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ESSAYS ON THE IMPACT OF OPENNESS FOR THE MACRO-ECONOMY

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ESSAYS ON THE IMPACT OF OPENNESS FOR THE MACRO-ECONOMY

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ABSTRACT

Globalization has become an unstoppable trend in nowadays world economy. It brings both risks and opportunities to a country. In order to seize the best part of globalization and avoid possible harms, it is important to comprehend the mechanisms of how openness impacts the overall economy. My dissertation includes three essays that contribute to understanding the impact of openness for the macro-economy. My first chapter starts from two novel observations – 1. Bilateral migration is pervasive across OECD countries, both for high-skilled and low-skilled workers; 2. Foreign affiliates of multinational corporations (MNCs) tend to hire a significantly larger fraction of migrant workers than domestic firms. These two observations challenge the traditional migration models, which assume foreign and native workers within a skill group are homogeneous. These facts also indicate that there exists a tight connection between migration and multinational corporations' activities. I formalize these two points into a general equilibrium model and demonstrate how MNCs and migration can come together to explain the aforementioned observations, and their welfare implications. In my second chapter, I use the theoretical model I developed in Chapter One for a quantitative discussion of immigration policies between the U.S. and Canada. I calibrate the model and implement counterfactual experiments to address two general policy considerations – the effect of migration quotas, and the welfare implication of moving cost adjustments. Contrary to common belief, I find that migration quotas have negative effect on native workers' real income. Further, lower moving costs in general help improving the welfare of workers from both countries. Finally, in the third chapter, I provide a theory to explain the observation that, before WWII, openness is general negatively related to long-term growth, while the relationship becomes positive after WWII. I argue that the effectiveness of technology diffusion between two trading economies is the key determinant of the net effect of openness to long-term growth. The more effective is technology diffusion between two countries, the more likely openness is good for their long-term growth.

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LIST OF ABBREVIATIONS

CDF	Cumulative Distribution Function
CES	Constant Elasticity of Substitution
EU	European Union
FDI	Foreign Direct Investment
G7	Group of 7
GDP	Gross Domestic Product
IT	Information Technology
KTI Industries	Knowledge- and Technology-Intensive Industries
MNC	Multinational Corporation
OECD	Organisation for Economic Co-operation and Development
R&D	Research and Development
SITC	Standard International Trade Classification

CAPTER ONE: BILATERAL MIGRATION AND MULTINATIONL CORPORATIONS – A GENERAL EQUILIBRIUM MODEL

Section One: Introduction

This chapter starts by observing two novel facts. First, bilateral migration flows are pervasive across OECD countries, both for high-skilled and low-skilled workers. Second, multinational corporations tend to hire a larger number of migrant workers than domestic firms. These facts challenge traditional perspectives of international migration. On the first point, the assumption that workers (native or migrant) are homogeneous within a skill group may not be suitable for modeling international migration because it does not explain bilaterality. On the second point, immigration can affect the local labor market not only from the supply side, but also from the demand side due to the operations of multinational corporations. Here, I formalize these two concepts into a general equilibrium framework and discuss its theoretical and quantitative implications.

The model contains two key components – labor migration and multinational corporations (MNCs). Workers migrate to maximize their personal incomes given their skill levels. There are two types of firms – local and foreign. I assume that workers can generate a higher marginal productivity when matching with firms that come from their origin country. The specification has two consequences. First, foreign firms tend to hire a larger proportion of migrant workers. Second, an increase in the number of immigrants expands the market share of foreign companies because they are gaining competitive advantage from a higher ratio of migrant workers to native workers. As shown in Helpman et. al. (2004), average industry productivity is affected by the extent of multinational firms' operations. Migration enhances the competitive advantage of foreign firms, thus indirectly affecting overall productivity.

There are two forces delivering bilateral migration within skill groups. First, the production technology is described by a nested-CES function that allows for the possibility that native and migrant workers are not perfectly substitutable[1]. The heterogeneity between native and migrant workers motivates firms to diversify their workforce to reduce average production costs. The need for workforce diversification drives bilateral migration between two countries. However, I show this channel alone tends to generate extreme patterns (either extremely high or extremely low bilaterality). The extreme patterns are not consistent with the data,

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[1] This specification is gaining popularity in the labor literature that analyzes the effects of immigration. Examples include Borjas (2003), Ottaviano and Peri (2012), and Docquier et. al. (2012).

which is why the model features a second channel. The second channel stems from the assumption that the marginal productivity of workers varies according to the firms' country of origin.[2] This feature together with the presence of multinational corporations creates additional demand for migrants and makes the model flexible enough to generate the wide range of migration patterns observed in the data.

My research contributes to a growing body of literature that analyzes the welfare effects of international migration using calibrated models. An early contribution by Hamilton and Whalley (1984) indicates that large cross-country TFP differences could be a source of substantial gains from international migration. Klein and Ventura (2007, 2009) argue that the coexistence of barriers to labor mobility and cross-country TFP differences is the result of a misallocation of the world's labor force. They develop a two-location growth model and calibrate international differences in labor quality and TFP to evaluate the welfare costs of barriers to international labor mobility. Benhabib and Jovanovic (2012) investigate the optimal level of migration using a calibrated one-sector model that assumes migration is the only redistributive tool. Recently Giovanni, Levchenko, and Ortega (2013) propose a quantitative multi-sector model that includes international

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[2] Many studies show that human capital is location-specific. Examples include Friedberg (2000), Krupka (2009), and Young (2013).

TFP differences, trade, remittances, and a heterogeneous workforce to explore different channels that could benefit countries sending and receiving migrants. These studies focus on migration flows that are mainly driven by international TFP differences. My research, on the other hand, provides insights on migration flows and their welfare implications among comparably developed countries. In my model, migration is mainly driven by international workforce heterogeneity and the operations of multinational corporations.

This chapter is closely related to Docquier, Ozden, and Peri (2012), which simulated the labor market effects of net immigration and emigration in OECD countries using an aggregate model, and featured nested-CES production function as in Ottaviano and Peri (2012). In their study, migration alters the industry-wise average productivity through schooling externality (as in Acemoglu and Angrist (2000)) and capital accumulation corresponding to different skill-compositions of the labor force. They find that emigration of high-skilled workers has a negative effect on less educated native workers, thus increasing inequality. My research is different from Docquier et. al. (2012) in two major ways. First, their paper separately discusses the effects on welfare of immigration and emigration to/from a country, while my research focuses on the general equilibrium resulting in the migration between two countries. Second, in my research, migration affects the average productivity of an economy through the channel of intra-industry reallocation as recognized in Melitz (2003) and Helpman et. al. (2004). Unlike the schooling externality in Decquier et. al. (2012), which always results in a decrease in the average productivity due to emigration of high-skilled workers, my model can generate mutual productivity gains due to migration.

From a broader perspective, my research complements a large body of literature that estimates gravity models of two-way migration. Mayda (2010) investigates the determinants of migration inflows into 14 OECD countries between 1980 and 1995 and analyzes the effect of migration on average income and income dispersion in destination and origin countries. Ortega and Peri (2011) jointly estimate the effects of trade and immigration on income with a gravity-based approach, as in Frankel and Romer (1999). On the selection and sorting issue, Grogger and Hanson (2012) argue that a simple model of income maximization can explain positive selection and sorting of immigrants to OECD countries. Beine et. al. (2012) discuss the effect of diaspora network on the selection of migrants. My analysis shares with these papers the emphasis on the underlying mechanisms of bilateral migration flows, but focuses on the general equilibrium perspective of the interaction between migration and multinational corporations.

There is a small but growing empirical literature looking at the impact of migrants on FDI in their origin countries. Examples include Kugler and Rapoport (2007) and Javorcik et. al. (2011). My analysis provides an alternative view that migrants can enhance the competitive advantage of firms from their country of origin, and thus bring more foreign business activities to the destination country. This view is gaining support from empirical studies such as Buch et. al. (2006) and field studies such as Harzing (2001) and Barry (2004).

Finally, I only model horizontal FDI (the form of FDI that aims to make sale in the host country). Brainard (1997) reports that more than 80 percent of US multinationals' overseas production is used to serve foreign markets, horizontal FDI seems to be the dominating form of multinationals' operations. However, it is inarguable that searching for cheaper labor substitutes is also an important driving force for firms to establish offshore affiliates. The trade-off between offshoring and migration is not covered by the model.

The rest of the chapter is organized as follows. Section 2 describes the observation of bilateral migration and migrant-firm matching patterns. Section 3 presents the model and Section 4 discusses the equilibrium in the symmetric and asymmetric cases. I conclude in Section 5.

Section Two: Stylized Facts

I examine the bilateral labor migration data of 30 OECD countries [3]in 2000 and finds that the migration of high-skilled labor[4] tends to be more bilateral[5] than that of low-skilled workers. Further, I examine how the interaction between income maximizing migrants and MNCs can forge the patterns observed. Connections between MNCs and immigrant workers from the same country of origin are not unexpected. For example, modern management practices usually require intensive team cooperation. People with the same cultural and language background can understand each other more easily, leading to more effective collaboration. Enterprises may also have their own proprietary production technology, which means it is generally more cost-efficient to hire expatriates for their foreign operations rather than train new employees abroad. I argue in this paper that the

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[3] OECD Stat DIOC database. Countries include Australia, Austria, Belgium, Canada, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Japan, Luxembourg, Mexico, Netherlands, New Zealand, Norway, Poland, Portugal, Slovak Republic, Spain, Sweden, Switzerland, Turkey, United Kingdom, and United States.

[4] Defined as people who are of working age and hold at least two-year college degrees

[5] Measured by how two-way migration flows are similar in sizes.

interaction does exist and it is theoretically important to consider both MNCs and migration together in evaluating immigration related policies.

The stylized facts regarding migration patterns among OECD countries and the connection between multinational corporations and migration are presented herein.

2.1 Migration Pattern among OECD Countries

OECD Statistics has collected rich datasets of bilateral migration stocks among OECD countries in 2000. The data sorts immigrants according to their duration of stay, country of origin, age, labor status, education attainment, and field of study. From this detailed data, we can examine whether people from different skill groups exhibit different migration patterns. Here I focus on two subgroups of the immigrants – high-skilled labor and low-skilled labor. I define high-skilled labor as people who are currently in the labor force and obtained at least two-year college degrees. Low-skilled labor are people who are in the labor force but do not have a college degree.

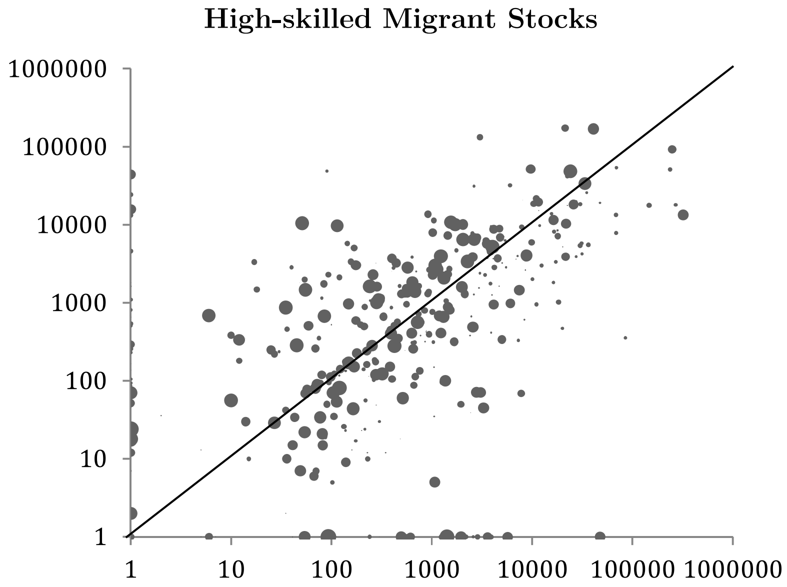

Figure 1: Log-scaled bilateral high-skilled labor migrant stocks among OECD countries (Each dot represents a country pair (*i*,*j*). The diameter of a dot is proportional to the distance between the pair of countries)

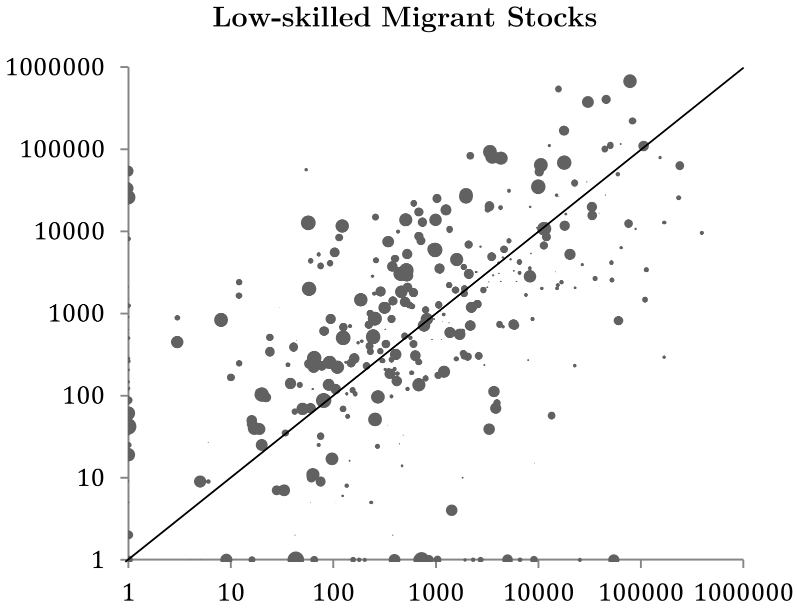

Figure 2: Log-scaled bilateral low-skilled labor migrant stocks among OECD countries (Each dot represents a country pair (*i*,*j*). The diameter of a dot is proportional to the distance between the pair of countries)

Log-scaled scatter plots of the bilateral migrant stocks for high-skilled and low-skilled workers are shown in Figure 1 and Figure 2 respectively. There is a large proportion of data points closely align on the 45-degree line for both high-skilled and low-skilled workers. This implies that two-way migrations between these country pairs are similar in sizes. This observation is not consistent with the common thought of one-way migration from poor countries to rich countries. As we can see from the figures, distance (shown by the diameter of a dot) between two countries does not have strong relationship with migration bilaterality. Many country pairs that are relatively far away from each other are still demonstrating strong migration bilaterality (located closely to the 45-degree line). The bilateral patterns shown in Figure 1 and Figure 2 actually are similar to the bilateral trade flows among OECD countries (Figure 3). The close analogy between trade and migration suggests us to think about the possibility that labor is not just simply a homogeneous factor of production, and there may be heterogeneities among workers from different countries that result in some international “trade” of talents.

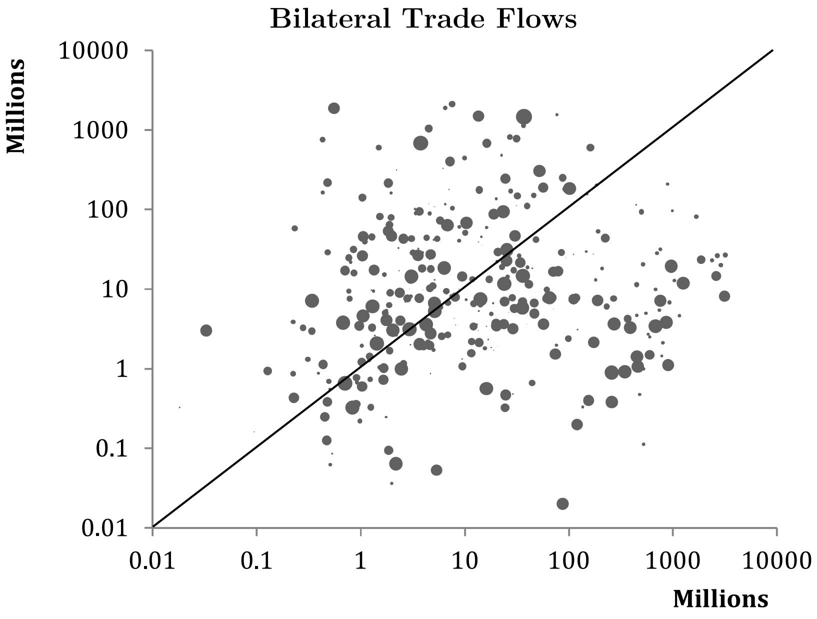

Figure 3: Log-scaled bilateral trades of commodities[6] in dollars between OECD countries in 2000 (Each dot represents a country pair (i,j). The diameter of a dot is proportional to the distance between the pair of countries)

I construct an index to measure the bilaterality of different migration groups. Suppose we denote migration stocks between two countries as $(m_{i,j}, m_{j,i})$, where $m_{i,j}$ is the stock of migrants from country j in country i and $m_{j,i}$ is the stock of migrants from country i in country j. The bilaterality index is:

$$Bilaterality\_Index(m_{i,j}, m_{j,i}) = 1 - \frac{|m_{i,j} - m_{j,i}|}{m_{i,j} + m_{j,i}}. \tag{1}$$

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[6] NBER-United Nations Trade Data.

Here we take the difference of two migration stocks divided by the sum. The index is 1 if $m_{i,j} = m_{j,i}$. To the other end, if $m_{i,j}$ is very different from $m_{j,i}$ then the index approaches to zero. This numerical measure allows us to summarize the average trends of the migration patterns of different groups of workers with a single number. I calculate index values for different migration groups, illustrated in Table 1.

Table 1: Migration bilaterality indices for OECD countries
*** Weight by the total migrant stocks among the country pair**
**** Numbers in parentheses are standard errors**

	All OECD	**European Union (EU)**	**GDP per capita > $20,000**
High-skilled			
Simple Average	0.4214 (0.0173)**	0.4285 (0.0260)	0.4674 (0.0239)
Weighted Average*	0.3947	0.5892	0.4451
Low-skilled			
Simple Average	0.3839 (0.0166)	0.4130 (0.0262)	0.4618 (0.0241)
Weighted Average*	0.2104	0.4357	0.3986

Table 1 shows that both high-skilled and low-skilled migration stocks exhibit a certain degree of bilaterality. According to the simple averages for all OECD countries, the numbers are around 40%. This means that if we normalize total migrants between a pair of countries to 100, then the average migration stock in one country is 80 and in another country is 20. Although people have the tendency to move to one country rather than another, the bilaterality is still significant and suggests that push/pull factors for international migration may not have the same effects on workers from different countries.

The average values of bilaterality index for high-skilled migration are consistently higher than the average values of index for low-skilled migration, especially if we consider the weighted averages. This suggests that workers with different skill levels face different push/pull factors for migration.

Finally, the average index values for the subset of countries in European Union (EU) are higher that the index values for all OECD countries. If we consider the weighted averages only, we can see that the index values for EU are much higher than the others. We know that EU has a highly integrated labor market. This would indicate that migration bilaterality is positively associated with economic integration.

2.2 Connection between Migration and MNCs

Multinational corporations play an important role in globalization. Anecdotal evidence suggests the hypothesis that multinational corporations are active in creating migration opportunities. For example, the Boston Consulting Group (BCG), a multinational consulting company that manages 6,200 consultants in 43 countries,[7] reports that they constantly deploy about 20% of their employees as expatriates to support foreign offices.

We can also detect this connection between multinationals and migration through the matching of migrants and MNCs. According to the Survey on Americans Overseas (Koppenfels (2012)), about half of American workers in for-profit private sectors abroad are working for international companies. Another survey by Taiwanese human resource agencies[8] shows that in 2011 there are about 75% of Taiwanese workers who work in the mainland China were working in international firms. These matching patterns demonstrate the existence of special connections between multinational corporations and migration.

Harzing (2001) conducted interviews with MNCs and found that they often employ expatriates to transfer management activities to foreign affiliates. Barry (2004) reports that Intel's decision to invest in Ireland is promoted by the ability to hire engineers from the U.S. Buch et al. (2006) finds that FDIs and labor

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[7] BCG.com. Retrieved 2013-03-06.

[8] 104 HR Agency, (2011), "Taiwan brain drain crisis survey" and 1111 HR Agency, (2011), "Taiwanese work abroad survey."

migration from the same country of origin are positively correlated in Germany's states.

