the middle cohort, although the model matches the migration of lower skilled agents slightly better. The fit between model and data could be significantly improved by calibrating each cohort's attachment to the migration rates of that cohort. This procedure would add little to the discussion about the fit of the model but might provide more confidence in the results of the policy experiments.

3.5 Policy Experiments

The goal of this paper is to develop a model of migration that can be used to answer policy questions in a qualitative way. Of special interest to Canadian policymakers are the effects of Canada's tax code on the flow of highly skilled people. To address these concerns, I perform two policy experiments. In the first experiment, I impose a uniform tax code across both countries. Tax harmonization tests the ability of the Canadian government to stem the flow of migrants using fiscal policy. The second experiment imposes the US wage structure on the Canadian economy. The imposition of uniform wage distributions isolates the effect of the tax code on migration. The US still offers higher wages, otherwise migration would be zero.

3.5.1 Tax Harmonization

Popular media cites the differing US and Canadian tax codes as the primary reason for the brain drain. I test this theory by setting the Canadian tax code equal to the US tax code in each decade. All other aspects of the model remain the same as the benchmark calibration. I keep the differing wage distributions as in the benchmark case. This tax policy shift is a large change from the benchmark case for Canada, both in terms of average tax rate and progressivity of the tax schedule. I also reduce the lump sum transfers of the Canadian government to match US levels, but this represents a smaller change than the tax code. The only channel pushing migration in this policy experiment is the differing wage opportunities between the two countries. Tables 3.5 and 3.6 document the migration rates by age and ability for the tax harmonization experiment, as well as reproduce the benchmark rates for comparison.

In both decades, harmonizing tax codes slows the outflows of workers from Canada, but not by much. Most importantly for tax revenues, the changes in taxes have relatively small effects on the most skilled workers. The largest drop in rates occurs in the lower part of the income distribution. This is exactly what you would expect given the tax differentials by income group. US tax increases in the 1990's further reduces the impact of tax harmonization on migration flows, especially at the higher brackets. The small drop in migration rates implies that changes in tax policy cannot directly stem the flow of highly skilled migrants; the differing wage opportunities dominate the migration decision. It is possible that the tax codes lead to these wage distributions. Human capital accumulation is certainly influenced by tax codes. By assuming college educated Canadians and US natives are perfect substitutes, the model ignores this channel. Given that the tax codes are roughly similar at the highest levels of income, the human capital story cannot explain the disproportionate migration of the highest income workers. It is also possible that tax codes affect the structure of production in a complex way that generates differing wage opportunities in each country. Investigating this channel would require the development of a new model.

3.5.2 Uniform Wage Distribution

This experiment removes the differing US premium from the model. By imposing the US wage distribution on Canada, only the tax codes cause differential migration rates by incomes. The average US wage remains higher, but the curvature of the difference is removed. Operationally, this means setting the Canadian wage distribution to a constant multiplier of the US wage distribution. The relative average wages in each country determine this multiplier. In other words, the multiplier is chosen to maintain the average PPP adjusted wages in each country for each decade. Tables 3.7 and 3.8 report the migration rates by ability and age for the Uniform Wage Distribution case.

The results of both decades are roughly the same. We see an increase in migration relative to the benchmark in some lower and middle income agents. This increase in migration is highest among the middle income agents, for whom the tax benefits of moving are highest. The largest declines in migration rates are among the high earners. There is significant decline at the top end of the income distribution for every age cohort. This is expected, as a common wage structure removes their main incentive to migrate. They face similar taxes in each country in this portion of the wage distribution. The common wage structure overwhelms the average wage difference between countries at the upper end of the wage distribution. The decrease in migration relative to the benchmark model for top quintile of earners is 35% in the first decade and 37% in the second decade. I thus conclude that the differing wage opportunities plays a large role in the migration of these high wage workers. Further investigation into the causes of these differing distributions is warranted.

3.6 Conclusion

I develop a model to investigate the extent to which economic motives explain observed migration patterns. I apply this model to migration of college educated workers from

Canada to the United States between 1980 and 2000. This period is a natural experiment, as college educated workers faced minimal political constraints on migration, thus lending itself to a study focused on economic motives. I used detailed census data to construct heterogeneous workers differing in age and income. I calibrate the model and perform policy experiments to examine the contribution of the tax code and wage structures to migration. There is considerable popular debate concerning the importance of the tax code on migration flows - especially on the migration of highly skilled workers from Canada to the United States. This model can directly address those concerns in a heterogeneous agent, overlapping generations framework. The calibrated model is quite successful in capturing the observed flows in each decade.