Finally, I show in Table 2 the matching of immigrant workers and foreign firms compared with local firms in Brazil. The data includes all exporters in the linked employer-employee data for Brazil[9] during the period 1995-2001 as described in Muendler and Rauch (2012). The definition of foreign firms is that they are FDI affiliates. [10]

Table 2: Proportions of immigrants hired by different types of firms
*** Numbers in parenthesis are standard errors**

Type of Firms	**Low-Skilled Immigrants**	**High-Skilled Immigrants**	**All Immigrants**
Domestic	0.0205 (0.0003)*	0.1964 (0.001)	0.0397 (0.0033)
Foreign	0.0113 (0.001)	0.2973 (0.0059)	0.0557 (0.0019)

Table 2 shows that foreign firms hire a higher proportion of immigrant workers on average than domestic firms. This is mainly due to the fact that foreign firms hire a much higher proportion of high-skilled immigrants than local firms. Domestic firms on average hire a higher proportion of low-skilled immigrants than

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[9] Code courtesy of S. Bazzi (Boston Univeristy)

[10] FDI indicator by J. Poole (UC – Santa Cruz)

foreign firms, but the difference is small. This lends support to the argument that there is a close connection between migration and multinational firms.

2.3 Summary of Empirics

This section illustrates two important observations. First, migrations between OECD countries in general exhibit significant bilaterality, and high-skilled migrations tend to be more bilateral then low-skilled migrations. Second, international firms tend to create migration opportunities and hire more migrants than local firms. This finding is supported by field studies and matching patterns between different types of workers and firms. The model I propose is aiming for reproducing these two key observations.

Section Three: Model

The model is a two-country general equilibrium model of FDI and labor migration. The model is based on Helpman, Melitz, and Yeaple (2004), which extends the Melitz's trade model to incorporate horizontal FDI. It provides an important insight that firm heterogeneity plays a significant role on the determination of FDI flows. In this paper, I will show that firm heterogeneity is also a major component that determines bilateral migration patterns. According to the data, migration patterns are different for low-skilled and high-skilled workers. Thus, I specify two types of workers in each country by their skill levels. Moreover, workers with the same skill level but from different countries are classified as different types of workers.

3.1 Consumer's Preference and Demand

A representative consumer's preferences are given by a CES utility function over a continuum goods index by ω:

$$\begin{cases} \underset{q(\omega)}{\text{Max}} \left(\int_{\omega \in \Omega} q(\omega)^{\frac{\sigma-1}{\sigma}} \right)^{\frac{\sigma}{\sigma-1}} \\ s.t. \quad \int_{\omega \in \Omega} p(\omega) q(\omega) = R \end{cases} , \tag{2}$$

where Ω is the set of available products, $q(\omega)$ is the quantity of the product ω that is consumed by the representative consumer, $p(\omega)$ is the price of the product ω. Further, goods are imperfect substitutable, the elasticity of substitution σ is larger than one. Finally, R is the aggregate expenditure.

As in Melitz (2003), the optimal consumption for a product variety is:

$$q^*(\omega) = \left[\frac{p(\omega)}{P} \right]^{-\sigma} \cdot \frac{R}{P}, \tag{3}$$

where P is the price index and

$$P = \left[\int_{\omega\in\Omega} p(\omega)^{1-\sigma} d\omega\right]^{\frac{1}{1-\sigma}}. \tag{4}$$

3.2 Firms

Every firm pays an entry cost f^Eat the time of entering the market. This entry cost includes all outlays for establishing a new firm such as production development and brand advertising. This paper does not explicitly discuss the structure of the entry cost. Note that when the number of new entries is not constrained, the ex-ante expected profit for firms would be offset by this cost in equilibrium. Firms are characterized by productivity parameter φ. Firms draw their productivity levels from a distribution with the CDF $G(\varphi)$ while entry.

After entry, firms decide if they want to stay in market given their own productivity levels. Less competitive firms that cannot make profits exit market. In addition, I assume that there is a proportion δ of firms that exit exogenously in each period. If a firm decides to stay operational, the next decision is that if it wants to sell in the domestic market only or enter the foreign market and become a multinational firm. In all cases, every firm pays a fixed cost f for its domestic production. Multinational firms pay fixed cost f^I for their offshore operations.

If a firm decides to become a multinational, then it would have two establishments. One produces domestically and serves only the home market. Another one produces and serves the foreign market. As in Helpman et. al. (2004), firms in equilibrium would not serve the foreign market without serving the home market. Furthermore, only highly competitive firms (with high enough productivity levels) become multinationals. This paper does not refer to trade because it would not alter the main implications of the model. The investigation remains focused on the relationship between migration and multinational firms.

Throughout the following paper, the term "firm" is used to denote the entire company (including its home headquarter and foreign affiliate), and "establishment" is used to denote a production unit. An establishment could be a firm's headquarter in the home country or a firm's foreign affiliate. All establishments owned by the same firm have the same productivity level and skill compatibility with different type of workers, but establishments make their own production decisions within their own markets.

The marginal cost for an establishment of a firm with productivity level φ is:

$$c_j^i(\varphi) = \frac{1}{\varphi} \cdot \overline{w}_j^i \,, \tag{5}$$

where index i denotes the country where the establishment is located and index j denotes the country of the firm's origin. Labor is the only input for production. $\overline{w}_j^i$ denotes the average wage rate for workers who work in the establishment.

3.3 Labor Endowments, Moving Costs, and Wage Rates

The model assumes there are two countries (denoted by country 1 and country 2) and four types of labor, respectively high-skilled workers from country 1, high-skilled workers from country 2, low-skilled workers from country 1, and low-skilled workers from country 2. Each country has endowments for high-skilled and low-skilled workers, which are denoted by $\overline{H}^i$ and $\overline{L}^i$ (for $i = \{1,2\}$).

Moving costs are separately specified according worker's skill level, source country, and destination country[11]. The moving costs for high-skilled migrants from country i to j is denoted by $\tau^{i,j}$ and for low-skilled migrants from country i to j is denoted by $t^{i,j}$. Here I assume that $\tau^{i,j}, t^{i,j} = 1$ if $i = j$ (there is no migration costs for native workers staying in their home country), and they are larger than one if $i \neq k$. The migration costs indicate that there are usually some extra outlays for employers to hire international workers. For example, in the U.S., employers need

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[11] The migration costs need not to be symmetric between two countries. Although transportation costs might be similar for moving back and forth, each country may have its unique regulations on immigration and thus impose different costs.

to pay H1-visa fees for international workers they hire. The research follows in Bojas' specification (1987) that the moving costs are proportional to worker's income.

I use nested-CES production function to aggregate different types of workers. The first layer provides a CES aggregator for high-skilled and low-skilled workers. The second layer provides a CES aggregator for immigrant and native workers within each skill level. This specification is similar to Ottaviano and Peri (2012).

The average wage rate for labor is defined as:

$$\bar{w}_j^i = \left(\alpha^\rho \cdot \left(\bar{s}_j^i\right)^{1-\rho} + (1-\alpha)^\rho \cdot \left(\bar{u}_j^i\right)^{1-\rho}\right)^{\frac{1}{1-\rho}}. \tag{6}$$

The index i again denotes where the establishment is located and index j denotes the firm's country of origin. $\bar{s}_j^i$ and $\bar{u}_j^i$ are respectively the average wage rates for high-skilled workers and low-skilled workers. ρ is the elasticity of substitution between low-skilled labor and high-skilled labor. $\alpha \in (0,1)$ is the output share of high-skilled workers.

The next layer is aggregation of immigrant and native workers:

$$\bar{s}_j^i = \left[\sum\nolimits_k \frac{\xi_j^k}{\sum_m \xi_j^m} \cdot \left(\tau^{i,k} \cdot s^{i,k}\right)^{1-\gamma}\right]^{\frac{1}{1-\gamma}} \tag{7}$$

$$\bar{u}_j^i = \left[\sum\nolimits_k \frac{\zeta_j^k}{\sum_m \zeta_j^m} \cdot \left(t^{i,k} \cdot u^{i,k}\right)^{1-\Gamma}\right]^{\frac{1}{1-\Gamma}} \tag{8}$$

$s^{i,k}$ is the wage rate for high-skilled workers who are from country k and work in country i. Similarly, $u^{i,k}$ is the wage rate for low-skilled workers who are from country k and work in country i. The parameters γ and Γ are elasticity of substitution between immigrant and native workers. The parameters ξ_j^k and ζ_j^k represent the compatibility (so called the skill compatibility parameters) between firms and workers that may come from different origins. I normalized these parameters to 1 if $i = k$, and they are assumed to be less than one if otherwise. Workers from different countries often have different cultural backgrounds, languages, and educational trainings so they tend to have less compatibility with firms from other countries.

3.4 Demands for Migrant Workers

By Shephard's lemma, firms' marginal demands for different types of workers are:

$$h_j^{i,k}(\varphi) = \frac{1}{\varphi} \cdot \alpha^{\rho} \cdot \frac{\xi_j^k}{\sum_m \xi_j^m} \cdot \left(\frac{1}{\tau^{i,k}}\right)^{\gamma} \cdot \left(\bar{w}_j^i\right)^{\rho} \cdot \left(\bar{s}_j^i\right)^{\gamma-\rho} \cdot \left(s^{i,k}\right)^{-\gamma} \tag{9}$$

$$l_j^{i,k}(\varphi) = \frac{1}{\varphi} \cdot (1-\alpha)^{\rho} \cdot \frac{\zeta_j^k}{\sum_m \zeta_j^m} \cdot \left(\frac{1}{t^{i,k}}\right)^{\Gamma} \cdot \left(\bar{w}_j^i\right)^{\rho} \cdot \left(\bar{u}_j^i\right)^{\Gamma-\rho} \cdot \left(u^{i,k}\right)^{-\gamma}. \tag{10}$$

We can see that marginal labor demands are decreasing functions in firm's productivity level and relative cost to other production factors.

Next, to find the aggregate labor demand, we first define the total demand of the representative establishment (with the average productivity of its kind). The total demand of the representative establishment that comes from country j and operates in country i is:

$$H_j^{i,k} = \begin{cases} q_j^i(\tilde{\varphi}) \cdot h_j^{i,k}(\tilde{\varphi}), & for\ j = k \\ q_j^i(\tilde{\varphi}^f) \cdot h_j^{i,k}(\tilde{\varphi}^f), & for\ j \neq k \end{cases} \tag{11}$$

$$L_j^{i,k} = \begin{cases} q_j^i(\tilde{\varphi}) \cdot l_j^{i,k}(\tilde{\varphi}), & for\ j = k \\ q_j^i(\tilde{\varphi}^f) \cdot l_j^{i,k}(\tilde{\varphi}^f), & for\ j \neq k \end{cases} \tag{12}$$

Here $H_j^{i,k}$ is the demand for high-skilled workers of the representative establishment and $L_j^{i,k}$ is the demand for low-skilled workers. $\tilde{\varphi}$ is the average productivity of local establishments and $\tilde{\varphi}^f$ is the average productivity of foreign establishments.

Finally, the total demand for migrants from country k to i is:

$$high\_skilled\_migrants^{i,k} = \sum_j M_j \cdot \chi_j^i \cdot H_j^{i,k} \tag{13}$$

$$low\_skilled\_migrants^{i,k} = \sum_j M_j \cdot \chi_j^i \cdot L_j^{i,k}, \tag{14}$$

where χ_j^i is the proportion of firms from country j that have an establishment in country i.

3.5 Migration Quota

Migration quotas are also usually implemented separately for workers with different skill levels. For example, in the U.S. there are different work visas (e.g., H-1B and H-2B) for different type of workers and each type of work visa has its own limit cap. Therefore, we can model the quotas independently for each type of workers. I discuss here only the case in which migration quotas are effective (i.e., where the constraint is binding).

In considering country i implementing an effective migration quota to workers of type n from country j, since the quota is effective, we can denote it as a percentage[12] of the total number of immigrants when there was no constraint. I denote the percentage by $\lambda_n^{i,j} \in [0,1]$, where $n = \{h, l\}$ denotes the skill level of workers, i denotes the country that implements the migration quota, and j denotes the country of origin of the workers. $\lambda_n^{i,j} = 1$ if immigration is

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[12] In reality, quotas are usually implemented as absolute numerical caps. However, if quotas are binding, then we can always find a one-to-one mapping between the percentage value and the absolute cap. These two denotations are equivalent in the context of the model.

unconstrained, $\lambda_n^{i,j} = 0$ if legal immigration is totally banned, and $\lambda_n^{i,j} \in (0,1)$ when immigration is allowed and an effective migration quota is implemented.

Section Four: General Equilibrium

The equilibrium is defined by the set of variables $\left\{\{\bar{\varphi}_i\}, \{\bar{\varphi}_{j,i}^f\}, \{\chi_i\}, \{M_i\}, \{s^{j,i}\}, \{u^{j,i}\}\right\}$, where $i = \{1,2\}$ denotes the country of origin $j = \{1,2\}$ denotes the destination country. $\bar{\varphi}_i$ is cutoff productivity for local firms, which is the lowest productivity level that firms with productivity levels lower than this threshold would exit the market. $\bar{\varphi}_{i,j}^f$ is the cutoff productivity for foreign firms form country i and operating in country j. χ_i is the proportion of firms from country i that are multinational. $s^{j,i}$ is the wage rate of high-skilled workers from country i and working in country j, and $u^{j,i}$ is the wage rate of low-skilled workers.

In addition, I assume that the productivity distribution is Pareto and $G(\varphi) = 1 - \left(\frac{B}{\varphi}\right)^{\kappa}$ $for\ \varphi \geq B$, where B is the scale parameter, and κ is the shape parameter.

4.1 Equilibrium Conditions

The following conditions determine the equilibrium. The derivation of the equilibrium is in Appendix A.

(1) Zero-cutoff Profit Condition

Since the production function is assumed to be increasing return to scale, the profit of a firm is an increasing function in productivity. There exist productivity levels $\bar{\varphi}_i$ and $\bar{\varphi}_{i,j}^f$ such that firms with productivity levels less than $\bar{\varphi}_i$ close down and only firms with productivity level higher than $\bar{\varphi}_i^f$ choose to become multinational firms. The zero cutoff profits condition can be expressed as a set of equations:

$$\pi_i^i(\bar{\varphi}_i) = 0 \tag{15}$$

$$\pi_i^j\left(\bar{\varphi}_{i,j}^f\right) = 0 \tag{16}$$

(2) Free Entry Condition

The ex-ante expected profit for a new entrant firm is:

$$V_i^E = E\left[\sum_{t=0}^{\infty}(1-\delta)^t \cdot \pi_i - f^E\right] = \frac{1 - G(\bar{\varphi}_i)}{\delta} \cdot \bar{\pi}_i - f^E \; . \tag{17}$$

Free entry of new firms drives the ex-ante expected profits to zero. Therefore, we have $V_i^E = 0 \; for \; \forall i$.

As in Melitz (2003) and Helpman et. al. (2004), we can use the condition (1) and (2) to solve $\{\bar{\varphi}_i\}$, $\{\bar{\varphi}_{i,j}^{f}\}$, and $\{\chi_i\}$.

(3) Labor Market Clearing and Migration Incentive Compatibility

If there is no migration quota workers are assumed to be able to move across countries by paying the moving costs. Therefore, in equilibrium, we must have the real incomes (adjusted for the moving costs) for workers who migrate to foreign countries equal to the real incomes for the same type of workers who stay in their home countries. Otherwise, workers would keep moving to the country where they can earn higher real wages. Further, the total labor demand should equal to total labor supply in all countries. We can use this condition to solve $\{M_i\}$, $\{s^{j,k}\}$, and $\{u^{j,k}\}$.

(4) Migration Quota

Notice that the equilibrium condition (3) holds true only if we do not have an effective migration quota in existence. If there are effective migration quotas, the countries that implement them would have excess demands for foreign workers. In this case, we have:

$$\frac{s^{i,j}}{P^i} > \frac{s^{j,j}}{P^j} \ \ if\ \lambda_h^{i,j} < 1 \tag{18}$$

$$\frac{u^{i,j}}{P^i} > \frac{u^{j,j}}{P^j}\ if\ \lambda_l^{i,j} < 1 \tag{19}$$

For workers who are form country j that are effectively regulated by migration quota in country i.

By our notation of the migration quota, the new supply functions of foreign workers are:

$$H^{S,i,j} = \lambda_h^{i,j} \cdot H^{E,i,j} \tag{20}$$

$$L^{S,i,j} = \lambda_l^{i,j} \cdot L^{E,i,j}\ , \tag{21}$$

where $H^{E,i,j}$ and $L^{E,i,j}$ are amounts of immigration from country j to i in the unconstraint equilibrium solved by using equilibrium condition (3). We can use these new supply functions to look for the equilibrium with binding migration quotas.

4.2 Analysis of the Equilibrium

4.2.1 International Labor Heterogeneity and Migration Pattern

An important channel in the model that generates bilateral migration flow is heterogeneity in workers from different countries. Since workers from different countries are not perfectly substitutable, firms are motivated to hire foreign workers to reduce the average production costs. However, I show here that this channel alone tend to generate extreme migration patterns.

We start by considering only migration of high-skilled workers, and a similar analysis can be applied to migration of low-skilled workers. If we shut down MNC (i.e., $\chi_i = 0\ \forall i$), then we can write the number of migrants from country j to i:

$$
\begin{gathered}
migrants^{i,j} = \left[\left(\frac{s^i}{\tau^{i,j}\cdot s^j}\right)^{1-\gamma} + \xi_i^j\right]^{\frac{\gamma}{1-\gamma}} \cdot D^{i,j}, where \\
D^{i,j} = \alpha^{\rho}\cdot\left(\frac{\sigma}{\sigma-1}\right)^{-\sigma}\cdot M_i\cdot\frac{R_i}{P_i^{1-\sigma}}\cdot\frac{\xi_i^j}{\left(1+\xi_i^j\right)^{\frac{1}{1-\gamma}-1}}\cdot\widetilde{\varphi}_i^{\sigma-1}\cdot(\overline{w}_i^i)^{\rho-\sigma}\cdot(\overline{s}_i^i)^{-\rho}
\end{gathered}
\tag{22}
$$

Here s^i denotes the real wage of high-skilled workers from country i. We can see that the number of high-skilled migrants from country j to i is decreasing in the wage (adjusted for the moving costs) of migrant workers, relative to the average cost for hiring high-skilled workers of firms from country i. The sensitivity of the number of migrants to the relative difference in migrants' wage, to the average wage, largely depends on the elasticity of substitution between workers from country i and country j (i.e., γ).

Now we consider the ratio of the number of high-skilled migrants from country j to i to the number of high-skilled migrants from country i to j, which is:

$$\frac{migrants^{i,j}}{migrants^{j,i}} = \left[\frac{\left(\frac{s^{i}}{\tau^{i,j} \cdot s^{j}}\right)^{1-\gamma} + \xi_{i}^{j}}{\left(\frac{s^{j}}{\tau^{j,i} \cdot s^{i}}\right)^{1-\gamma} + \xi_{j}^{i}}\right]^{\frac{\gamma}{1-\gamma}} \cdot \frac{D^{i,j}}{D^{j,i}}. \tag{23}$$

First, if two countries are symmetric, then the ratio is always 1. This means that between two symmetric countries, the migration flow is perfectly bilateral. Second, suppose we have two asymmetric countries but they are similar enough so that $\frac{D^{i,j}}{D^{j,i}} \approx 1$ and in equilibrium we have $s^{j} > s^{i}$, then the number of migrants from country i to j is smaller than the number of migrants from country j to i (i.e., $\frac{migrants^{i,j}}{migrants^{j,i}} < 1$) and the magnitude of the difference depends on relative wages and the elasticity of substitution between workers from country i and country j.

The migration bilaterality is getting lower while the elasticity of substitution is getting larger. Consider the fact that foreign and native high-skilled workers are usually seen as close substitutes (Ottaviano and Peri (2012) estimate this elasticity in the U.S. is about 33). A small difference in wage rates could be augmented to a large difference in the amount of migration stocks in two countries.

4.2.2 Migration and Multinational Corporations

In 4.2.1, I show that international labor heterogeneity is an important driving factor of bilateral migration, but that alone tends to generate extreme migration patterns. Here I discuss how the operations of multinational corporations can balance this out, allowing the model to be flexible enough to generate a wide range of migration patterns. Again, the discussion focuses on the migration of high-skilled workers and a similar analysis can be applied to migration of low-skilled workers.

Consider the case with MNCs. The number of high-skilled migrant from country j to country i is:

$$migrants^{i,j} = \left\{\left[\left(\frac{s^i}{\tau^{i,j} \cdot s^j}\right)^{1-\gamma} + \xi_i^j\right]^{\gamma} \cdot D^{i,j}\right\} + \left\{\left[\xi_j^i \cdot \left(\frac{s^i}{\tau^{i,j} \cdot s^j}\right)^{1-\gamma} + 1\right]^{\gamma} \cdot E^{i,j}\right\}, where \tag{24}$$

$$D^{i,j} = \alpha^{\rho} \cdot \left(\frac{\sigma}{\sigma - 1}\right)^{-\sigma} \cdot M_i \cdot \frac{R_i}{P_i^{1-\sigma}} \cdot \frac{\xi_i^j}{\left(1 + \xi_i^j\right)^{\frac{1}{1-\gamma}-1}} \cdot \tilde{\varphi}_i^{\sigma-1} \cdot (\overline{w}_i^i)^{\rho-\sigma} \cdot (\overline{s}_i^i)^{-\rho}$$

$$E^{i,j} = \alpha^{\rho} \cdot \left(\frac{\sigma}{\sigma - 1}\right)^{-\sigma} \cdot M_j \cdot \chi_j \cdot \frac{R_i}{P_i^{1-\sigma}} \cdot \frac{1}{\left(1 + \xi_i^j\right)^{\frac{1}{1-\gamma}-1}} \cdot \left(\tilde{\varphi}_j^f\right)^{\sigma-1} \cdot \left(\overline{w}_j^i\right)^{\rho-\sigma} \cdot \left(\overline{s}_j^i\right)^{-\rho}$$

Compared to (22), we have an additional component (in the second large bracket), which is due to demand of foreign establishments in country i. Notice that the positions of the compatibility parameter (ξ) are different in the components. This is because international firms have higher compatibility with workers from their origin country than with native workers in the destination country.

We compare the bilateral migration flow between the two countries that is due to operations of multinational corporations with a ratio:

$$ratio = \left[\frac{\xi_j^i \cdot \left(\frac{s^i}{\tau^{i,j} \cdot s^j}\right)^{1-\gamma} + 1}{\xi_i^j \cdot \left(\frac{s^j}{\tau^{j,i} \cdot s^i}\right)^{1-\gamma} + 1}\right]^{\gamma} . \tag{25}$$

The ratio compares the second components of $migrants^{i,j}$ and $migrants^{j,i}$ as defined in (24). $E^{i,j}$ and $E^{j,i}$ are dropped since they are dominated when γ is large. The ratio gives us a sense of the relative contribution of multinational corporations to migration flows in different countries.

Assuming that two countries are asymmetric and in equilibrium we have $s^j > s^i$ as in 4.2.1. Further, for simplicity, we assume that the moving costs and the skill compatibility are symmetric between two countries (i.e., $\tau^{i,j} = \tau^{i,j}$ and $\xi_j^i = \xi_i^j$). With these assumptions, the ratio in (97) is larger than 1 and increasing in γ.

The result indicates that multinational corporations contribute much more to migration flow from country j to i than the flow from country i to j. Notice that this trend is the opposite of the one mentioned in 4.2.1. In 4.2.1 we see that with international wage difference, workers tend to move from low-income country to high-income country and cause low migration bilaterality. However, multinational corporations provide another channel to balance this trend by providing an extra demand for migrant workers from high-income country to low-income country.

4.2.3 Migration and Productivity

The cutoff productivity for domestic and foreign establishments according equilibrium condition (1) and (2) are:

$$\bar{\varphi}_i = \left[\frac{f + \chi_{i,j} \cdot f^I}{\delta \cdot f^E} \cdot \frac{\sigma - 1}{1 + \kappa - \sigma}\right]^{\frac{1}{\kappa}} \cdot B \tag{26}$$

$$\bar{\varphi}^f_{i,j} = \bar{\varphi}_i \cdot \frac{\overline{w}^j_i}{\overline{w}^i_i} \cdot \frac{P^i}{P^j} \cdot \left(\frac{R^j}{R^i} \cdot \frac{f}{f^I}\right)^{\frac{1}{1-\sigma}}, \tag{27}$$

where $\bar{\varphi}_i$ is the cutoff productivity for domestic establishments in country i, $\bar{\varphi}^f_{i,j}$ is the cutoff productivity for foreign establishments in country j from country i, and $\chi_{i,j}$ is the proportion of firms from country i that have foreign establishments in country j. This proportion is:

$$\chi_{i,j} = \left[\frac{\overline{w}^j_i}{\overline{w}^i_i} \cdot \frac{P^i}{P^j} \cdot \left(\frac{R^j}{R^i} \cdot \frac{f}{f^I}\right)^{\frac{1}{1-\sigma}}\right]^{-\kappa}. \tag{28}$$

In this paper, migration affects overall productivity through its indirect effect on intra-industry reallocation of market shares among firms with different productivity. To illustrate this point, this paper posits a special case where only migration from country i to j is allowed. In comparing this case to the case of disallowing migration, we can derive that the ratio $\frac{\bar{w}_i^j}{\bar{w}_i^i}$ is higher when migration is allowed due to international labor heterogeneity and higher skill compatibility between firms and workers from the same origin. We can see from (97) that a higher ratio $\frac{\bar{w}_i^j}{\bar{w}_i^i}$ leads to a higher proportion of multinational firms, which in (26) increases the cutoff productivity[13].

Migration from country i to j also tends to increase the cutoff productivity for foreign establishment from country i to j ($\bar{\varphi}_{i,j}^f$) because foreign establishments from country i are gaining competitive advantage (with a larger $\frac{\bar{w}_i^j}{\bar{w}_i^i}$) due to migration. The tougher competition brought by highly productive foreign firms causes intra-industry reallocation of market shares to more productive firms and increases aggregate productivity in country j.

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[13] As well as aggregate productivity since it is proportional to the cutoff productivity as recognized in Melitz (2003).

In general, the model shows that the movement of both immigrants and emigrants leads to productivity gains. Immigrants bring more foreign business activities, which increase local competition and uplift overall productivity. On the other hand, emigrants enhance offshore business opportunities that attract more new entrants in the origin country.

Section Five: Conclusion

This paper established a general equilibrium model to discuss the interaction between migration and multinational corporations and the welfare implications. Theoretically, I illustrated that the operations of multinational corporations are important for forming bilateral migration patterns. Second, migration can affect aggregate productivity through multinationals' operations. Without MNCs, migration does not have any effect on aggregate productivity. The impact on productivity (and therefore welfare) of interaction between migration and multinationals should be something policy makers are aware of.

CHAPTER TWO: QUANTITATIVE ANALYSIS OF BILATERAL GRATION POLICIES BETWEEN THE U.S. AND CANADA

Section One: Introduction

Using the model I developed in Chapter One, I consider several counterfactual policy experiments to understand the welfare implications of multinational firm and labor mobility. I calibrate the model to US and Canadian data[14] to evaluate the impact of policy changes. First, if we shut down MNC, then bilateral migration flows are dominated by migrants from the U.S. to Canada due to country-size effect, where the smaller country has a higher marginal return on labor force growth. In this case, Canadian workers gain but US workers lose from the openness. On the other hand, with MNCs, the U.S. becomes the net receiving country of both high-skilled and low-skilled migrants and native workers in all countries benefiting from the openness to migration. Welfare improvements though are largely due to openness to MNCs, and migration enhances these gains. [15] This illustrates the important role of MNC's on the welfare implication of migration.

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[14] The United States and Canada are used here to demonstrate how migration interacts with MNCs to generate the observed pattern and the welfare implications. Similar exercise can be applied to any other pairs of OECD countries.

[15] The gains in the real wages are ranging from 0.3% to 0.6% under the calibrated moving costs. Under free migration, the gains are ranging from 5% to 23%.

Theoretically, when there was no MNC, migration could be thought as merely the relocation of production factors without an external effect on overall productivity. In this case, only the countries receiving net human capital benefit from the relocation. With MNCs, migration is not only a process of relocating production factors across countries, but it also affects the aggregate productivity through the interaction with MNCs that causes the intra-industry reallocation of market shares to more productive firms. Furthermore, migration reduces variable costs of MNCs' offshore establishments and results in more available product varieties to consumers. Both channels contribute to an increase in global production efficiency (measured by real GDP per capita). Therefore, in addition to the welfare gains due to the openness to MNCs, migration stimulates even further gains. [16]

Second, contrary to the traditional view that migration quotas preserve the career opportunities of native workers, the results of this analysis show that reciprocal migration quotas (where both countries implement similar rules to limit migration inflow) in general have negative effects on native workers' real wages. Instead of preserving the career opportunities of native workers, reciprocal

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[16] This result does not take into account for the transition path between the two equilibria, which may incur welfare costs in the short-run.

migration quotas protect early immigrants from the competition of potential latter immigrants that are limited by the quotas. This regulation hurts native workers since the quotas prevent the economy from achieving higher production efficiency though a similar mechanism, as argued in the first point.

Third, the welfare implications of reducing the moving costs are complex. In general, reducing moving costs improves the welfare of native workers. However, the welfare improvements are not necessary evenly distributed among all skill groups of workers. My results show that there are cases where the benefits accrue to one group of native workers more than another due to substitution. For example, if we reduce the moving costs for only high-skilled migrants from both countries, Canadian low-skilled workers end up being worse off even when real per capita GDP is higher because they are substituted out by US high-skilled workers. These distributional effects of change in migration policy suggest that policy makers should be cautious about the side effect of unwanted inequality when introducing new migration policies to improve the total welfare.

The rest of the chapter is organized as follows. Section 2 describes calibration strategies and results, and implements sensitivity analysis. Section 3 presents counterfactual experiments to assess welfare implications of migration quotas and moving cost interventions. I conclude in Section 4.

Section Two: Calibration and Sensitivity Analysis

2.1 Calibration

I sort the parameters into two broad categories. The first category contains parameters that pertain to industry characteristics, which includes the elasticity of substitution over products σ, the entry cost f^{E}, the fixed production cost for local establishments f, the fixed production cost for foreign establishments f^{I}, and the shape parameter κ and the scale parameter B of the Pareto productivity distribution. The second category contains parameters that pertain to the labor market, including labor endowments $\bar{H}^{i}$ and $\bar{L}^{i}$, migration costs $\tau^{i,j}$and $t^{i,j}$, skill compatibilities ξ_{j}^{i} and ζ_{j}^{i}, the share parameter of high-skilled labor α, and elasticities of substitution among different types of labor ρ, γ, and Γ.

The elasticity of substitution over products and the shape parameter of the productivity distribution are calibrated according to Luttmer (2007) and Broda and Weinstein (2004). Broda and Weinstein report that the median elasticity of their estimation for sectors at the 5-digit SITC level in the U.S. is 2.7. I use this number to calibrate the parameter σ. Luttmer reports that to match the tail shape of the firm size distribution in the U.S., the ratio $\frac{\kappa}{\sigma-1}$ should equal to 1.06, which implies that $\kappa = 1.8$.

According to the Business Dynamic Statistics by the U.S. Census Bureau, the exit rate in 2000 of firms that are older than five years is about 9% and the exit rate of firms in their first year is 23.9%. I use 9% as the exogenous exit rate of firms (i.e., $\delta = 0.09$) and 23.9% as the endogenous survival rate of the newly established firms. The endogenous survival rate implied by the model is $\mathbb{P}(\varphi \geq \bar{\varphi}) = \left(\frac{B}{\bar{\varphi}}\right)^{\kappa} = \left[\frac{f+\chi_i \cdot f^I}{\delta \cdot f^E} \cdot \frac{\sigma-1}{1+\kappa-\sigma}\right]^{-1}$. By normalizing f and B both to 1, we can use this formula to calibrate f^E to match the observed survival rate of new firms.

The proportion of multinational firms in the U.S. according to Bernard (2009) is about 1%. I use this to calibrate f^I since the proportion of multinational firms is given by $\chi_i = \left[\frac{\bar{w}_i^j}{\bar{w}_i^i} \cdot \frac{P^i}{P^j} \cdot \left(\frac{R^j}{R^i} \cdot \frac{f}{f^I}\right)^{\frac{1}{1-\sigma}}\right]^{-\kappa}$.

To calibrate labor endowments, I normalize the total population in the U.S. to 10 and adjust the population of Canada by the relative country size. The actual number of high-skilled and low-skilled workers in each country depends on the ratio of college-graduates to non-college-graduates. According to the OECD Stat country profiles, we have $\overline{H}^1 = 3.58$, $\overline{H}^2 = 0.4367$, $\overline{L}^1 = 6.42$, and $\overline{L}^2 = 0.6743$.

The elasticities of substitution over different types of labor are calibrated according to the estimation by Ottaviano and Peri (2012), where we have $\rho = 2$, $\gamma = 33$, and $\Gamma = 11.1$. The share parameter of high-skilled labor α is calibrated to match the income distribution of the U.S. in 2000. According to the UNU-WIDER World Income Inequality Database V2.0c, incomes paid to the top 30% of wage earners is 58.24% of the total wage payments and to the top 40% is 68.36% of the total payments. Since the high-skilled endowment in the U.S. is calibrated to be 35.8% of the total labor force, I use linear interpolation to calculate the percentage of total income payments to high-skilled workers in the U.S., which is 64%. I calibrate α to so that the percentage of total income payments to high-skilled workers in the U.S. match this number.

Finally, the migration costs $\tau^{i,j}$ and $t^{i,j}$ and the skill compatibility parameters are calibrated to best the migration pattern between the U.S. and Canada. According to the OECD Stat DIOC database, the high-skilled migrants from the U.S. to Canada is 0.24% of its high-skilled labor force, high-skilled migrants from Canada to the U.S. is 5.55%, low-skilled migrants from the U.S. to

Canada is 0.24% of the low-skilled labor force, and low-skilled migrants from Canada to the U.S. is 4.14%. Further, the bilaterality index for high-skilled workers is 0.53 and for low-skilled workers is 0.38. These are the targeting numbers to match. The calibration result is summarized in Table 3.

Table 3: Calibration result (country 1 denotes the U.S. and country 2 denotes Canada)

Parameter	Calibrated Value	Description	Source
$\{\bar{H}^1, \bar{L}^1\}$	{3.58,6.42}	Labor endowments	OECD Stat
$\{\bar{H}^2, \bar{L}^2\}$	{0.4367,0.6744}		OECD Stat
$\tau^{1,2}$	1.1896	Moving costs of high-skilled migrants	To match migration pattern
$\tau^{2,1}$	1.0984		To match migration pattern
$t^{1,2}$	1.5585	Moving Costs of low-skilled migrants	To match migration pattern
$t^{2,1}$	1.5835		To match migration pattern
ξ_2^1	0.9373	Skill compatibility parameters for high-skilled workers	To match migration pattern
ξ_1^2	0.8483		To match migration pattern
ζ_2^1	0.7741	Skill compatibility parameters for low-skilled workers	To match migration pattern
ζ_1^2	0.9027		To match migration pattern
ρ	2	Elasticity of substitution between high-skilled and low-skilled workers	Ottaviano and Peri (2012)
γ	33	Elasticity of substitution between native and foreign high-skilled workers	Ottaviano and Peri (2012)
Γ	11.1	Elasticity of substitution between native and foreign low-skilled workers	Ottaviano and Peri (2012)
σ	2.7	Elasticity of substitution over different products	Broda and Weinstein (2004)
δ	0.07	Exogenous firm exit rate	Business Dynamic Statistics by the U.S. Census Bureau
κ	1.8	Parameters of productivity distribution	Luttmer (2007)
B	1		Normalization
α	0.7	Output share of high-skilled workers	UNU-WIDER World Income Inequality Database
f	1	Fixed production costs	Normalization
f^I	76		Bernard (2009)
f^E	325.27	Entry cost	Business Dynamic Statistics

Table 4 shows that the percentages of immigrant workers that different types of firms hire compared to their native workforces. We can see that the percentages of high-skilled immigrants are higher than low-skilled immigrants for all types of firms. Foreign firms tend to hire more immigrants than local firms. The ranges of the percentage of immigrant workers hired are 0.6 to 2.35 for high-skilled workers, and 0.36 to 1.19 for low-skilled workers. These patterns are roughly consistent with the pattern we observed in the Brazil data. If we consider the case that MNC is not allowed, then the matching patterns are very different in two countries. This is due to the fact that migration pattern is nearly unilateral without MNC.

Table 4: Percentage of immigrants hired by different type of firms

USA

	With MNCs		Without MNC
	Local Firms	Foreign Firms	Local Firms
High-Skilled	0.61	0.76	0.04
Low-Skilled	0.36	0.52	0.04

Canada

	With MNCs		Without MNC
	Local Firms	Foreign Firms	Local Firms
High-Skilled	1.88	2.35	22.40
Low-Skilled	0.84	1.19	6.44

2.2 Sensitivity Analysis

The calibrated model can closely reproduce the observed data. However, we still wondering how sensitive the simulation is result to the change of the parameters. In this subsection, I discuss the sensitivity analysis of selected key parameters that determine the migration pattern. The key parameters include elasticity of substitution between native and foreign workers, migration costs, and compatibility parameters between different types of firm and worker.

Figure 4 shows the changes in migration stocks and migration bilaterality corresponds to different elasticity of substitution between US and Canadian high-skilled workers. The magnitude of bilateral migration stocks are decreasing in the elasticity of substitution. This result indicates three facts: 1. The magnitude of migration is decreasing in the elasticity of substitution. 2. The relationship between the elasticity of substitution and bilaterality of migration is not linear, the bilaterality first decreasing and then increasing as the elasticity of substitution increasing. 3. Elasticity of substitution between US and Canadian high-skilled workers does not only affect the migration pattern of high-skilled workers, but also affects the migration pattern of low-skilled workers. This links to the complementarity between migration workers and multinational firms from the same country. Less high-skilled migration affects the multinationals' activities and in turn affects the migration pattern of low-skilled migration.

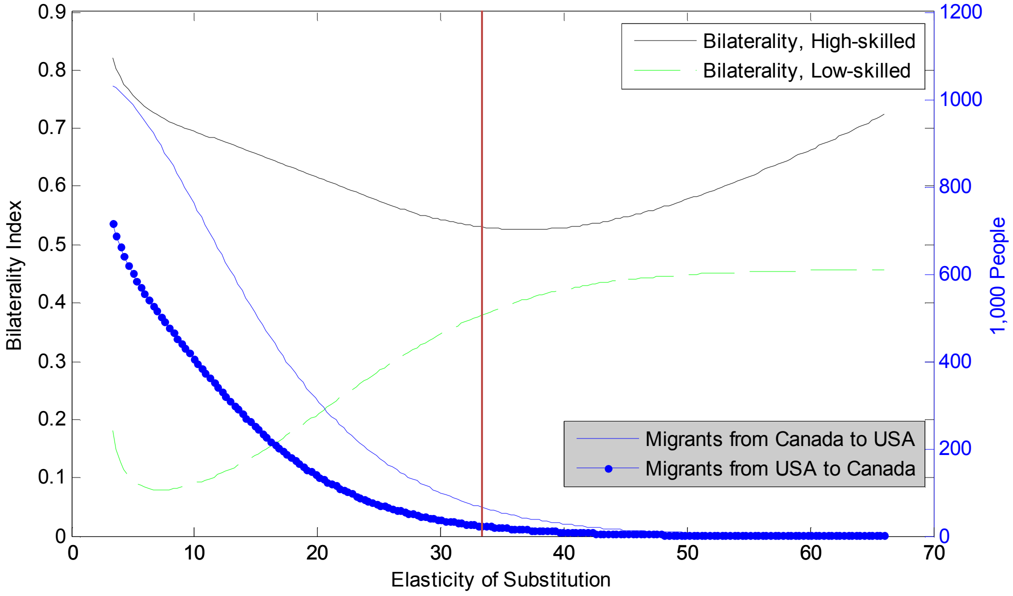

Figure 4: Sensitivity of elasticity of substitution between high-skilled workers from different countries (the red line marks the benchmark value $\gamma = 33$)

Next, I present the change of migration magnitude and pattern regards to the change of the moving costs. Figure 5 shows the result of high-skilled migration between the U.S. and Canada if we change the calibrated moving costs for US emigrants. It is not surprising that the magnitude of high-skilled migration from the U.S. to Canada is decreasing in the moving costs. Notice that because in the calibrated economy (and also in the data), there are more migrants from Canada to the U.S. than migrants from the U.S. to Canada. Therefore, in the range of the moving costs we are presenting in Figure 5, bilaterality of high-skilled migration is decreasing in the moving costs of high-skilled US emigration to Canada. Once again, we also see that the magnitude and pattern of low-skilled migration is affected by the change due to the interaction between migrants and multinational firms.