The results of the policy experiments suggest that the Canadian government has limited ability to directly stem the flow of highly skilled migrants. The relative wage offerings at the higher levels of income dominate any tax differential or calibrated attachment to Canada. This result holds true through both decades. Adopting the US tax code does little to stem the flow of high wage earners. This result becomes stronger in the 1990-2000 period. These flows have serious revenue implications for the Canadian government. The model takes an agnostic stance on what determines the observed wage distributions. The second policy experiment demonstrates that if the Canadian wage distribution looked more similar to the US wage distribution, the flow of highly skilled people would drop significantly. Many government policies and social norms contribute to the formation of observed wage distributions. Further investigation into this question is needed.

This model could be applied to other situations where there are economic motives to migrate and low political barriers. Newer members of the European Union often send large numbers of workers to older, richer members. This would be a natural area for future research. South to North migration is less easily studied in this framework, as political and legal barriers to migration are quite high for South to North migration.

Figure 3.1: Distribution of US wages CA and Native born

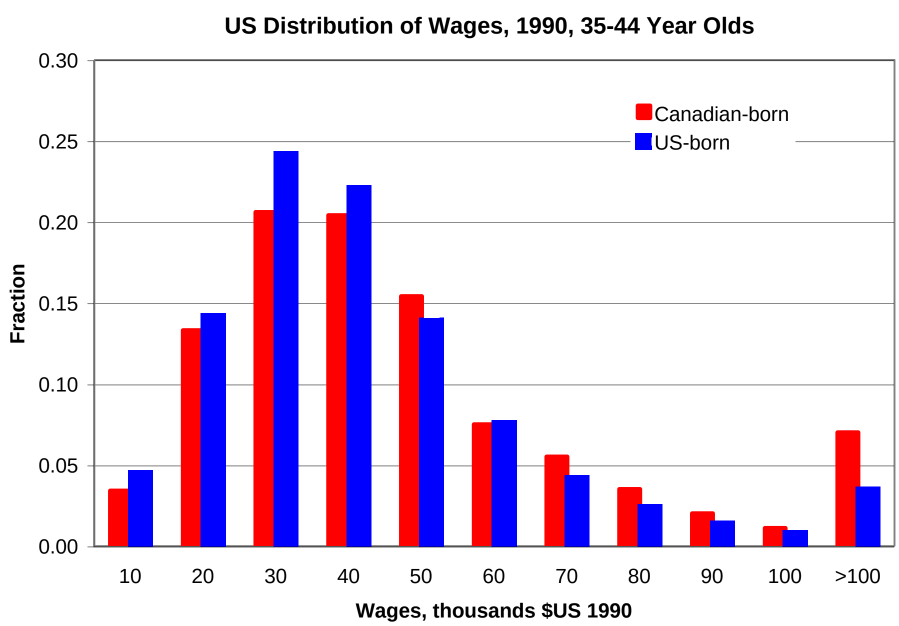

Figure 3.2: 1985 CA and US Effective Tax Rates

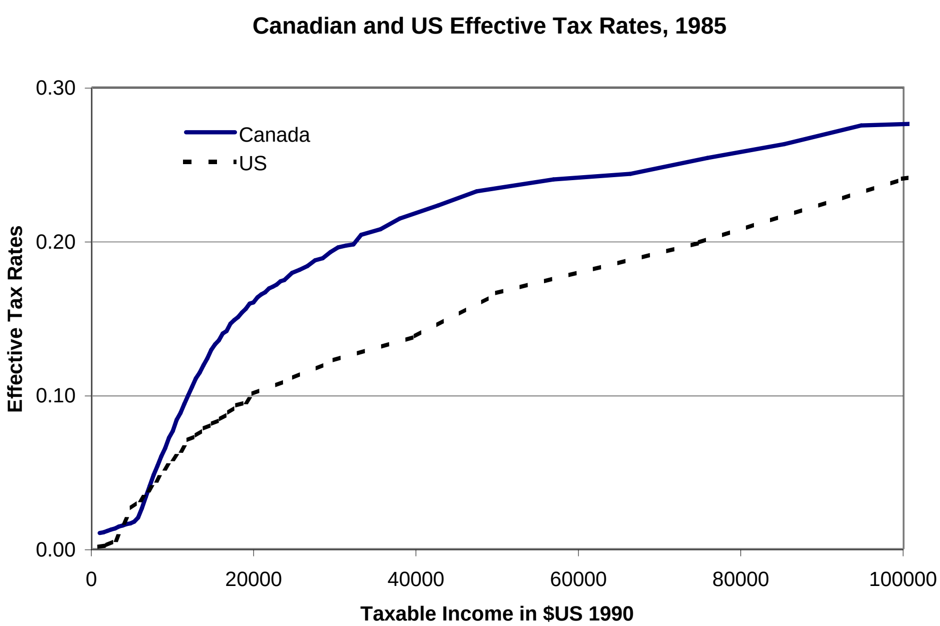

Figure 3.3: 1990 CA and US Effective Tax Rates

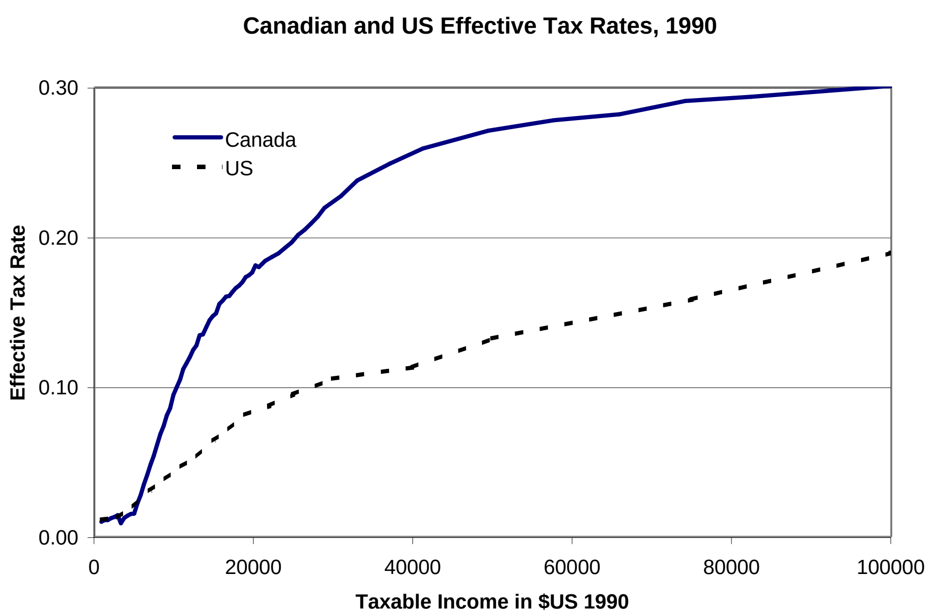

Figure 3.4: US Premium by Wage Percentile

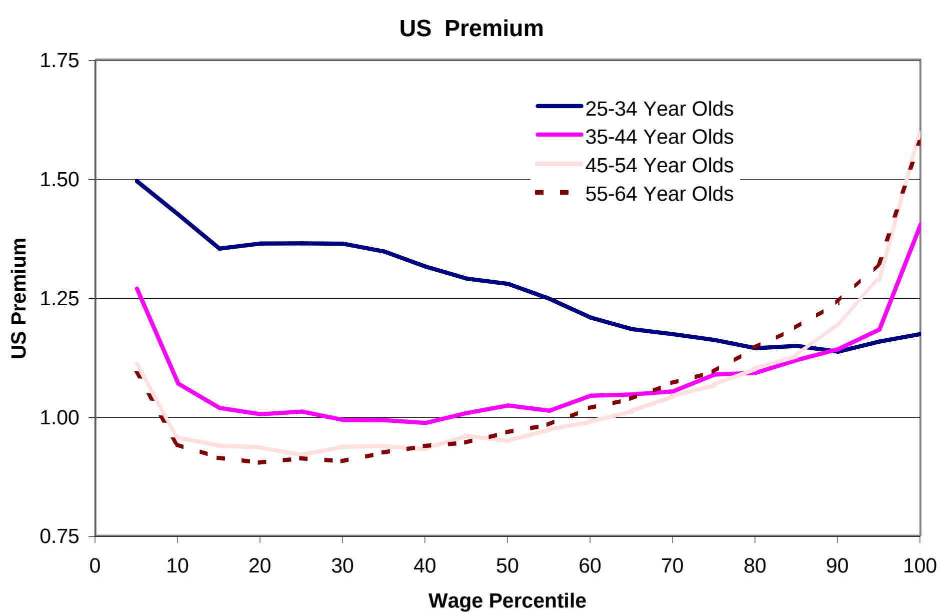

Table 3.1: 1980-1990 US Wages by Ability and Age from the 1990 US Census, public use microsample