Figure 6 depicts high-skilled migration in the case that the moving costs of Canadian emigration to the U.S. are changing. The result is mostly symmetric to the case shown in Figure 5. One notable difference between Figure 5 and Figure 6 is that the bilaterality is decreasing as the moving costs decreasing in Figure 6 rather than increasing as in Figure 5. The bilaterality keeps increasing in the moving costs until it reaches the perfect bilaterality and starts to decrease in the moving costs. This indicates that decrease in the moving costs for US high-skilled emigration to Canada or increase the moving costs for Canadian high-skilled emigration to the U.S. in a certain range can improve the imbalance between US high-skilled emigrants to Canada and Canadian high-skilled emigrants to the U.S.

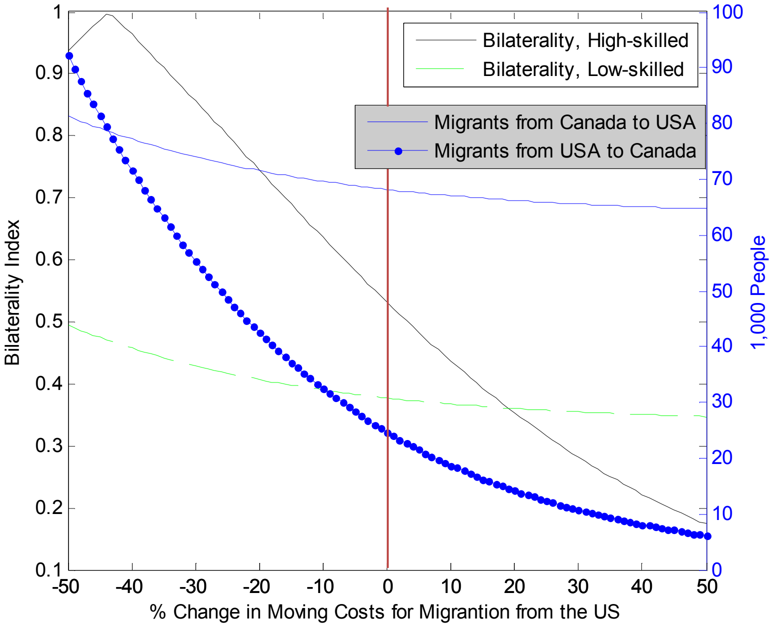

Figure 5: Sensitivity of the moving costs for high-skilled migrants from the U.S. to Canada

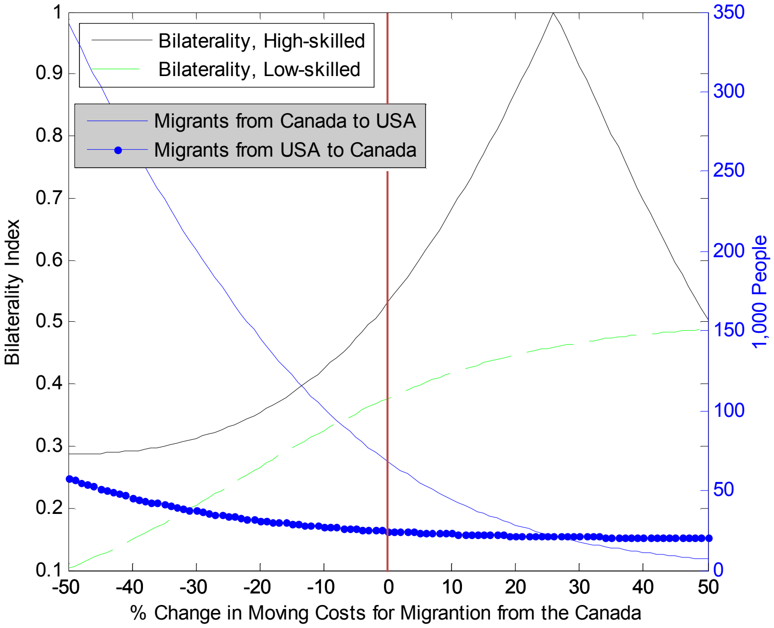

Figure 6: Sensitivity of the moving costs for high-skilled migrants from Canada to the U.S.

I model the matching pattern between different types of workers and firms by the compatibility parameters. Figure 6 shows that simulation result of changing in the compatibility between high-skilled Canadian workers and US firms. We see that the magnitude of high-skilled migration does not change much by changing the compatibility parameter. The proportion of immigrant workers work in the firms from their home country increases in the compatibility for the both countries. Notice that here we just increase the compatibility between high-skilled Canadian workers and US firms but not the compatibility between high-skilled US workers and Canadian firms. However, not only the proportion of Canadian high-skilled immigrants in the U.S. work in firms from their home country increases, but also the proportion of US high-skilled immigrants in the Canada work in firms from their home country increases. The increase in compatibility between Canadian high-skilled workers and US firms also leads to increasing demand of US multinational firms in Canada for Canadian workers, and bid up Canadian workers' wage. Therefore, Canadian firms also tend to hire more US immigrant workers as substitute.

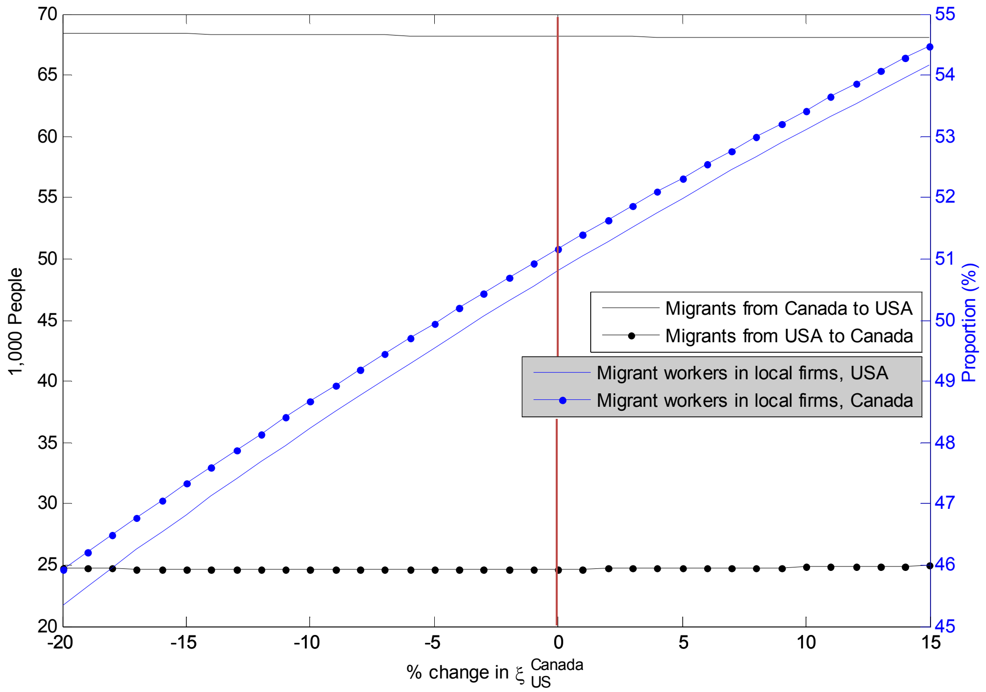

Figure 7: Sensitivity of skill compatibility between US high-skilled workers and Canadian firms

Section Three: Counterfactual Experiments

In this section we consider counterfactual experiments in evaluating quantitatively the impact of policy changes in regard to international migration between the U.S. and Canada.

3.1 Openness to Migration and MNCs

Four scenarios are compared: (1) Autarky, (2) Openness to migration only, (3) Openness to MNC only, and (4) Openness to both migration and MNCs. The result is summarized in Table 5, which includes the equilibrium real wages, details of migration flow, masses of firms, productivity, and real GDP per capita for each case.

Starting from the economy under autarky, opening to FDI increases real wages for all types of workers. In addition, opening up to migration enhances the welfare gains. However, if we only have migration alone, then US workers end up with lower wages compared to autarky. On productivity, migration alone does not change cutoff productivity compare to autarky. If we have MNCs, then migration begins to impacts on cutoff productivity by interacting with MNCs, that causing intra-industry reallocation as shown in Chapter One.

Migration patterns are almost unilateral when we disallow MNCs (as shown by the bilaterality indexes, which are 0.0438 for high-skilled migrants and 0.0098 for low-skilled migrants). Migration from the U.S. to Canada dominates the total bilateral migration flow due to the country-size effect that a smaller country has a higher return to population increase. When we allow for MNCs, migration bilaterality is comparatively much higher than before; the bilaterality indexes in this case are 0.5333 for high-skilled migrants and 0.379 for low-skilled migrants. This illustrates that MNCs are an important driving factor for bilateral migration.

Table 5: Simulation result for static comparison
* Normalized to 1
** Normalized to 100

Scenarios	Autarky	Migration Only	MNCs Only	Migration & MNCs
Real Wage				
Low-skilled, USA	1*	0.9819	1.3705	1.3760
Low-skilled, Canada	0.8676	1.2503	1.4459	1.4502
High-skilled, USA	3.1950	3.1825	4.3930	4.4111
High-skilled, Canada	2.5624	3.3731	4.2817	4.3062
Migration				
Low-skilled, USA to Canada	-	0.0759	-	0.0065
Low-skilled, Canada to USA	-	0.0017	-	0.0278
Bilaterality Index, Low-skilled	-	0.0438	-	0.379
High-skilled, USA to Canada	-	0.1835	-	0.0088
High-skilled, Canada to USA	-	0.0009	-	0.0242
Bilaterality Index, High-skilled	-	0.0098	-	0.5333
Mass of Firms				
Local, USA	0.5836	0.5695	0.3311	0.3328
Foreign, USA	-	-	0.0033	0.0034
Local, Canada	0.4194	0.7109	0.3337	0.3361
Foreign, Canada	-	-	0.0033	0.0034
Productivity				
Local Cutoff, USA	0.8502	0.8502	1.1662	1.1666
Foreign Cutoff, USA	-	-	15.0300	15.0334
Local Cutoff, Canada	0.8502	0.8502	1.1639	1.1638
Foreign Cutoff, Canada	-	-	14.9928	14.9860
Aggregate, USA	4.6550	4.6550	8.9042	8.9100
Aggregate, Canada	4.6550	4.6550	8.8675	8.8633
Real GDP per Capita				
USA	100**	98.31	137.34	138.17
Canada	85.89	123.44	143.37	144.41

Notice that compared to the MNCs Only case, in the Migration & MNCs case, the overall productivity in Canada is actually decreasing, whereas, Canadian real per capita GDP and the real wages for Canadian workers in all skill levels are still higher. Moreover, the mass of firms in both countries is higher in the Migration & MNCs case than in the MNC Only case. This illustrates that migration increases global production efficiency (characterized by higher real per capita GDPs in both countries) through two channels - productivity improvement and increase in product varieties. This is similar to the extensive margin and intensive margin of gains due to openness to trade as discussed in Melitz (2003). Here the U.S. is gaining from both channels by opening to migration. Canada is gaining from increasing product varieties and losing productivity. For both countries, the net result is that they have higher real per capita GDPs and real wages for all workers.

Lastly, the benefits of openness in general accrue more to high-skilled workers than low-skilled workers. This distributional effect of migration is due to substitutions, since the output share of low-skilled workers is smaller than the output share of high-skilled workers as calibrated. Low-skilled workers are more vulnerable to foreign substitutes and thus obtain less gain from openness.

3.2 Changes in Migration Costs

Here I consider the impact of bilateral change in moving costs. The change in moving costs could come from countries adopting new regulations on immigration, such as new standards for migrant's background checks or different tax treatments for foreign workers.

Figure 10 [17] shows the labor market outcome of bilateral changes in migration costs to all type of migrants. We notice from Figure 10a that in general real income is increasing as moving costs are decreasing, with the exception of low-skilled Canadian workers (illustrated by a hump-shaped curve around the original equilibrium point). The general gains are due to improvements in global production efficiency. As shown in Figure 11d, the real per capita GDPs of both countries are increasing as moving costs are decreasing. However, the gains are not necessarily evenly distributed among all workers. Since the output share of low-skilled workers is much less than the output share of high-skilled workers, low-skilled workers are more likely to be substituted out by foreign workers. We can see from Figure 10a

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[17] See Appendix B.

that low-skilled workers gain less on their real wages from lower moving costs compared to their high-skilled counterparts.

The gains in production efficiency come from two channels. First, we see from Figure 11a that the mass of all types of establishment is increasing as moving costs are decreasing. This is similar to the extensive margin gain of trade as recognized in Melitz (2003). Second, we can see in Figure 11c that aggregate productivity is shifting by changing the moving costs. The United States is gaining in productivity with lower moving costs, while Canada is losing productivity with lower moving costs. This is due to intra-industry reallocation of market shares due to interaction between migration and MNCs. This is similar to the intensive margin gain of trade but here we could also have intensive margin loss due to decreasing the moving costs. Overall, the first force dominates so that production efficiency (as measured by GDPs per capita) increases.

Figure 12 shows that the simulation results for the moving costs change only for high-skilled migrants. In this case, the negative effect on aggregate productivity in Canada due to reducing the moving costs dominates and the real per capita GDP in Canada decreases. In terms of real wage, Canadian low-skilled workers lose from the deduction of moving costs, while other types of workers gain from the deduction. This shows that greater openness to migration may not always be beneficial to native workers. Here we have the counter example: Since the relative moving costs are even higher for Canadian low-skilled workers to move across the border, they are more likely to be substituted by other types of workers. Further, Canadian firms are relatively less compatible with low-skilled US workers (compared to compatibility between US firms and Canadian low-skilled workers), so the fact that Canadian low-skilled workers become relatively less mobile causes Canadian multinationals to lose their competitive advantages in US market. This in turn causes aggregate productivity in Canada to fall rapidly, reducing the real GDP per capita in Canada.

On the other hand, Figure 13 shows that if we only reduce the moving costs for low-skilled workers, we have mutual gains to all type of workers in both countries. The real per capita GDPs in the two countries are increasing as the moving costs are being reduced. Global production efficiency is improved due to greater openness to migration in this case.

Comparing the three different scenarios above - the moving costs are reduced for all type of migrants, the moving costs are reduced for high-skilled migrants only, and the moving costs are reduced for low-skilled migrants only - we can see that policies that aiming for greater migration could potentially be mutual beneficial, but may benefit one country and hurt another. The key is whether the mobility of less mobile workers is improved. If the moving costs for less mobile workers are reduced, then we can achieve welfare gains for all type of workers in both countries. Otherwise, if the policy induces further relative immobility, then the immobile workers are negatively impacted by migration.

3.3 Migration Quota

In this subsection, I consider bilateral migration quotas in three scenarios – 1. Migration quotas are applied to all types of migrants, 2. Migration quotas are applied to high-skilled migrants only, and 3. Migration quotas are applied to low-skilled migrants only.

The results of counterfactual experiments with regard to bilateral migration quotas are presented in Figure 14 - Figure 16. Notice that in general migration quotas increase real wages for immigrant workers but reduce real wages for native workers who stay in their home country. We see some exceptions, for example, if migration quotas are only applied to high-skilled migrants, then Canadian low-skilled workers who stay in Canada gain (as shown in Figure 15). Also, if migration quotas are only applied to low-skilled migrants, then Canadian high-skilled workers who stay in Canada gain (as shown in Figure 16). However, other types of workers who stay in their home country lose due to the quotas. In general, we do not see migration quotas achieving mutual gains for two countries, or even gains to all native workers within one country.

Figure 17 shows real per capita GDPs in two countries for each scenario. Except for the real per capita GDP in Canada increasing as the migration quotas are applied to high-skilled migrants, real GDP per capita in general is decreasing as there are more constrains on migration. This reiterates the point that migration quotas are reducing international production efficiency. Even if in some cases a country may gain from quotas, we see from our simulation that the gains accrue more to immigrant workers than native workers who stay in their home country.

Section Four: Concluding Remarks

In this chapter, I calibrate the model to US and Canadian data and implement counterfactual experiments to discuss the welfare implications of bilateral migration. I show that migration can improve international production efficiency and increase welfare for workers in all skill groups in both countries.

Migration can achieve mutual gains through the interaction with multinationals. Migrants bring more foreign business opportunities for firms from their home country, and thus increase available product varieties. Aggregate productivity is also affected by migration since migration interacts with multinationals and causes intra-industry reallocation. Without multinationals, migration does not affect aggregate productivity.

I discuss the impact of bilateral change in moving costs. Three scenarios are considered – the moving costs are reduced for all migrants, the moving costs are reduced for high-skilled migrants, and the moving costs are reduced for low-skilled workers. We see from the analysis that reducing the moving costs has two effects. First, it affects multinationals' activities, so aggregate productivity and total available product varieties changing accordingly. Second, workers with lower mobility tend to lose, or gain less, from greater openness to migration due to substitution among different types of workers. In general, policies that reduce relative immobility tend to result in mutual gains for all types of workers in both countries, whereas policies which increase relative immobility tend to benefit workers with high mobility and hurt workers with low mobility.

The simulation result shows that migration quotas in general reduce real wages for native workers who stay in their home country and protect early immigrants from competition with potential immigrants who are limited by the quotas. Real per capita GDPs in both countries in general are also reduced due to migration quotas.

CHAPTER THREE: ON THE IMPACT OF TRADE OPENNESS FOR ECONOMIC GROWTH

Section One: Introduction

Many studies show that trade openness benefits economic growth.[18] A well-known case is the spectacular growth story of the four Asian tigers (Hong Kong, Singapore, South Korea, and Taiwan) in the second half of the 20th century. Among many proposed explanations, these achievements are usually attributed to the export-oriented industrial policies that were implemented in these countries.

The theoretical trade literature argues that trade openness can boost social welfare either by comparative advantage or by increased product variety. These theories provide some clues to understand those successful economic development stories. On the other hand, another strand of empirical studies[19] reports that the association of trade openness and growth is a rather new phenomenon: before World War II, a negative correlation was usually observed. Overall, the mechanism that links trade openness to long-term economic growth is still unclear.

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[18] For example, Frankel and Romer (1999), Harrison (1996), Dollar and Kraay (2003), Alcala and Ciccone (2004), and Wacziarg and Welch (2008).

[19] For example, O'Rourke (2000), Vamvakidis (2002), Yanikkaya (2003), and Clemens and Williamson (2004).

In this chapter, I propose a model that can generate either of these contradictory observations. By investigating the interaction between reallocation of market shares, productivity growth, and technology diffusion after trade, I identify two important factors that determine whether increased trade openness causes a higher or a lower long-term growth rate. The first factor is driven by firm heterogeneity. Since firms have different productivity levels, they are affected by trade openness in different ways. More productive firms have higher market shares than less productive firms. I show that this crowding out phenomenon suffocates effective domestic R&D activities and in turn slows down the growth rate. The second factor is that trading partners can pool research resources (either physical or intellectual) to some extent through technology diffusion. If this can bolster up the average quality of research to overcome less effective R&D, then trade can induce higher growth rates. By comparing these two factors, I conclude that the efficiency of technology diffusion is the critical element to determine whether trade openness benefits growth.

I explore this implication quantitatively to answer two questions. First, what do the data say about the effect of trade openness on U.S. economic growth? I calibrate the model to match U.S. aggregate data and I find that the efficiency of technology diffusion required for higher long-term growth rate is much smaller than the one estimated in Grossman and Helpman (1995) and in this chapter. This implies that current trade openness is beneficial to U.S. economic growth. Second, if a country increases its degree of openness to pursue a higher long-term growth rate, what should it be aware of? My counterfactual experiments show that the efficiency of technology diffusion is more critical for sectors where products are more substitutable. Trade barriers can help to preserve domestic R&D if technology diffusion is not in place or not efficient enough.

My model extends Melitz (2003) to consider the possibility of productivity growth. I assume that in every period the average productivity of newly entering firms is higher than the average productivity of incumbent firms. Therefore, the economy shifts to a new equilibrium with higher TFP in every period. Although TFP is assumed to be growing, the speed is endogenously determined by research efforts.

To account for aggregate research efforts, I use the number of new products that are introduced into the market rather than R&D expenditures. This is because spending on R&D does not automatically make it effective. On the other hand, if a new product is viable in the market, then the associated R&D must be effectively implemented to a certain degree. Therefore, I take the number of new products as a proxy for the accumulation of knowledge capital stock (a term that I borrow from Grossman and Helpman (1991c), where it is used to describe the quantifiable intellectual resources in an economy). The speed of the accumulation process determines the pace of productivity growth.

This chapter is closely related to Baldwin and Robert-Nicoud (2008). Baldwin and Robert-Nicoud also start from firm heterogeneity and identify two offsetting effects of trade on long-term growth rate. Their result is similar to my findings. However, I characterize economic growth by looking at the production sector of the economy, while they look at the R&D sector. I believe both models capture essential aspects of essential aspects of economic growth. The similar results of these two models show robustness of the findings to different modeling approaches.

Other related papers include Eaton and Kortum (2001) and Grossman and Helpman (1991c). Eaton and Kortum (2001) discuss two offsetting effects of trade openness on growth, which stem from market incentives of the R&D sector. These two effects perfectly cancel out each other in their baseline model. In my chapter, the offsetting effects are caused by reallocation of market shares and technology diffusion. Further, I show that the net result can be determined by technology diffusion efficiency. Grossman and Helpman (1991c) argued that knowledge capital has public good characteristics and thus the R&D investments in decentralized markets are less than the socially optimal level. This deficiency can be made up by technology diffusion. Therefore, trade openness benefits long-term growth. In my chapter, not only do I recognize the positive effect of trade openness on growth through technology diffusion, but I also show that reallocation of market shares due to firm heterogeneity can lower the growth rate.

The rest of the chapter is organized as follows. In section 2, I describe the model and solve the equilibrium in autarky. In section 3, I expand the model to an open economy with the possibility of technology diffusion and find the associate equilibrium solution. In these two sections, I also show that these equilibria have balanced growth. In section 4, I compare the two equilibria that are derived in sections 2 and 3 for the implications of the model on growth. I show that technology diffusion efficiency is the key factor to determine the net effect of trade openness. In section 5, I present a quantitative analysis to show the impact of trade openness to the U.S. economy and discuss some policy recommendation for countries that are pursuing a higher degree of trade openness. Concluding remarks and suggestions for future research topics are in section 6.

Section Two: Model (Closed Economy)

The model is based on Melitz (2003). There is a continuum of production firms in the economy. Each firm produces its own variety of consumption good. The market structure is the Dixit-Stiglitz style monopolistic competition. New firms can enter the market by paying a sunk cost. I see this as R&D expenditures to develop products. Incumbent firms exit the market if their operations is no longer profitable give their productivity. There is also an exogenous shock for every firm with the same probability in each period. Time is discrete and indexed by t=0,1,2,3,....

In addition to Melitz' model, I include the possibility of productivity improvement. In each period, the lower bound of productivity distribution of new firms is monotonically increasing over time. Although by assumption the lower bound is shifting up for sure (so that average productivity is increasing over time since I assume that firm productivity is always from the same family of distributions), how fast the lower bound moves depending on the mass of operating firms in each period.

2.1 Consumer's Problem

Consumers are homogeneous and have CES preference. I abstract from inter-temporal substitution in this paper. Therefore, consumers optimize their utilities for each period separately subject to their budget constraints. The optimization problem is:

$$\begin{cases} \max_{q(\omega)} \ U = \left(\int_{\omega\in\Omega} q(\omega)^{\frac{\sigma-1}{\sigma}} d\omega\right)^{\frac{\sigma}{\sigma-1}} \\ \quad s.t. \ \int_{\omega\in\Omega} p(\omega)q(\omega)d\omega = R \end{cases}, \tag{29}$$

where Ω is the set of available products, R is the aggregate expenditure, $q(\omega)$ is the quantity consumed of variety ω (where $\omega \in \Omega$), $p(\omega)$ is the price of ω, and σ is the elasticity of substitution over the varieties.

The solution of the optimization problem in equation (97) is:

$$q(\omega) = \left(\frac{p(\omega)}{P}\right)^{-\sigma} \frac{R}{P}, \tag{30}$$

where $P = \left(\int_{\omega\in\Omega} p(\omega)^{1-\sigma} \, d\omega\right)^{\frac{1}{1-\sigma}}$ is the aggregate price index.

This solution indicates that the demand of product ω is an inverse function of its price to the aggregate price index.

2.2 Production and Pricing

Labor is the only factor for production in this economy. I abstract from labor market dynamic in this model and assume total labor supply in every period is constant and inelastic. Here after, I normalize both labor supply L and wage to one.

A firm pays both fixed and variable costs to produce. The total cost function can be expressed as:

$$c(q,\varphi) = f + \frac{q}{\varphi}, \tag{31}$$

where q denotes the quantity produced and φ is the firm-specific productivity level.

Combining equation (30) and (97), we can get the profit-maximizing price given productivity level φ is:

$$p(\varphi) = \frac{\sigma}{(\sigma-1)\varphi} \tag{32}$$

Based on (97), revenue r and profit π of a firm with productivity level φ can be expressed as:

$$r(\varphi) = p(\varphi)q(\varphi) = \left(\frac{\sigma - 1}{\sigma}\varphi R\right)^{\sigma-1} R \tag{33}$$

$$\pi(\varphi) = \left(\frac{\sigma - 1}{\sigma}\varphi R\right)^{\sigma-1} \frac{R}{\sigma} - f \tag{34}$$

2.3 Firm's Entry and Exit

A new entrant pays a sunk cost f_E to get its productivity draw with cdf $G(\varphi)$. The distribution has zero density if $\varphi < B_t$, where B_t denotes the lower bound of the available production technologies in period t. This lower bound is assumed to increase over time, which can be thought as obsoleting process of old technologies.

Firms exit the market endogenously or are hit by exogenous shocks. Endogenously, a firm exits the market if its productivity cannot survive market competition. This can happen right in the first period when the firm entered or in consecutive periods. Exogenously, every firm that successfully entered the market faces an exogenous exiting shock with probability δ in every period, which is independent of productivity.

2.4 Firm's Productivity Level and Growth

In describing economic growth, I assume old technologies are continuously replaced by new technologies. The obsoleting rate depends on the R&D activities, for which I use mass of firms M_t as the proxy. As old technologies are obsoleting, the lower bound of the available production technologies is increasing. Explicitly, the productivity lower bound in period t is defined as:

$$B_t = B_0 \cdot \prod_{s=1}^{t-1} (\lambda \cdot M_s)^{\kappa} \, , \tag{35}$$

where $\kappa > 0$ is a constant and λ is an unit adjustment parameter. κ is the elasticity of the productivity lower bound with respect to the cumulative mass of firms. I will show later when the productivity distribution is Pareto, aggregate productivity is increasing linearly in B_t. Therefore, κ is also the elasticity of aggregate productivity with respect to cumulative mass of firms. λ is chosen to guarantees $\lambda \cdot M_s > 1 \; \forall s$, so that the productivity lower bound is indeed improving over time with cumulative mass of firms.

Under the assumption that the productivity distribution is Pareto, death rate of firms is constant in every period. Therefore, M_t is proportional to number of successful new entrants in period t. In my model, I measure effective R&D efforts by number of marketable ideas (that is, number of successful new entrants in this economy). Therefore, M_t is a good proxy for effective R&D efforts in period t. I do not use R&D spending here because monetary spending does not necessary guarantee effective R&D results. However, a viable product must results from effective R&D efforts.

2.5 Equilibrium Conditions

An equilibrium in autarky in period t is defined by a set of variables $(\bar{\varphi}_t, \bar{\pi}_t, M_t)$. $\bar{\varphi}_t$ is the cutoff productivity that describes the minimum productivity level that a firm need to survive the market competition. $\bar{\pi}_t$ is the average profit of firms in the market. Finally, M_t is the mass of firms. I use the same three equilibrium conditions as in Melitz (2003) to determine these variables. The three equilibrium conditions are the zero cutoff profit condition, the labor market clearing condition and the free entry condition. I discuss each condition in the following subsections.

2.5.1 Zero Cutoff Profit Condition

As seen in Melitz (2003), the profits of firms are positively associated with their productivity levels. Therefore, there exists a productivity threshold for breaking even. Firms with lower productivity levels than this threshold exit the market immediately. This implies that:

$$\pi(\bar{\varphi}_t) = 0\,, \tag{36}$$

where $\bar{\varphi}_t$ is the cutoff productivity.

Combining (34) and (97), we can derive the average profit in period t is:

$$\bar{\pi}_t = f\left[\left(\frac{\tilde{\varphi}(\bar{\varphi}_t)}{\bar{\varphi}_t}\right)^{\sigma-1} - 1\right] \tag{37}$$

$\tilde{\varphi}(\bar{\varphi}_t)$ is the average productivity and can be expressed as:

$$\tilde{\varphi}(\bar{\varphi}_t) = \left[\frac{1}{1-G(\bar{\varphi})}\int_{\bar{\varphi}}^{\infty} \varphi^{\sigma-1}\, g(\varphi)d\varphi\right]^{\frac{1}{\sigma-1}}, \tag{38}$$

where $g(\varphi)$ is pdf of the productivity distribution.

2.5.2 Labor Market Clearing Condition

In the equilibrium, labor market clearing requires the aggregate expenditure equals to the total labor income. Since wage and labor supply are normalized to 1, we have the labor market clearing condition:

$$R = 1. \tag{39}$$

2.5.3 Free Entry Condition

We can write the expected profit for new entrants as:

$$\begin{aligned} v_t^E &= E_t\left[\sum\nolimits_s prob(firm\ survives\ in\ period\ s)\cdot \pi_s\right] - f_E \\ &= \sum\nolimits_{s=0}^{\infty}\left[(1-\delta)^s\left(1-G(\bar{\varphi}_{t+s})\right)\right]\cdot \bar{\pi}_t - f_E. \end{aligned} \tag{40}$$

The only cost to establish a new firm is the R&D expenditure for productivity draw. Therefore, if the market opens to new entrants, the expected profit should be driven down to be the same as the sunk cost for productivity draw. Otherwise, there will be more entrepreneurs try to establish new firms to seize positive expected net profit. We set $v_t^E = 0$ to get the free entry condition as:

$$\sum_{s=0}^{\infty}\left[(1-\delta)^s\left(1-G(\bar{\varphi}_{t+s})\right)\right]\cdot \bar{\pi}_t = f_E. \tag{41}$$

2.6 Equilibrium in Closed Economy

To solve the equilibrium explicitly, I assume the firm productivity distribution is Pareto with shape parameter α and scale parameter B_t (i.e., $G(\varphi) = 1 - \frac{B_t^\alpha}{\varphi^\alpha}$ for $\varphi > B_t$).

We can substitute (38) to the zero cutoff profit condition (37) to derive the average profit as:

$$\bar{\pi}_t = \left(\frac{\sigma - 1}{1 + \alpha - \sigma}\right)\cdot f\ \ \forall t. \tag{42}$$

Since average profit is the same in every period, we have $\bar{\pi}_t = \bar{\pi}\ \ \forall t$.

Notice that:

$$P\left(\varphi|B_{t-1} \geq \bar{\varphi}_t|_{\varphi|B_{t-1}} \geq B_t\right) = \left(\frac{B_t}{\bar{\varphi}_t}\right)^{\alpha} = P(\varphi|B_{t-1} \geq \bar{\varphi}_t)\,, \tag{43}$$

where $\varphi|B_{t-1}$ is a random variable with Pareto distribution with scale parameter B_{t-1}, and $\varphi|B_{t-1}$ is a random variable with Pareto distribution with scale parameter B_t. The first probability is how likely an incumbent firm from the last period can survive in the current period. The second probability is how likely a new entrant can survive in the current period. (97) implies that the productivity distribution of the incumbent firms after endogenous exit is the same as the productivity distribution formed by the new entrants in the current period. Therefore, we have the same solution for $\bar{\pi}_t$ as in Melitz (2003) even though my model considers the possibility of productivity improvement.

To solve M_t from the labor market clearing condition, I use the aggregation equation $R = M_t r_t(\tilde{\varphi}_t)$ and the revenue function $r_t(\varphi) = \left(\frac{\sigma-1}{\sigma}\varphi P_t\right)^{\sigma-1} R$. Further, the aggregate price index is $P_t = \left(\int_{\varphi\geq 0} p_t(\varphi)^{1-\sigma}\, M_t g_t(\varphi) d\varphi\right)^{\frac{1}{1-\sigma}}$ so that $P_t = M^{\frac{1}{1-\sigma}} p_t(\tilde{\varphi}_t)$, where $p_t(\tilde{\varphi}_t)$ is defined as in (32). Therefore, we can substitute these equations in the labor clearing condition and get:

$$M_t = \frac{1}{\sigma(\bar{\pi}_t + f)} \tag{44}$$

Since the average profit is constant over time (i.e., $\bar{\pi}_t = \bar{\pi} \ \forall t$), the mass of the firms is constant as well. Therefore, we denote the mass of firms in every period by M.

Finally, by my assumption of Pareto distribution with cdf $G(\bar{\varphi}_{t+s}) = 1 - \left(\frac{B_t}{\bar{\varphi}_{t+s}}\right), \forall s = 1,2,3,\dots$. Substitute the cdf in the free entry condition (41) to obtain:

$$\left(\frac{B_t}{\bar{\varphi}_t}\right)^{\alpha} = \frac{f_E}{\bar{\pi}} - \sum_{s=1}^{\infty} \left[(1-\delta)^s \left(\frac{B_t}{\bar{\varphi}_{t+s}}\right)^{\alpha}\right], \forall t = 0,1,2,\dots \tag{45}$$

I derive the solution of the cutoff productivity by first showing that a constant ratio $\frac{B_t}{\bar{\varphi}_t}$ in every period t solves equation (97) and therefore $\bar{\varphi}_t$ is proportional to B_t.

Theorem 1. $\frac{B_t}{\bar{\varphi}_t} = c$ solves equation (97), where c is a constant.

Proof. Suppose $\frac{B_t}{\bar{\varphi}_t} = c \ \forall t$, then we can write equation (97) as:

$$\begin{aligned} c^{\alpha} &= \frac{f_E}{\bar{\pi}} - \sum_{s=1}^{\infty} \left[(1-\delta)^s \cdot \left(\frac{B_t}{B_{t+s}}\right)^{\alpha} \cdot \left(\frac{B_{t+s}}{\bar{\varphi}_{t+s}}\right)^{\alpha}\right] \\ &= \frac{f_E}{\bar{\pi}} - \sum_{s=1}^{\infty} [(1-\delta)^s \cdot (\lambda M)^{-\kappa\alpha s} \cdot c^{\alpha}], \end{aligned},$$

where I use the solution for the labor market clearing condition and the definition of B_t to get the latter equality.

Simplifying the previous equation, we can solve c from $c^{\alpha} = [1-(1-\delta)(\lambda M)^{-\kappa\alpha}]\frac{f_E}{\bar{\pi}}$ as long as $(1-\delta)(\lambda M)^{-\kappa\alpha} < 1$ (or equivalently $\frac{f}{L} < (1-\delta)^{-\frac{1}{\kappa\alpha}}\frac{1+\alpha-\sigma}{\sigma\alpha}\lambda$). This condition indicates that the ratio of the fixed production cost divided by the aggregate labor income should not exceed an upper bound determined by parameters. In this case, $\left(\frac{B_t}{\bar{\varphi}_t}\right) = c^{\alpha} = [1-(1-\delta)(\lambda M)^{-\kappa\alpha}]\frac{f_E}{\bar{\pi}}$ $\forall t$ solves equation (97).

Using Theorem 1 we can solve the cutoff productivity in each period as:[20]

$$\begin{aligned} \bar{\varphi}_t &= \left[\frac{\bar{\pi}/f_E}{1-(1-\delta)(\lambda M)^{-\kappa\alpha}}\right]^{1/\alpha} B_t \\ &= \left[\frac{\bar{\pi}/f_E}{1-(1-\delta)(\lambda M)^{-\kappa\alpha}}\right]^{1/\alpha} \cdot B_0 \cdot (\lambda M)^{\kappa t}, \;\; \forall t = 0,1,2,3,\ldots. \end{aligned} \tag{46}$$

Further, by (43) we see that $\left(\frac{B_t}{\bar{\varphi}_t}\right)^{\alpha}$ is the survival rate of the incumbent firms in the next period. Since Theorem 1 implies that $\left(\frac{B_t}{\bar{\varphi}_t}\right)^{\alpha}$ is constant, the death rate of

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[20] In Melitz (2003), the cutoff productivity in the closed economy is $\varphi^{Melitz} = \left(\frac{\pi}{f_E\delta}\right)^{\frac{1}{\alpha}} B_0$. Comparing this to ϕ_0, since we assume that $\lambda M > 1$, the cutoff productivity at time zero in my model is less than the cutoff productivity in the Melitz's case (i.e., $\varphi_0 \leq \varphi^{Melitz}$). This is because productivity improvement in my model reduces the chances of incumbent firms to survive in consecutive periods, which leads to smaller ex-ante expected payoff. Therefore, fewer firms are trying to enter the market and the level of the cutoff productivity is lower compared to Melitz's case.

firms is also constant. Therefore, as I have argued that M_t is a perfect proxy for number of successful new entrants in this economy because the death rate of firms is constant across time.

In summary, in the closed economy, we have the equilibrium as:

$$\begin{aligned}
\bar{\varphi}_t &= \left[\frac{\bar{\pi}/f_E}{1-(1-\delta)(\lambda M)^{-\kappa\alpha}}\right]^{1/\alpha} \cdot B_0 \cdot (\lambda M)^{\kappa t} \\
\bar{\pi}_t &= \bar{\pi} = \left(\frac{\sigma-1}{1+\alpha-\sigma}\right) \cdot f \;\; \forall t \\
M_t &= M = \frac{1}{\sigma(\bar{\pi}_t + f)} \;\; \forall t.
\end{aligned}$$

2.7 Balanced Growth in the Closed Economy

We can compute the growth rate from the equilibrium. First of all, notice that the average productivity given $\bar{\varphi}_t$ (denoted by $\tilde{\varphi}_t(\bar{\varphi}_t)$) can be computed by substituting equation (97) into equation (38). The solution is:

$$\begin{aligned}
\tilde{\varphi}_t(\bar{\varphi}_t) &= \left(\frac{\alpha}{1+\alpha-\sigma}\right)^{\frac{1}{\sigma-1}} \cdot \bar{\varphi}_t \\
&= \left(\frac{\alpha}{1+\alpha-\sigma}\right)^{\frac{1}{\sigma-1}} \cdot \left[\frac{\bar{\pi}/f_E}{1-(1-\delta)(\lambda M)^{-\kappa\alpha}}\right]^{1/\alpha} \cdot B_0 \cdot (\lambda M)^{\kappa t}.
\end{aligned} \tag{47}$$

Taking logarithms on both sides of (97), we can see that the average productivity grows approximately at the rate:

$$\kappa \cdot \log(\lambda M). \tag{48}$$

Further, the aggregate price level in this economy can be expressed as:

$$P_t = M^{\frac{1}{1-\sigma}} p(\tilde{\varphi}_t) = M^{\frac{1}{1-\sigma}} \cdot \frac{\sigma}{\sigma-1} \cdot \tilde{\varphi}_t^{-1}\ , \tag{49}$$

where $p(\cdot)$ is the firm optimal price as defined in (32). From equation (97) we can see that P_t changes at the rate $-\kappa \cdot \log(\lambda M)$. In other words, the aggregate price level is decreasing at the same rate as aggregate productivity growth. Since in this economy wage is normalized to 1 and the nominal aggregate expenditure is fixed, both real wage and real GDP (real aggregate expenditures) are increasing at the same rate $\kappa \cdot \log(\lambda M)$ as the price index decreasing over time. We say the model generates balanced growth since TFP, real wage, and real GDP of the economy grow at the same rate.