	Age			
percentile	25–34	35–44	45–54	55-64
1–5	6.2	6.5	6.7	5.7
6–10	10.6	12.0	12.4	11.1
11–15	13.2	15.9	16.6	15.2
26–20	15.4	18.9	20.0	18.8
21–25	17.4	21.1	22.9	21.7
26–30	19.1	23.4	25.4	24.7
31–35	20.4	25.3	28.0	27.4
36–40	21.9	27.3	30.2	30.0
41–45	23.6	29.5	32.4	32.3
46–50	24.9	31.0	35.0	35.1
51–55	26.5	33.4	37.7	38.1
56–60	28.3	35.6	40.3	40.7
61–65	30.0	38.4	43.5	44.3
66–70	31.8	40.8	47.1	48.4
71–75	34.3	44.2	50.7	51.8
76–80	36.7	48.4	56.0	57.8
81–85	40.1	52.9	62.6	65.3
86–90	44.5	61.0	73.4	77.0
91–95	51.9	76.1	94.1	100.0
96–100	86.7	142.0	173.7	182.2

Table 3.2: 1990 Canadian Wages and US Premium by Ability and Age from 1989 CA Census, public use microsample, author's calculations

	Canadian Wages ('000 of PPP-adjusted 1990 $US)				US Premium (Percent)			
percentile	25–34	35–44	45–54	55–64	25–34	35–44	45–54	55–64
1–5	4.8	5.8	6.2	4.6	29.0	13.9	7.1	25.3
6–10	9.7	12.4	13.4	9.2	9.4	-2.7	-7.3	20.7
11–15	12.8	16.6	18.3	13.3	3.8	-4.7	-9.0	14.0
16–20	15.0	19.6	22.1	16.9	2.9	-3.5	-9.6	11.3
21–25	16.7	22.3	25.1	20.0	4.3	-5.6	-8.9	8.3
26–30	18.5	24.2	28.0	23.0	2.9	-3.1	-9.4	7.6
31–35	19.9	26.5	30.4	26.3	2.4	-4.4	-7.9	4.5
36–40	21.5	28.4	32.0	29.0	2.2	-3.7	-5.7	3.3
41–45	22.9	30.3	34.1	31.4	3.0	-2.7	-4.9	3.0
46–50	23.8	31.6	36.1	34.0	4.8	-1.8	-2.9	3.2
51–55	25.2	33.4	37.9	36.6	4.9	-0.1	-0.6	4.0
56–60	26.7	35.1	39.1	38.7	5.9	1.5	3.0	5.3
61–65	28.0	36.9	41.2	41.2	7.1	4.2	5.5	7.7
66–70	29.6	38.4	43.2	44.0	7.6	6.2	8.9	10.1
71–75	30.9	40.1	45.6	46.8	10.8	10.2	11.2	10.6
76–80	32.7	42.6	47.7	50.6	12.3	13.6	17.5	14.2
81–85	35.1	45.6	51.7	57.0	14.3	16.0	21.1	14.5
86–90	38.1	49.2	57.2	65.2	16.9	24.1	28.3	18.1
91–95	42.8	56.6	68.0	76.6	21.2	34.6	38.3	30.5
96–100	60.0	84.9	105.3	113.3	44.4	67.3	65.0	60.8

Figure 3.5: Calibration Results for 25-34 year olds. Attachment is calibrated to match this cohort.