Section Three: Open Economy

In this section, I present the model with a set of symmetric countries that open to trade with each other. Since there are no differences in factor prices in the symmetric case, I normalize the wages in both countries to one. The symmetric setup is the most basic case that we can understand the relationship between trade openness and growth.

3.1 Technology Diffusion

Evidently, when a country opens to trade, the R&D sector can access part of R&D resources from its trading partner. Empirical studies in support of this claim are abundant in literature such as Grossman and Helpman (1991a), Coe and Helpman (1995) and Eaton and Kortum (1999). I use the empirical form of technology diffusion from Coe and Helpman (1995), which assume constant elasticity of domestic TFP growth with respect to the total knowledge capital stocks of foreign trading partners.

In this paper, I assume that technology transmission is independent of trade volume because I believe this best illustrates the process of technology diffusion in modern technology-based production sectors. For example, in the IT industry, a new algorithm can be reverse engineered and understood once the software has been released. This type of technology transmission does not depend on the trade volume from the foreign firm that originally developed the algorithm. A similar scenario is likely to happen in the knowledge-intensive and technology-intensive industries (KTI industries). According to the 2012 Science and Engineering Indicators by the National Science Board,[21] global value added of KTI industries

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[21] National Science Board: http://www.nsf.gov/nsb/

comprises 30% of the world estimated GDP in 2010. Furthermore, the value added of KTI industries comprises 40% of the GDP in the U.S., 32% in the EU, and 30% in Japan. These shares of KTI industries are growing steadily over time. In this paper I focus on the form of technology diffusion that best illustrates the KTI industries.

When there is technology diffusion between two countries, the evolution of the technology lower bound becomes:

$$B_{t,h} = B_{0,h} \cdot \prod_{s=1}^{t-1} \left(\lambda \cdot M_{s,h}\right)^{\kappa_h} \cdot \left\{B_{0,f} \cdot \prod_{s=1}^{t-1} \left(\lambda \cdot M_{s,f}\right)^{\kappa_f}\right\}^{\theta_{h,f}}, \qquad (50)$$

where h denotes the home country and f indices the foreign trading partner. $\theta_{h,f}$ is the elasticity of the domestic lower bound of available technology with respect to the foreign knowledge stocks.

3.2 Exporting Cost Structure

To export, firms pay different fixed and variable costs than for their domestic sales. First, the fixed cost for the production of exports is f^X, where I assume $f^X > f$. This higher cost factors in the overheads of exporters to maintain the distributing infrastructures and networks in the foreign country. Second, exporters pay iceberg costs for shipping and handling, which is denoted by τ. An exporter needs to ship out τ units of good to assure the delivery of one unit of good. To cover this iceberg cost, exporters charge the price $p^X(\varphi) = \tau \cdot p(\varphi)$ in the foreign market, where $p(\varphi)$ is the price they charge in the home market. With these two costs we can write the profit function for exporters as:

$$\pi^X(\varphi) = \left(\frac{\sigma - 1}{\sigma} \cdot \frac{\varphi}{\tau} \cdot P\right)\frac{R}{\sigma} - f^X. \tag{51}$$

3.3 Equilibrium Conditions and Solution

As shown in Melitz (2003), only firms with relatively high productivity can afford to export to the foreign market. This is because exporting incurs higher costs than for domestic sales. Therefore, there is a cutoff that separates exporters and non-exporters based on their productivity levels. This cutoff productivity, denoted by $\bar{\varphi}_t^X$, can be solved by the zero cutoff export profit condition:

$$\pi^X(\bar{\varphi}_t^X) = 0. \tag{52}$$

With the assumption that the productivity distribution is Pareto, we can solve the export cutoff productivity as:

$$\bar{\varphi}_t^X = \tau\left(\frac{f^X}{f}\right)^{\frac{1}{\sigma-1}}\bar{\varphi}_t. \tag{53}$$

We can see from (97) that the exporting cutoff productivity is proportional to the cutoff productivity $\bar{\varphi}_t$ in every period.

With the cutoff productivity $\bar{\varphi}_t$ and the export cutoff productivity $\bar{\varphi}_t^X$, we can categorize firms into two types. The first type of firms are firms that have productivity levels between $\bar{\varphi}_t$ and $\bar{\varphi}_t^X$. The firms of this type find that it is profitable to sell only in the domestic market. Another type of firms have productivity levels higher than $\bar{\varphi}_t^X$. They do not only sell in the domestic market, but also exploit their superior productivity to earn more profit from the foreign market. The ex-ante probability for a new entrant to be an exporter is $\frac{1-G_t(\bar{\varphi}_t^X)}{1-G_t(\bar{\varphi}_t)}$, where $G_t(\cdot)$ is cdf of the productivity distribution. Under the assumption that the productivity distribution is Pareto with scale parameter B_t, this probability can be written as $\frac{\left(f/_{f^X}\right)^{\frac{1}{\sigma-1}}}{\tau}$.

The average profit in this case consists of two components. The first component is corresponding to the average profit of domestic sales, which is $f\left[\left(\frac{\tilde{\varphi}(\bar{\varphi}_t)}{\bar{\varphi}_t}\right)^{\sigma-1}-1\right]$. The second component accounts for the fact that a share $\frac{1-G_t(\bar{\varphi}_t^X)}{1-G_t(\bar{\varphi}_t)}$ of firms export to the foreign market and earn average profit

$f^X\left[\left(\frac{\tilde{\varphi}(\bar{\varphi}_t^X)}{\bar{\varphi}_t^X}\right)^{\sigma-1}-1\right]$ from export. Therefore, average profit of new entrants can be solved as:

$$\begin{aligned}\bar{\pi}_t &= f\left[\left(\frac{\tilde{\varphi}(\bar{\varphi}_t)}{\bar{\varphi}_t}\right)^{\sigma-1}-1\right]+\frac{1-G_t(\bar{\varphi}_t^X)}{1-G_t(\bar{\varphi}_t)}\cdot f^X\left[\left(\frac{\tilde{\varphi}(\bar{\varphi}_t^X)}{\bar{\varphi}_t^X}\right)^{\sigma-1}-1\right] \\ &= \left(\frac{\sigma-1}{1+\alpha-\sigma}\right)\cdot\left[f+\left(\frac{(f/f^X)^{\frac{1}{\sigma-1}}}{\tau}\right)\cdot f^X\right],\end{aligned} \tag{54}$$

where the latter equality is derived by substituting in the definition of the average productivity (97) and cdf of the underlying Pareto productivity distribution. (97) indicates that in the open economy average profit is also constant in every period. Therefore, we denote average profit by $\pi, \forall t$.

As in the autarky case, the labor market clearing condition mandates that the aggregate revenue of firms in a country equals to the aggregate labor income. The aggregate revenue of firms at time t is $R = M_t\cdot r(\tilde{\varphi}_t) = M_t\cdot\sigma\cdot\left(\bar{\pi}+f+\frac{1-G_t(\bar{\varphi}_t^X)}{1-G_t(\bar{\varphi}_t)}f^X\right)$. The aggregate labor income is 1 since we normalize both labor supply and wage to one. Therefore, the labor market clearing condition can be solved as:

$$\begin{aligned}R = 1 \quad &\Leftrightarrow M_t\cdot\sigma\cdot\left(\bar{\pi}+f+\frac{1-G_t(\bar{\varphi}_t^X)}{1-G_t(\bar{\varphi}_t)}f^X\right)=1 \\ &\Leftrightarrow M_t=\left\{\sigma\left[\bar{\pi}+f+\left(\frac{\left(f/f^X\right)^{\frac{1}{\sigma-1}}}{\tau}\right)f^X\right]\right\}^{-1}, \forall t.\end{aligned} \tag{55}$$

Again, under the Pareto assumption, the mass of firms is constant over time. Therefore, we can denote the mass of firms by $M, \forall t$.

Finally, the ex-ante expected value of firms has the same expression as in the autarky case (i.e., $v^E = \sum_{s=0}^{\infty}\left[(1-\delta)^s\left(1-G(\bar{\varphi}_{t+s})\right)\right]\cdot\bar{\pi} - f_E$) with different expected profit ($\bar{\pi}$) and cutoff productivity ($\bar{\varphi}_t$) due to the possibility of export. However, this does not alter the expression of the free-entry condition as in the autarky case, which is:

$$\sum_{s=0}^{\infty}\left[(1-\delta)^s\left(\frac{B_t}{\bar{\varphi}_{t+s}}\right)^{\alpha}\right] = \frac{f_E}{\bar{\pi}}. \tag{56}$$

We can use the same argument in Theorem 1 to show that the ratio $\frac{B_t}{\bar{\varphi}_t}$ is constant for all t and find the solution for the cutoff productivity in each period:

$$\bar{\varphi}_t = \left[\frac{\bar{\pi}/f_E}{1-(1-\delta)(\lambda M)^{-(1+\theta)\kappa\alpha}}\right]^{1/\alpha}\cdot B_0\cdot(\lambda M)^{(1+\theta)\kappa t}, \forall t = 0,1,2,3,\ldots, \tag{57}$$

where θ is the technology diffusion parameter. Comparing (97) to the solution in the autarky case (46), we have an extra term $(1+\theta)$. This is how technology diffusion affects productivity growth rate in the open economy.

In summary, in the symmetric open economy equilibrium we have:

$$
\begin{aligned}
\bar{\varphi}_t^X &= \tau\left(\frac{f^X}{f}\right)^{\frac{1}{\sigma-1}}\bar{\varphi}_t\\
\bar{\varphi}_t &= \left[\frac{\bar{\pi}/f_E}{1-(1-\delta)(\lambda M)^{-(1+\theta)\kappa\alpha}}\right]^{1/\alpha}\cdot B_0\cdot(\lambda M)^{(1+\theta)\kappa t}\\
\bar{\pi}_t &= \left(\frac{\sigma-1}{1+\alpha-\sigma}\right)\cdot\left[f+\left(\frac{(f/f^X)^{\frac{1}{\sigma-1}}}{\tau}\right)\cdot f^X\right],\forall t\\
M_t &= \left\{\sigma\left[\bar{\pi}_t+f+\left(\frac{(f/f^X)^{\frac{1}{\sigma-1}}}{\tau}\right)f^X\right]\right\}^{-1},\forall t.
\end{aligned}
$$

3.4 Balanced Growth in the Symmetric Open Economy

In this symmetric open economy case, the average productivity given $\bar{\varphi}_t$ is solved by substituting equation (97) into (38):

$$
\tilde{\varphi}_t(\bar{\varphi}_t) = \left(\frac{\alpha}{1+\alpha-\sigma}\right)^{\frac{1}{\sigma-1}}\cdot\left[\frac{\bar{\pi}/f_E}{1-(1-\delta)(\lambda M)^{-(1+\theta)\kappa\alpha}}\right]^{1/\alpha}\cdot B_0^{1+\theta}\cdot(\lambda M)^{(1+\theta)\kappa t} \tag{58}
$$

Taking logarithm on the both side of (97), we can get the approximate productivity growth rate to be:

$$
(1+\theta)\cdot\kappa\cdot\log(\lambda M). \tag{59}
$$

Before I turn to the aggregate price index in open economy, since there are foreign products selling in the domestic market, we need compute the mass and the average productivity of all firms that are selling in the domestic market. The portion of foreign exporters is $\frac{1-G_t(\bar{\varphi}_t^X)}{1-G_t(\bar{\varphi}_t)} = \frac{(f/f^X)^{\frac{1}{\sigma-1}}}{\tau}$. Therefore, the mass of all firms selling in the domestic market is:

$$M^{total} = \left(1 + \frac{(f/f^X)^{\frac{1}{\sigma-1}}}{\tau}\right)M. \tag{60}$$

The average productivity of foreign exporters is $\tilde{\varphi}_t(\bar{\varphi}_t^X) = \tilde{\varphi}_t\left(\tau\left(\frac{f^X}{f}\right)^{\frac{1}{\sigma-1}}\bar{\varphi}_t\right) = \tau\left(\frac{f^X}{f}\right)^{\frac{1}{\sigma-1}}\tilde{\varphi}_t(\bar{\varphi}_t)$. Therefore, the average productivity of all firms selling in the domestic market is:

$$\begin{aligned} \tilde{\varphi}_t^{total} &= \frac{1}{M^{total}}\left[\frac{1-G_t(\bar{\varphi}_t^X)}{1-G_t(\bar{\varphi}_t)} \cdot M \cdot \tilde{\varphi}_t(\bar{\varphi}_t^X) + M \cdot \tilde{\varphi}_t(\bar{\varphi}_t)\right] \\ &= 2 \cdot \tilde{\varphi}_t(\bar{\varphi}_t) \cdot \left(1 + \frac{(f/f^X)^{\frac{1}{\sigma-1}}}{\tau}\right)^{-1}. \end{aligned} \tag{61}$$

With M^{total} and $\tilde{\varphi}_t^{total}$, we can compute the aggregate price index in this economy as:

$$P_t = \left(M^{total}\right)^{\frac{1}{1-\sigma}} p\left(\tilde{\varphi}_t^{total}\right) = \left(1 + \frac{(f/f^X)^{\frac{2-\sigma}{1-\sigma}}}{\tau}\right) \cdot \frac{\sigma}{\sigma-1} \cdot M^{\frac{1}{1-\sigma}} \cdot [2 \cdot \tilde{\varphi}_t(\bar{\varphi}_t)]^{-1}. \tag{62}$$

From (97), we can see that the aggregate price index is decreasing at the same rate as the domestic aggregate productivity growth. Therefore, we have balanced growth also in the open economy.

Section Four: Economic Growth Implications

Two equilibria are solved previously. On one extreme, we have a complete closed economy. On another extreme, we have two symmetric countries that trade with each other. In this section, I compare these two cases to gain insights on what determines the way that trade openness affects long-term economic growth. For the comparison purpose, I use the superscript T to denote the trade case and A to denote the autarky case.

Consider the situation in which there is no technology diffusion (i.e., $\theta = 0$), the growth rates in the two cases have exactly the same expression ($\kappa \cdot log(\lambda M)$). However, market is more concentrated in the open economy caused by market share reallocation to high productivity firms. This leads to two consequences. One consequence is that the mass of firms producing in each country is lower in the open economy compares to the mass of firms in the closed economy (i.e., $M^T < M^A$). Under my formulation of productivity growth, a smaller mass of firms results a slower progression of productivity improvement. Another consequence of a higher degree of market concentration to high productivity firms is that the incumbent firms have higher profit in average (i.e., $\bar{\pi}^T > \bar{\pi}^A$). From the equilibrium solutions, a higher average profit implies a higher aggregate productivity level. However, this level effect does not contribute to growth. Therefore, without technology diffusion trade openness hurts long-term economic growth.

With technology diffusion (i.e., $\theta > 0$), trade openness can still affect growth in two opposite directions. Comparing the growth rates in the two cases ((48) and (59)), we can see the condition for trade openness to promote growth is:

$$(1+\theta)\cdot\log(\lambda M^{T}) > \log(\lambda M^{A})\,, \tag{63}$$

or equivalently $\theta > \frac{\log(M^{A}/M^{T})}{\log(\lambda M^{T})}$ since I assume $\lambda M^{i} > 1\; for\; i = A, T$.

We substitute the solutions of M^{A}, M^{T}, $\bar{\pi}^{A}$ and $\bar{\pi}^{T}$ into (63) and get the lower bound of technology diffusion efficiency for trade to benefit growth is:

$$\theta > \frac{\log\left(1+\frac{(f/f^{X})^{\frac{1}{\sigma-1}}}{\tau}\cdot\frac{f^{X}}{f}\right)}{\log\left[\lambda\frac{1+\alpha-\sigma}{\sigma\alpha}\left(f+\frac{(f/f^{X})^{\frac{1}{\sigma-1}}}{\tau}\cdot f^{X}\right)\right]}. \tag{64}$$

This lower bound shows the lowest required technology diffusion efficiency for trade openness to improve long-term economic growth. In other words, trade openness is promoting growth if the associated technology diffusion is efficient enough. In next section, I present a quantitative analysis of this statement.

Section Five: Quantitative Analysis

In this section I investigate the model implications from a quantitative perspective. This section is organized in three parts. First, I extend the empirical study in Coe and Helpman (1995) to discuss the empirical motivation of the model specification for international technology diffusion. Second, I calibrate the technology diffusion efficiency lower bound (97) with the U.S. macroeconomic data to examine the lower bond in two dimensions. One dimension is that we can understand if the calibrated technology diffusion efficiency of the U.S. market with its trading partners exceeds this theoretical lower bound or not. Another dimension is that we can get a glance of how the lower bound changes corresponding to different sets of possible macroeconomic parameters. Third, in this section, I elaborate the sensitivity analysis of the lower bound with respect to different sets of parameters by counterfactual experiments.

5.1 Motivation of the Technology Diffusion Modeling

In Coe and Helpman (1995), the elasticity of TFP growth with respect to a trade-weighted-sum of foreign knowledge capital stocks is constant. I use a similar specification but with the plain sum of foreign knowledge capital stocks as described in section 2. This specification stems from the prevailing form of technology diffusion in knowledge- and technology-intensive industries. I show that this argument is empirically reasonable by the following regressions.

$$\log F_i = \alpha_i + \beta_{1,i} \cdot \log S_i^d + \beta_{2,i} \cdot G7 \cdot \log S_i^d + \beta_{3,i} \cdot m \cdot \log S_i^{f,weighted} + \epsilon_i \quad (65)$$

$$\log F_i = \alpha_i + \beta_{1,i} \cdot \log S_i^d + \beta_{2,i} \cdot G7 \cdot \log S_i^d + \beta_{3,i} \cdot \log S_i^f + \epsilon_i \quad (66)$$

In (65) and (97), countries are indexed by i, F_i is TFP of country i, S_i^d is the domestic knowledge capital stock (cumulative R&D spending in the data), $S_i^{f,weighted}$ is the trade-share-weighted-sum of foreign partners' knowledge capital stocks, S_i^f is the plain sum of foreign partners' knowledge capital stocks, $G7$ is the indicator for G7 countries, and m is the ratio of the total value of imported goods and services to GDP. (65) is from Coe and Helpman (1995) and (97) is modified from (65) by replacing the trade-share-weighted-sum of foreign knowledge capital stock ($m \cdot \log S_i^{f,weighted}$) by the plain sum($\log S_i^f$).

I use the same set of data and estimation method as in Coe and Helpman (1995). The data includes 21 OECD countries plus Israel during the period 1970-1990. The estimations are reported in Table 6[22].

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[22] As a convention of the pooled cointergration method, I do not report the standard deviation association with each estimated coefficient because it is usually biased.

Table 6: Regression results of equation (65) and (97)

Variable	Equation (65) (Coe and Helpman)	Equation (97)
$\log S_i^d$	0.078	0.0058
$G7 \cdot \log S_i^d$	0.156	0.1023
$m \cdot \log S_i^{f,weighted}$	0.294	
$\log S_i^f$		0.2107
Standard Error	0.044	0.0434
R^2	0.651	0.7116
R^2 adjusted	0.630	0.6950

Comparing two columns of Table 6, we can see that the elasticities of TFP growth with respect to $m \cdot \log S_i^{f,weighted}$ and $\log S_i^f$ are roughly the same. Furthermore, based on adjusted R^2, the regression model (97) has better fit. This supports the statement that some forms of technology diffusion between trading partners are independent from trade shares.