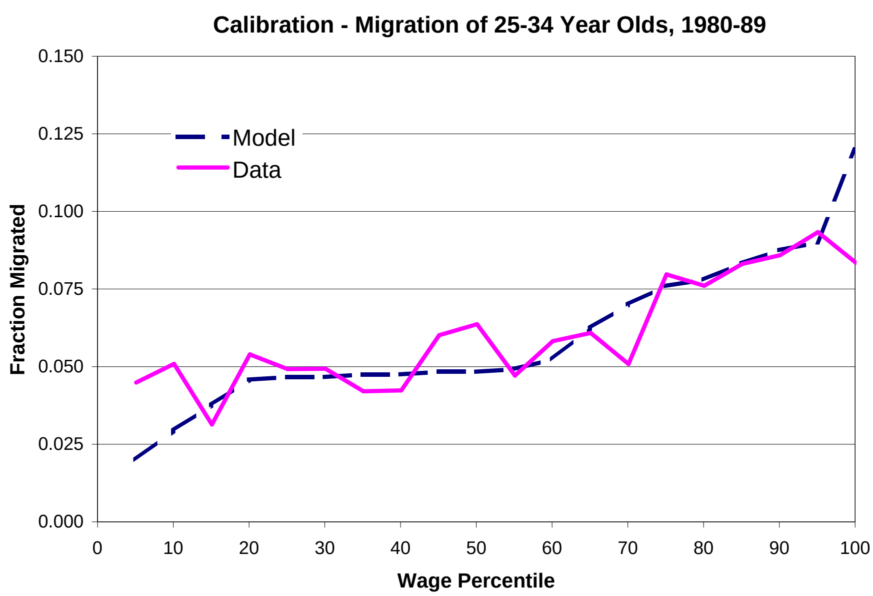

Figure 3.6: Calibration Results for 35-44 year olds. Attachment is taken from 25-34 year old cohort.

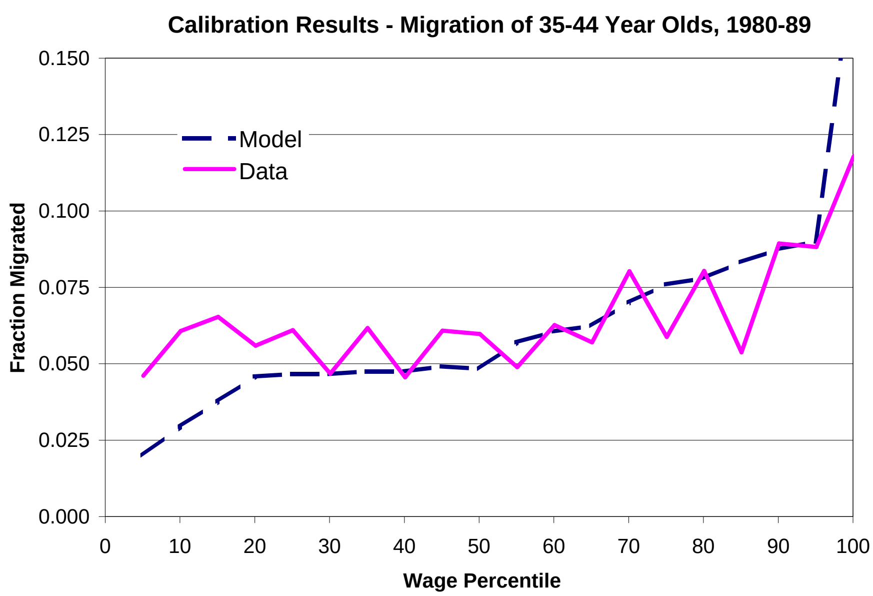

Table 3.3: 1980-1990 Migration Rates by Ability and Age, model compared to data

	Data			Benchmark Model		
percentile	25–34	35–44	45–54	25–34	35–44	45–54
1–5	7.7	14.7	18.4	8.5	0.0	0.0
6–10	10.2	11.9	22.9	8.2	0.0	0.0
11–15	11.3	14.2	26.3	8.6	0.0	0.0
16–20	8.3	13.1	26.5	8.4	0.4	0.0
21–25	9.9	10.9	21.4	8.5	0.7	0.0
26–30	7.7	8.9	22.4	8.6	5.6	0.0
31–35	9.2	11.9	17.3	8.6	5.5	0.0
36–40	8.9	13.8	22.1	8.2	6.1	5.1
41–45	8.6	12.7	18.2	9.1	6.8	5.8
46–50	9.3	13.0	28.8	9.8	7.7	7.5
51–55	9.6	11.5	23.6	9.8	9.1	9.8
56–60	9.3	11.2	22.2	10.3	10.4	12.4
61–65	9.9	13.7	23.9	10.8	12.1	13.7
66–70	10.9	10.2	20.4	11.2	12.9	15.1
71–75	11.2	15.2	20.6	12.5	15.2	16.0
76–80	10.8	11.6	20.8	12.9	15.8	18.5
81–85	9.1	14.7	25.3	13.8	16.3	19.7
86–90	13.2	14.7	27.2	14.0	17.9	21.1
91–95	12.7	19.2	23.8	14.2	20.6	24.4
96–100	18.1	24.8	29.7	18.1	25.1	30.1

Table 3.4: 1990-2000 Migration Rates by Ability and Age, model compared to data

	Data			Benchmark Model		
percentile	25–34	35–44	45–54	25–34	35–44	45–54
1–5	8.4	18.0	17.2	10.2	0.1	0.0
6–10	12.2	17.3	18.5	11.7	0.4	0.0
11–15	12.9	20.8	25.6	12.1	1.1	0.0
16–20	11.4	22.5	27.9	12.2	1.3	0.6
21–25	10.3	21.9	26.4	12.7	2.8	0.9
26–30	7.5	19.2	25.7	12.8	6.9	2.5
31–35	11.2	18.8	24.3	12.9	7.0	4.0
36–40	10.8	19.3	25.6	13.0	9.2	6.1
41–45	11.6	21.6	24.0	13.8	11.5	9.8
46–50	13.1	21.9	19.2	13.1	13.0	11.2
51–55	12.7	19.4	23.5	13.2	13.9	12.0
56–60	14.0	24.6	24.1	13.3	14.1	14.7
61–65	13.5	20.0	25.1	13.5	14.5	15.4
66–70	13.4	21.1	23.9	13.9	15.2	16.1
71–75	14.9	24.9	23.7	14.4	17.8	18.2
76–80	15.6	23.7	23.6	15.8	18.3	21.9
81–85	15.2	24.5	25.2	17.0	18.8	22.3
86–90	17.1	23.9	26.9	20.3	19.0	24.0
91–95	20.7	25.2	25.4	21.9	24.9	26.7
96–100	26.3	26.8	27.2	24.5	29.6	29.8

Table 3.5: 1980-1990 Migration Rates for Tax Harmonization

	Benchmark Model			Tax Harmonization Model		
percentile	25–34	35–44	45–54	25–34	35–44	45–54
1–5	8.5	0.0	0.0	5.2	0.0	0.0
6–10	8.2	0.0	0.0	5.6	0.0	0.0
11–15	8.6	0.0	0.0	7.0	0.0	0.0
16–20	8.4	0.4	0.0	7.3	0.0	0.0
21–25	8.5	0.7	0.0	7.3	0.2	0.0
26–30	8.6	5.6	0.0	7.5	1.1	0.0
31–35	8.6	5.5	0.0	7.6	2.9	0.0
36–40	8.2	6.1	5.1	7.6	4.7	0.0
41–45	9.1	6.8	5.8	8.0	5.9	2.5
46–50	9.8	7.7	7.5	8.1	6.1	3.8
51–55	9.8	9.1	9.8	8.1	6.4	5.1
56–60	10.3	10.4	12.4	8.4	8.0	10.3
61–65	10.8	12.1	13.7	8.5	8.7	12.6
66–70	11.2	12.9	15.1	8.6	10.2	13.5
71–75	12.5	15.2	16.0	9.3	10.6	13.9
76–80	12.9	15.8	18.5	10.2	13.0	15.2
81–85	13.8	16.3	19.7	11.7	13.8	17.6
86–90	14.0	17.9	21.1	12.1	15.3	19.8
91–95	14.2	20.6	24.4	13.8	18.3	26.4
96–100	18.1	25.1	30.1	16.9	24.7	28.1