5.2 Calibration

In Section 4, I derive the minimum required technology diffusion efficiency (64) for trade openness to be pro-growth. Here, I calibrate the model to the U.S. economic data to gain more insights from this lower bound. For the calibration, I rewrite equation (64) as:

$$\theta > \frac{\log\left(\frac{M^A}{M^T}\right)}{\log(\lambda M^T)} = \frac{\log\left(1 + \frac{(f/f^X)^{\frac{1}{\sigma-1}}}{\tau} \cdot \frac{f^X}{f}\right)}{\log(\lambda M^T)}. \tag{67}$$

The value of $\log(\lambda M^T)$ is hard to be calibrated directly. Instead, from the model we have the equilibrium growth rate $\kappa \cdot (1+\theta) \cdot \log(\lambda M^T)$ in the open economy. Therefore, we can calibrate $\kappa \cdot (1+\theta) \cdot \log(\lambda M^T)$ all together to be the contemporary US long-term growth rate. To implement this approach, I rewrite equation (97) again as:

$$\frac{\theta}{\kappa \cdot (1+\theta)} > \log\left(1 + \frac{\left(f/f^X\right)^{\frac{1}{\sigma-1}}}{\tau} \cdot \frac{f^X}{f}\right) \Big/ \kappa \cdot (1+\theta) \cdot \log(\lambda M^T). \tag{68}$$

I use the following steps to compute the calibration value of (97). First, I calibrate the value of $\frac{\left(f/f^X\right)^{\frac{1}{\sigma-1}}}{\tau}$. Notice that $\left[\frac{(f/f^X)^{\frac{1}{\sigma-1}}}{\tau}\right]^{\alpha}$ is the proportion of exporters in a country according to the model. In this formula, α can be calibrated by matching the ratio $\frac{\alpha}{\sigma-1}$ to the tail shape of the firm size distribution. I cite Luttmer (2007) that reports $\frac{\alpha}{\sigma-1} = 1.06$. Further, from Broda and Weinstein (2004), the central 90% of the elasticity of substitution σ at the 3-digit SITC sector level are estimated to be range from 1.8 to 6.1 with the median 2.7. By plugging in σ, we can backward deduce the value of α. For the proportion of exporters, I refer to Bernard, Jensen et al. (2007): the percentage of firms that export in the U.S. aggregate manufacturing sector is 18% based on data from the 2002 U.S. Census of Manufactures. By setting $\left[\frac{(f/f^X)^{\frac{1}{\sigma-1}}}{\tau}\right]^{\alpha} = 18\%$ and plugging in the computed value of α, we can get the value of $\frac{(f/f^X)^{\frac{1}{\sigma-1}}}{\tau}$ for each case of σ and τ. Second, I refer to Alvarez and Lucas (2007) for the value of τ. They discussed that from estimations of gravity equation, the value of τ can be as high as 1.54. On the other hand, they pointed out that from estimations of direct transportation costs, τ could be as low as 1.11. This value is also reported in Garetto (2013) as a calibration result. Further, in Alvarez and Lucas' paper, they chose $\tau = 1.33$ to compromise these two types of estimations. Therefore, I compute three calibrations that have τ equals to 1.11, 1.33, and 1.54 respectively. Finally, I compute the average yearly growth rate of real US GDP from 1960 to 2011 is 3% by the data from the U.S. Bureau of Economic Analysis and set $\kappa \cdot (1+\theta) \cdot \log(\lambda M^T) = 3\%$. The calibration result is summarized in Table 7.

Table 7 Calibration result for different σ and τ

σ	1.8 (10^{th}percentile)	2.7 (Median)	6.1(90^{th}percentile)
α	0.85	1.8	5.4

$\tau = 1.11$

$\frac{f^X}{f}$	4.64	4.22	2.96
$\frac{\left(f/f^X\right)^{\frac{1}{\sigma-1}}}{\tau}$	0.13	0.39	0.73
Lower bound of $\frac{\theta}{\kappa\cdot(1+\theta)}$	15.96	32.24	38.31
Lower bound of θ if $\kappa = 0.0058$	0.1	0.23	0.29

$\tau = 1.33$

$\frac{f^X}{f}$	4.01	3.1	1.18
$\frac{\left(f/f^X\right)^{\frac{1}{\sigma-1}}}{\tau}$	0.13	0.39	0.73
Lower bound of $\frac{\theta}{\kappa\cdot(1+\theta)}$	14.20	26.26	20.64
Lower bound of θ if $\kappa = 0.0058$	0.09	0.18	0.14

$\tau = 1.54$

$\frac{f^X}{f}$	3.57	2.42	0.56
$\frac{\left(f/f^X\right)^{\frac{1}{\sigma-1}}}{\tau}$	0.13	0.39	0.73
Lower bound of $\frac{\theta}{\kappa\cdot(1+\theta)}$	12.90	21.99	11.36
Lower bound of θ if $\kappa = 0.0058$	0.08	0.15	0.07

According to the model, the elasticity of TFP with respect to the domestic knowledge capital stock is κ and the elasticity with respect to the total foreign knowledge capital stock is $\kappa \cdot \theta$. Therefore, in each group of calibration I also report the lower bound of θ with estimated κ for non-G7 countries from (66). In all cases, the calibrated lower bound is far less than the estimated value of θ, which is $\frac{0.2107}{0.0058} \approx 36.33$. Thus, the model predicts current openness of the U.S. to trade is beneficial to economic growth.

Notice that I do not use estimated κ for G7 countries for theoretical concern. The upper bound of the ratio $\frac{\theta}{1+\theta}$ is 1 when $\theta > 0$. Since the calibrated values of $\frac{\theta}{\kappa(1+\theta)}$ are much larger than 1 in general, κ is required to be small to get the ratio $\frac{\theta}{1+\theta}$ in the reasonable range. In other words, the calibration result is not compatible with the empirical estimation for G7 countries. This inconsistency could due to model abstractions from the real world. For example, in this paper I do not consider the possibilities that countries have different productivity distributions or sizes. It is also possible that efficiency of innovation increases with level of TFP. These conditions go beyond the scope of this paper and could be the subjects of future research.

5.3 Counterfactual Experiments

In this section, I implement two experiments to address the questions (1) How does the elasticity of substitution over product varieties affects the technology diffusion efficiency lower bound? (2) How does the iceberg cost of international trade affects the lower bound? In these two experiments, I make the following assumptions. First, the range of κ is $(0,1)$. This assumption is consistent with the estimations in Motivation of the Technology Diffusion Modeling. Second, the tail shape of the firms size distribution is fixed such that $\frac{\alpha}{\sigma-1} = 1.06$ as estimated by Luttmer (2007). Finally, I set the ratio of the fixed cost for exports to the fixed cost for domestic production (i.e., $\frac{f^X}{f}$) equals to 3, which is the average value that I computed from the previous calibration result.

In the first experiment, I compute the corresponding lower bound of θ according to equation (64) for every possible κ. Three values of the elasticity of substitution (i.e., σ) are considered as in the calibration subsection. The result is presented in Figure 8. The curved lines depict the lowest θ that is required for trade to be pro-growth. We can see from the graph that the lower bound of θ is shifting rightward as σ getting smaller. In other words, the required technology diffusion efficiency is lower when the product varieties are less substitutable. This result shows that when a sector has higher diversity of products, trade openness is more likely to improve its growth rate. We can also understand this as when consumers are seeing products to be very different from each other, trade openness has less effect for market competition toughness. Therefore, technology diffusion efficiency is less crucial.

For trade policy concern, since trade openness does not necessary promote long term growth. This experiment result implies that the prospective technology diffusion efficiency should be carefully evaluate before actually open to trade, especially for sectors with high elasticity of substitution.

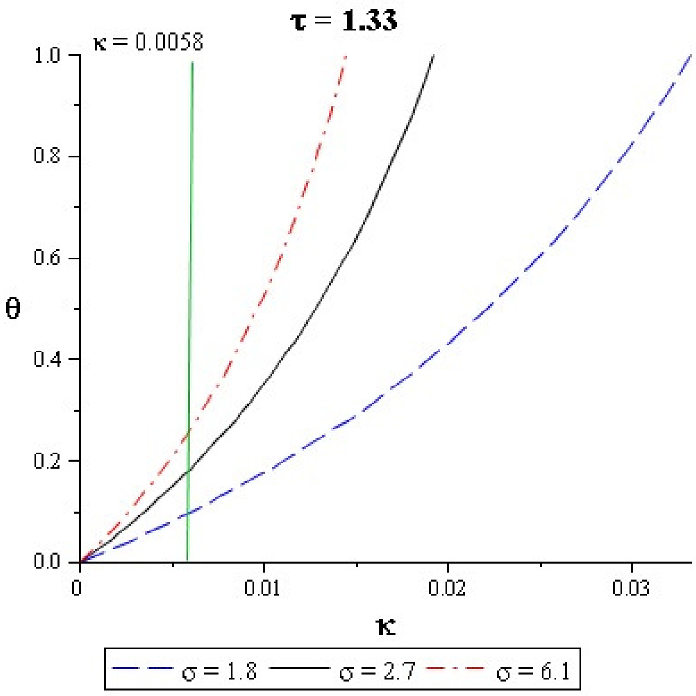


Figure 8: Technology efficiency lower bounds for each possible *κ* and different elasticities of substitution

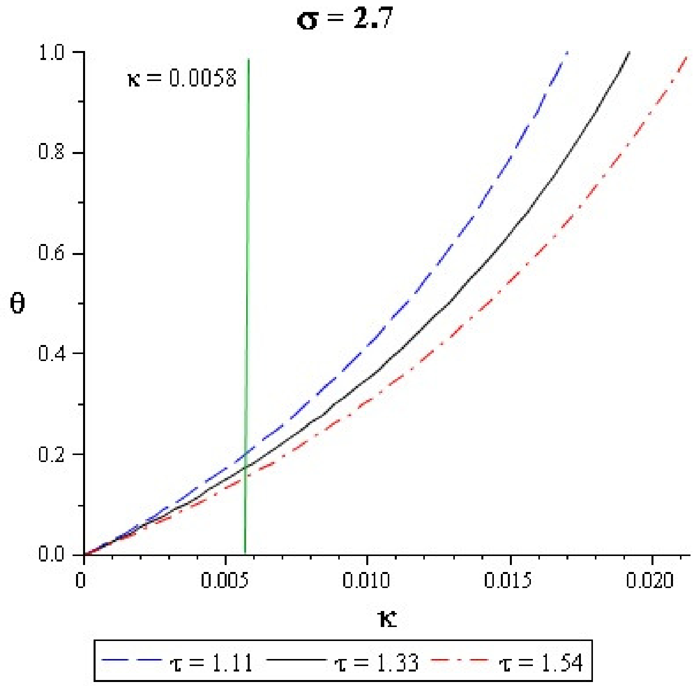


Figure 9: Technology efficiency lower bounds for each possible κ and different iceberg trade costs

The second experiment is computing the lower bound of θ for all values of τ as in the calibration subsection. The result is presented in Figure 9. We can see from the figure that the lower bound of θ is shifting rightward when the iceberg cost τ increases.

A policy-relevant implication is that when technology transmission is not efficient enough, trade barriers (measured by τ) can reduce the negative impact for growth. If we believe sectors that involve in international trade can finally adapt the environment and have enough technology diffusion efficiency, gradually rather than suddenly open to trade should be considered because: 1. This allows more time for the sectors to acquire sufficient technology diffusion efficiency. 2. This can lower the risk that the sectors exposed to international market are not ready and the increased openness can reduce their growth rates.

Section Six: Concluding Remarks

In this paper, I propose a model that can rationalize contradictory observations of the correlation between trade openness and economic growth. While most of popular trade theories predict that trade openness benefits the local economy unambiguously, I show that this argument may no longer be true when concerning long-term economic growth.

The model is extended from Melitz (2003), which is a trade model with firm heterogeneity and an increasing return to scale production function. In my model, I incorporate the possibility of productivity growth and technology diffusion. The interaction between reallocation of market shares that stems from firm heterogeneity and domestic R&D activities brings the major finding of this paper: the increased toughness of market competition suffocates the effective local R&D activities. In the model, this effect manifests in the way that it is harder for entrepreneurs to introduce new products to the market. Since I measure effective R&D activities by number of successful new entrants, this causes slower productivity growth.

That implies that without technology diffusion, trade openness damps long-term economic growth. However, after trade, trading partners find it possible to pool their physical and intellectual R&D resources in a manner that bolsters effective R&D results. I formulate this possibility and show that the efficiency of technology diffusion is the critical element that determines if trade openness promotes growth or not.

I investigate the sensitivity of technology diffusion efficiency to economic parameters quantitatively. I obtain two informative results. First, by calibrating the model to the U.S. economy, I conclude that average technology diffusion efficiency for the U.S. is much higher than the required lower bound for promoting growth. Second, the lower bound of technology diffusion efficiency for promoting growth increases with the elasticity of substitution over products and decreases with iceberg trade costs. The second result suggests two policy implications: (1) The prospective technology diffusion efficiency should be carefully evaluated for sectors with high elasticity of substitution. (2) For sectors with less technology diffusion efficiency, gradually lowering trade barrier could protect domestic R&D and allow enough time for the R&D sector to adapt a tougher market competition.

The purpose of this paper is to provide a parsimonious model that reconciles contradictory observations on the correlation between trade openness and growth. The model is abstract from several international economic realities. For example, countries in the world usually have different sizes and different productivity distributions. Further, this paper does not discuss how the mechanisms could potentially be different if there more than two countries in the economy. These could be valuable inquiries for future research.

APPENDIX A: DERIVATION OF GENERAL EQUILIBRIUM

The equilibrium is defined by the set of variables $\left\{\{\bar{\varphi}_i\},\{\bar{\varphi}_i^f\},\{\chi_i\},\{M_i\},\{s^{j,k}\},\{u^{j,k}\}\right\}$ for $i=\{1,2\}$ denotes the firm's original country and $(j,k)=\{(1,1),(1,2),(2,1),(2,2)\}$ denotes the wage rate for workers who come from country k and work at country j. Similarly to the symmetric case, we use the following equilibrium conditions to solve the equilibrium.

1. Zero Cutoff Profits

The zero cutoff profits condition can be expressed as a set of equations:

$$\pi_i^i(\bar{\varphi}_i)=0 \tag{69}$$

$$\pi_i^j(\bar{\varphi}_i^f)=0 \tag{70}$$

The profit function and revenue function of establishments are:

$$r_j^i(\varphi)=\left(\frac{\sigma}{\sigma-1}\cdot\frac{1}{\varphi}\cdot\frac{\overline{w}_j^i}{P_i}\right)^{1-\sigma}\cdot R_i \tag{71}$$

$$\pi_j^i(\varphi)=\begin{cases} r_j^i(\varphi)\cdot\dfrac{1}{\sigma}-f^I, if\ i\neq j \\ r_j^i(\varphi)\cdot\dfrac{1}{\sigma}-f, if\ i=j \end{cases}, \tag{72}$$

The index i denotes the country where the establishment located and the index j is the country of origin of the establishment. R_i and P_i are respectively the aggregate expenditure and the price index of country i.

We substitute (69) and (70) into (97) to derive the solution for $\bar{\varphi}_i^f$:

$$\bar{\varphi}_{1,2}^f = \bar{\varphi}_1 \cdot \frac{\overline{w}_1^2}{\overline{w}_1^1} \cdot \frac{P^1}{P^2} \cdot \left(\frac{R^2}{R^1} \cdot \frac{f}{f^I}\right)^{\frac{1}{1-\sigma}} \tag{73}$$

$$\bar{\varphi}_{2,1}^f = \bar{\varphi}_2 \cdot \frac{\overline{w}_2^1}{\overline{w}_2^2} \cdot \frac{P^2}{P^1} \cdot \left(\frac{R^1}{R^2} \cdot \frac{f}{f^I}\right)^{\frac{1}{1-\sigma}}, \tag{74}$$

where $\overline{w}_j^i$ is the unit price of labor bundles for establishments from country j and located at country i, P^i is the price index at country i, R^i is the aggregate expenditure of country i.

We can derive from (69), (70), and (73) to get the equations for the average profit of firms as:

$$\bar{\pi}_i = f \cdot \left[\left(\frac{\tilde{\varphi}_i}{\bar{\varphi}_i}\right)^{\sigma-1} - 1\right] + \chi_i \cdot f^I \cdot \left[\left(\frac{\tilde{\varphi}_i^f}{\bar{\varphi}_i^f}\right)^{\sigma-1} - 1\right], for\ i = \{1,2\}, \tag{75}$$

where $\tilde{\varphi}$ is the average productivity of local establishments and $\tilde{\varphi}^f$ is the average productivity of foreign establishments.

2. Free Entry

Free entry of new firms drives the ex-ante expected profits to zero (i.e., $V_i^E = 0\ for\ i = \{1,2\}$). According to this, we derive the average profit of firms as:

$$\bar{\pi}_i = f^E \cdot \left(\frac{\delta}{\left({}^{B}/_{\bar{\varphi}_i} \right)^{\kappa}} \right). \tag{76}$$

We combine (75) and (97) to derive the solution for the cutoff productivity for local establishment as:

$$\bar{\varphi}_i = \left[\frac{f + \chi_i \cdot f^I}{\delta \cdot f^E} \cdot \frac{\sigma - 1}{1 + \kappa - \sigma} \right]^{\frac{1}{\kappa}} \cdot B \;\; for\ i = \{1,2\}\,. \tag{77}$$

The probabilities of being a multinational firm are:

$$\chi_1 = \frac{1 - G\left(\bar{\varphi}_1^f\right)}{1 - G(\bar{\varphi}_1)} = \left[\frac{\overline{w}_1^2}{\overline{w}_1^1} \cdot \frac{P^1}{P^2} \cdot \left(\frac{R^2}{R^1} \cdot \frac{f}{f^I} \right)^{\frac{1}{1-\sigma}} \right]^{-\kappa} \tag{78}$$

$$\chi_2 = \frac{1 - G\left(\bar{\varphi}_2^f\right)}{1 - G(\bar{\varphi}_2)} = \left[\frac{\overline{w}_2^1}{\overline{w}_2^2} \cdot \frac{P^2}{P^1} \cdot \left(\frac{R^1}{R^2} \cdot \frac{f}{f^I} \right)^{\frac{1}{1-\sigma}} \right]^{-\kappa} \tag{79}$$

3. Labor Market Clearing

The labor market clearing condition requires that the aggregate labor supply should equal to the aggregate labor demand for all types of labor in all countries. The labor market clearing condition can be written as:

$$H^{D,1,1} + H^{D,2,1} = \overline{H}^1 \tag{80}$$

$$H^{D,2,2} + H^{D,1,2} = \overline{H}^2 \tag{81}$$

$$L^{D,1,1} + L^{D,2,1} = \overline{L}^1 \tag{82}$$

$$L^{D,1,1} + L^{D,2,1} = \overline{L}^2\,, \tag{83}$$

where $H^{D,i,j}$ is the aggregate demand in country i for high-skilled workers from country j, and $L^{D,i,j}$ is the aggregate demand in country i for high-skilled workers from country j. The aggregate labor demands are:

$$H^{D,1,j} = M_1 \cdot H_1^{1,j} + M_2 \cdot \chi_2 \cdot H_2^{1,j} \tag{84}$$

$$H^{D,2,j} = M_2 \cdot H_2^{2,j} + M_1 \cdot \chi_1 \cdot H_1^{2,j} \tag{85}$$

$$L^{D,1,j} = M_1 \cdot L_1^{1,j} + M_1 \cdot \chi_2 \cdot L_2^{1,j} \tag{86}$$

$$L^{D,2,j} = M_2 \cdot L_2^{2,j} + M_1 \cdot \chi_1 \cdot L_1^{2,j} \tag{87}$$

I normalize $u^{1,1}$ to 1 and use (86) and (97) to solve for $u^{2,2}$, $M_1$and M_2.