Table 3.6: 1990-2000 Migration Rates for Tax Harmonization

	Benchmark Model			Tax Harmonization Model		
percentile	25–34	35–44	45–54	25–34	35–44	45–54
1–5	10.2	0.1	0.0	12.9	0.0	0.5
6–10	11.7	0.4	0.0	11.1	0.0	1.2
11–15	12.1	1.1	0.0	11.6	0.7	0.9
16–20	12.2	1.3	0.6	11.9	2.3	1.3
21–25	12.7	2.8	0.9	11.9	1.8	1.5
26–30	12.8	6.9	2.5	12.5	4.5	3.1
31–35	12.9	7.0	4.0	12.4	3.9	3.9
36–40	13.0	9.2	6.1	11.7	5.0	4.0
41–45	13.8	11.5	9.8	10.8	8.7	6.2
46–50	13.1	13.0	11.2	8.1	11.4	8.8
51–55	13.2	13.9	12.0	9.9	11.6	10.0
56–60	13.3	14.1	14.7	10.7	13.5	12.4
61–65	13.5	14.5	15.4	12.2	14.2	13.6
66–70	13.9	15.2	16.1	12.5	14.8	15.0
71–75	14.4	17.8	18.2	13.0	16.3	17.5
76–80	15.8	18.3	21.9	14.3	16.6	20.3
81–85	17.0	18.8	22.3	16.1	17.0	21.9
86–90	20.3	19.0	24.0	18.7	17.3	23.5
91–95	21.9	24.9	26.7	20.4	23.5	25.6
96–100	24.5	29.6	29.8	23.5	26.1	28.1

Table 3.7: 1980-1990 Migration Rates for Uniform Wage Distribution

	Benchmark Model			Uniform Wage Model		
percentile	25–34	35–44	45–54	25–34	35–44	45–54
1–5	8.5	0.0	0.0	4.1	0.0	0.0
6–10	8.2	0.0	0.0	4.8	0.0	0.5
11–15	8.6	0.0	0.0	5.1	0.0	1.4
16–20	8.4	0.4	0.0	6.2	2.0	3.9
21–25	8.5	0.7	0.0	6.0	3.1	4.1
26–30	8.6	5.6	0.0	6.8	3.3	5.0
31–35	8.6	5.5	0.0	6.7	5.9	5.2
36–40	8.2	6.1	5.1	6.5	6.5	8.8
41–45	9.1	6.8	5.8	7.9	7.7	8.6
46–50	9.8	7.7	7.5	8.6	9.0	9.7
51–55	9.8	9.1	9.8	7.3	9.1	10.0
56–60	10.3	10.4	12.4	7.0	10.5	11.6
61–65	10.8	12.1	13.7	7.8	11.1	12.5
66–70	11.2	12.9	15.1	7.2	11.5	12.2
71–75	12.5	15.2	16.0	7.9	12.4	12.0
76–80	12.9	15.8	18.5	8.2	13.7	11.8
81–85	13.8	16.3	19.7	10.5	13.0	13.5
86–90	14.0	17.9	21.1	11.0	14.6	14.0
91–95	14.2	20.6	24.4	12.3	14.3	15.3
96–100	18.1	25.1	30.1	13.6	15.7	18.9

Table 3.8: 1990-2000 Migration Rates for Uniform Wage Distribution

	Benchmark Model			Uniform Wage Model		
percentile	25–34	35–44	45–54	25–34	35–44	45–54
1–5	10.2	0.1	0.0	8.0	0.0	1.1
6–10	11.7	0.4	0.0	9.2	0.1	1.8
11–15	12.1	1.1	0.0	10.0	1.7	2.1
16–20	12.2	1.3	0.6	10.5	2.0	2.5
21–25	12.7	2.8	0.9	10.7	2.9	2.6
26–30	12.8	6.9	2.5	11.1	5.1	4.0
31–35	12.9	7.0	4.0	12.5	6.9	4.7
36–40	13.0	9.2	6.1	13.9	8.5	7.0
41–45	13.8	11.5	9.8	13.3	10.0	10.1
46–50	13.1	13.0	11.2	14.5	13.8	12.8
51–55	13.2	13.9	12.0	14.4	14.6	13.5
56–60	13.3	14.1	14.7	13.9	15.7	15.4
61–65	13.5	14.5	15.4	13.5	16.1	15.9
66–70	13.9	15.2	16.1	12.5	15.9	16.1
71–75	14.4	17.8	18.2	13.1	15.5	15.5
76–80	15.8	18.3	21.9	12.9	15.2	15.3
81–85	17.0	18.8	22.3	13.1	13.4	16.0
86–90	20.3	19.0	24.0	14.3	12.0	17.1
91–95	21.9	24.9	26.7	15.5	15.1	18.4
96–100	24.5	29.6	29.8	18.9	17.6	20.3

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Appendix A

Trade Appendix

A.1 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 GDP data for each country.

Table A.1: Data Concordance: This table links the sectoral data between US and Canada.

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