4. Migration Incentive Compatibility Condition

If there is no migration quota workers are assumed to be able to move across countries by paying the moving costs. Therefore, in equilibrium, we must have the real incomes for workers who migrate to foreign countries equal to the real incomes for the same type of workers who stay in their home countries. Otherwise, workers would keep moving to the country where they can earn higher real wages. The incentive compatibility condition can be written as:

$$\frac{s^{1,2}}{P^1} = \frac{s^{2,2}}{P^2} \tag{88}$$

$$\frac{s^{2,1}}{P^2} = \frac{s^{1,1}}{P^1} \tag{89}$$

$$\frac{u^{1,2}}{P^1} = \frac{u^{2,2}}{P^2} \tag{90}$$

$$\frac{u^{2,1}}{P^2} = \frac{u^{1,1}}{P^1} \tag{91}$$

Wage variables can be solve by (84), (85), and (88)-(97).

5. Migration Quota

Notice that the fourth equilibrium condition holds true only if we do not have an effective migration quota in presence. If there are migration quotas, the countries that implement effective migration quotas would have excess demands for foreign workers. In this case, we have:

$$\frac{s^{i,j}}{P^i} > \frac{s^{j,j}}{P^j} \ \ if\ \lambda_h^{i,j} < 1 \tag{92}$$

$$\frac{u^{i,j}}{P^i} > \frac{u^{j,j}}{P^j} \ if\ \lambda_l^{i,j} < 1\ , \tag{93}$$

For workers who are form country j that are effectively regulated by migration quota in country i.

By our notation of the migration quota, the supplies of foreign workers are:

$$H^{S,i,j} = \lambda_h^{i,j} \cdot H^{E,i,j} \tag{94}$$

$$L^{S,i,j} = \lambda_l^{i,j} \cdot L^{E,i,j}\ , \tag{95}$$

where $H^{E,i,j}$ and $L^{E,i,j}$ are amounts of immigration from country j to i in the unconstraint equilibrium solved by using equilibrium condition 4.

We can rewrite (80)-(83) as:

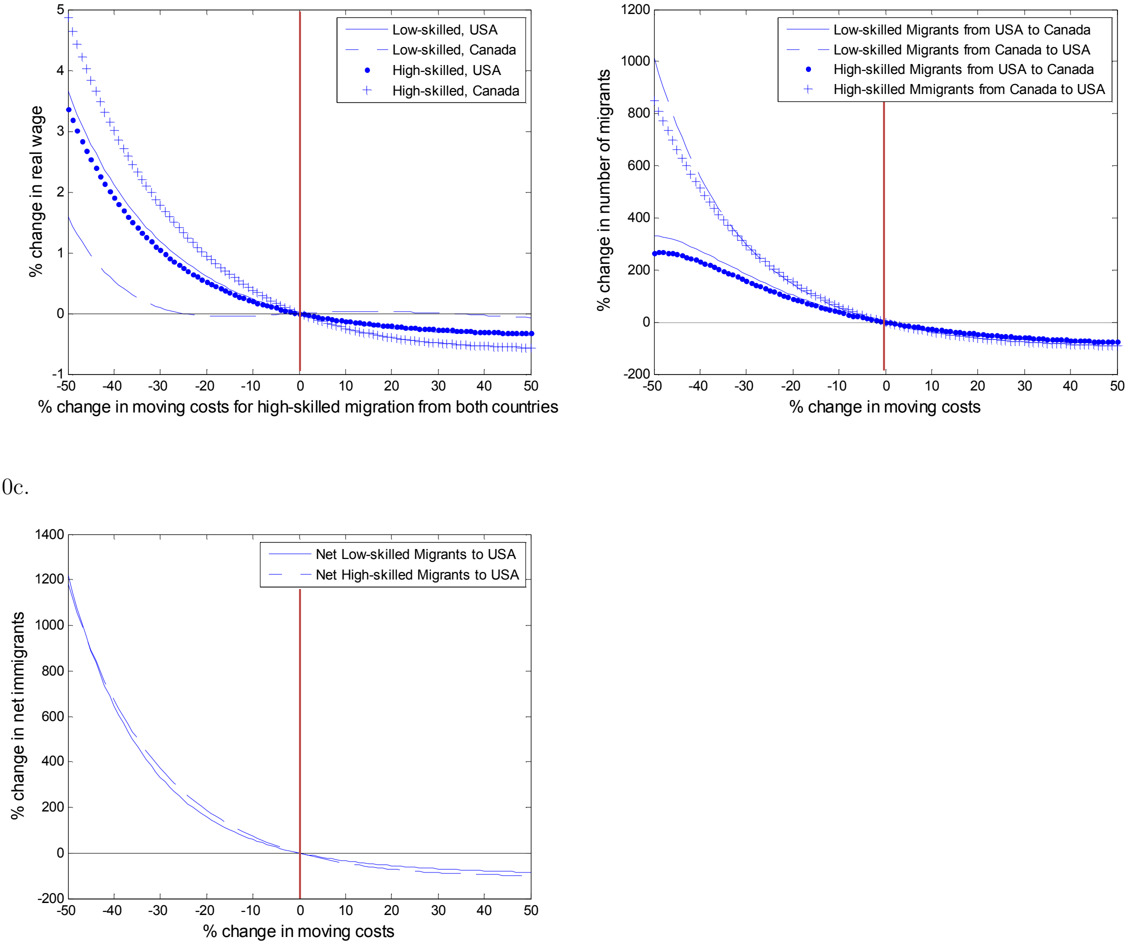
$$H^{D,i,j} = H^{S,i,j} \tag{96}$$

$$L^{D,i,j} = L^{S,i,j}\ , \tag{97}$$

where $i, j = \{1,2\}$. We can then use (96) and (97) to solve equilibrium wages when effective immigration quotas are in presence.

APPENDIX B: SIMULATION RESULTS

Figure 10: Labor market outcomes as moving costs changing for all migrants

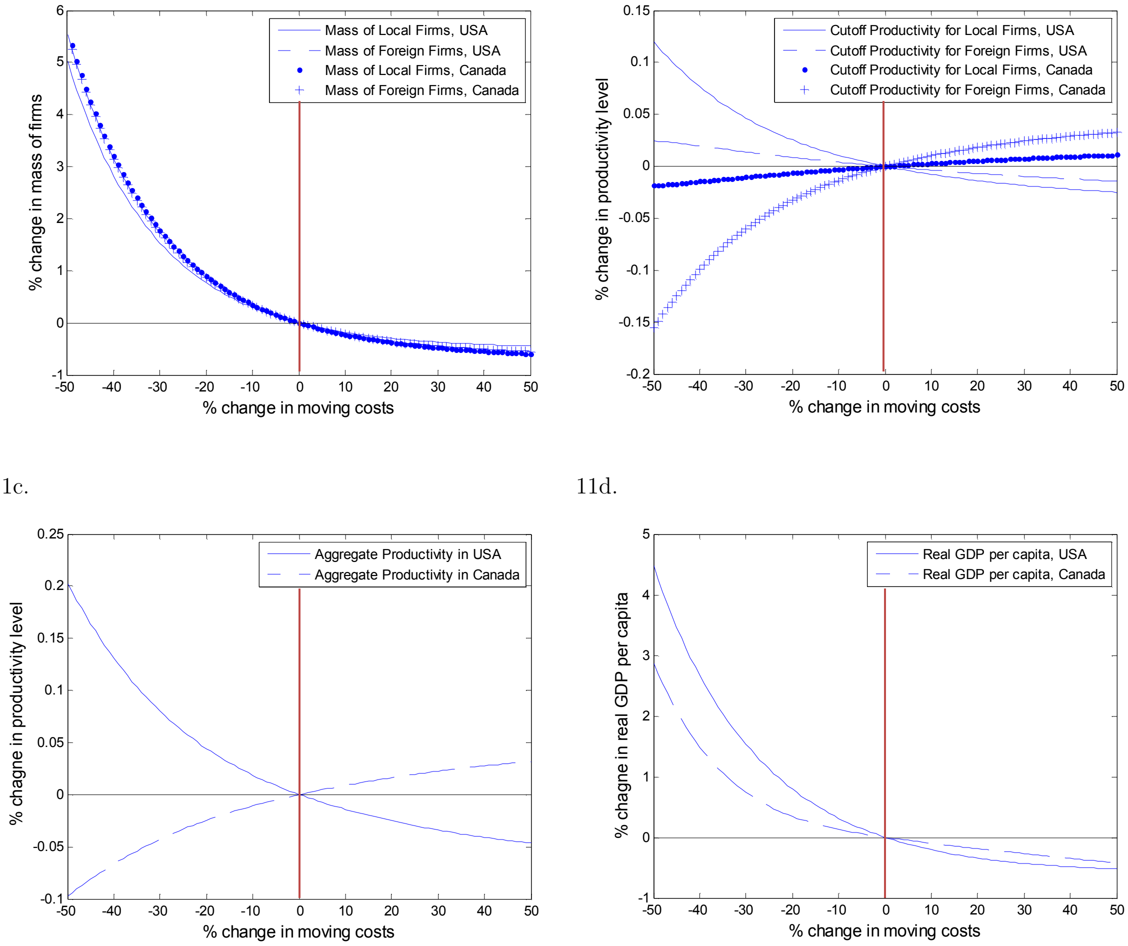


10a.

10b.

10c.

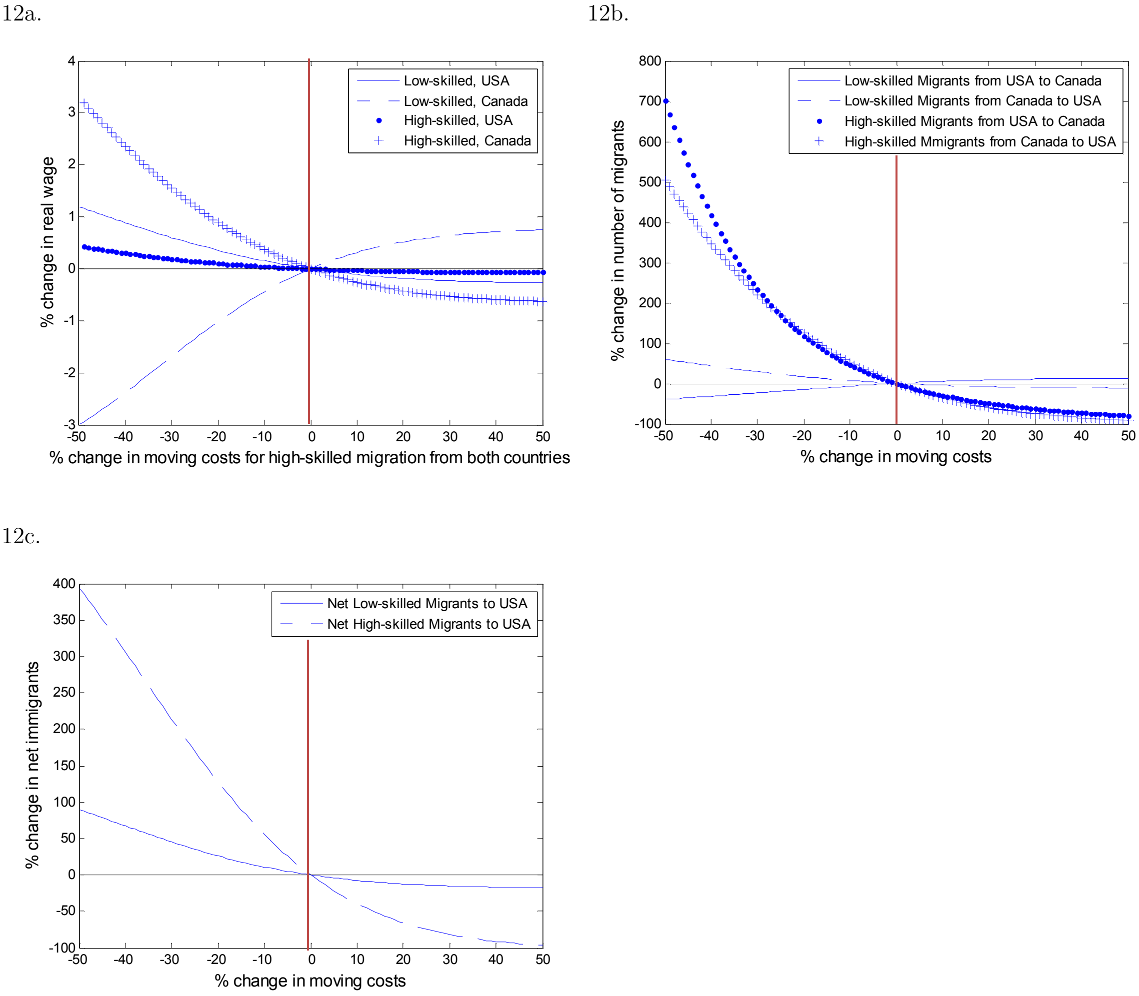
Figure 11: Mass of firms and intra-industry reallocation as moving costs changing for all migrants



11a. 11b.

11c. 11d.

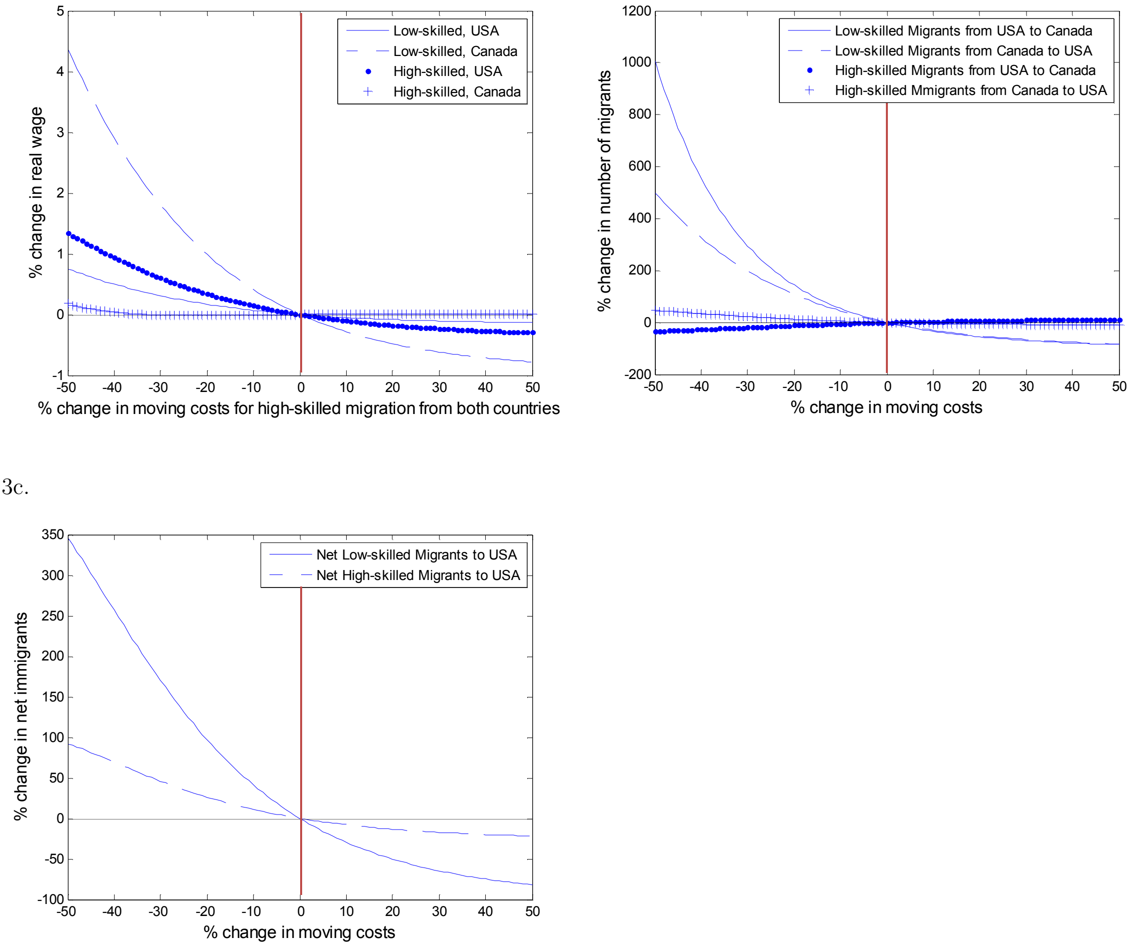
Figure 12: Simulation result for moving costs changes for high-skilled migrants


12a.

12b.

12c.

Figure 13: Simulation result for moving costs changes for low-skilled migrants



13a.

13b.

13c.

Figure 14: Income changes due to bilateral quotas for all migrants
(Solid line represents real wage of native workers and dashed line represents real wage of foreign workers)

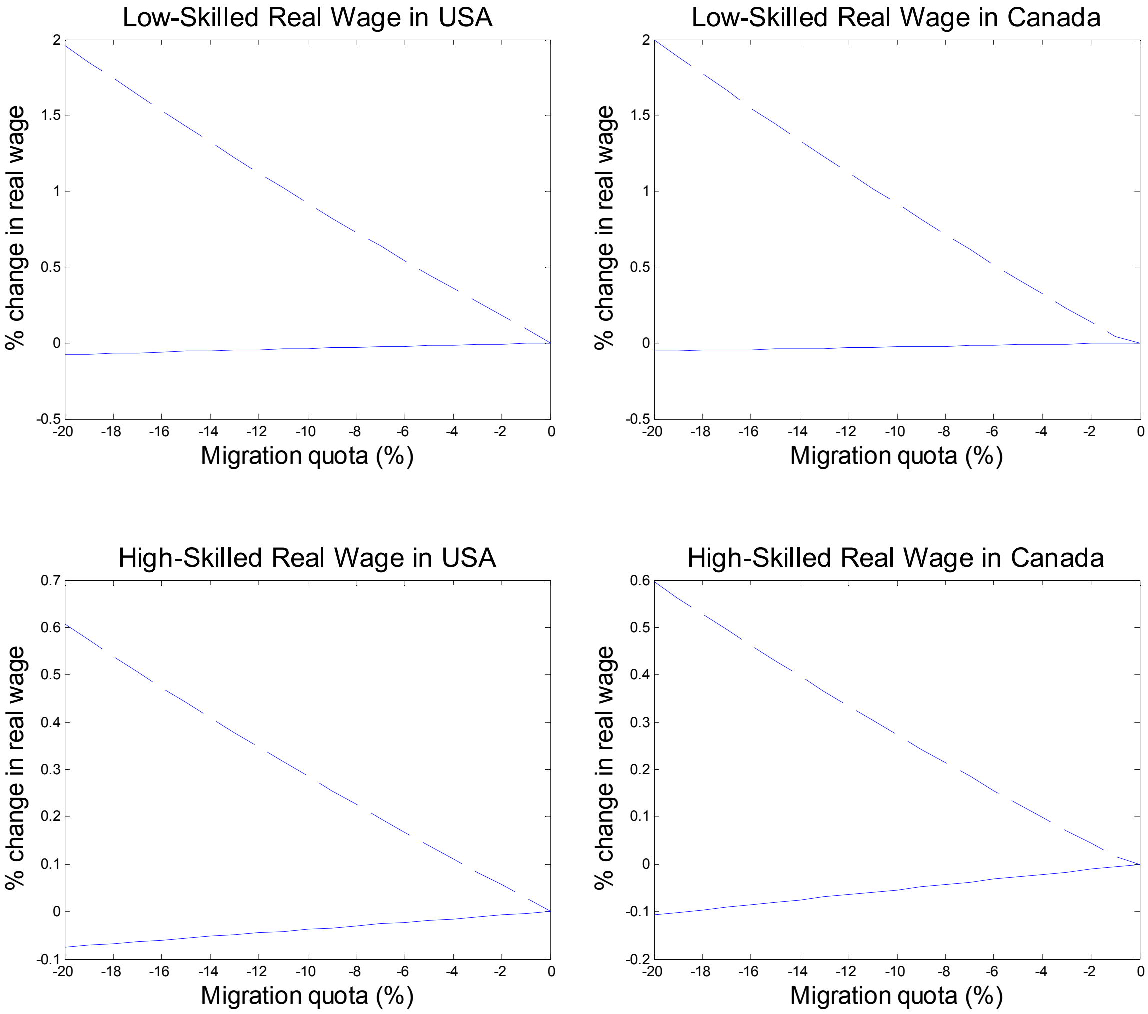
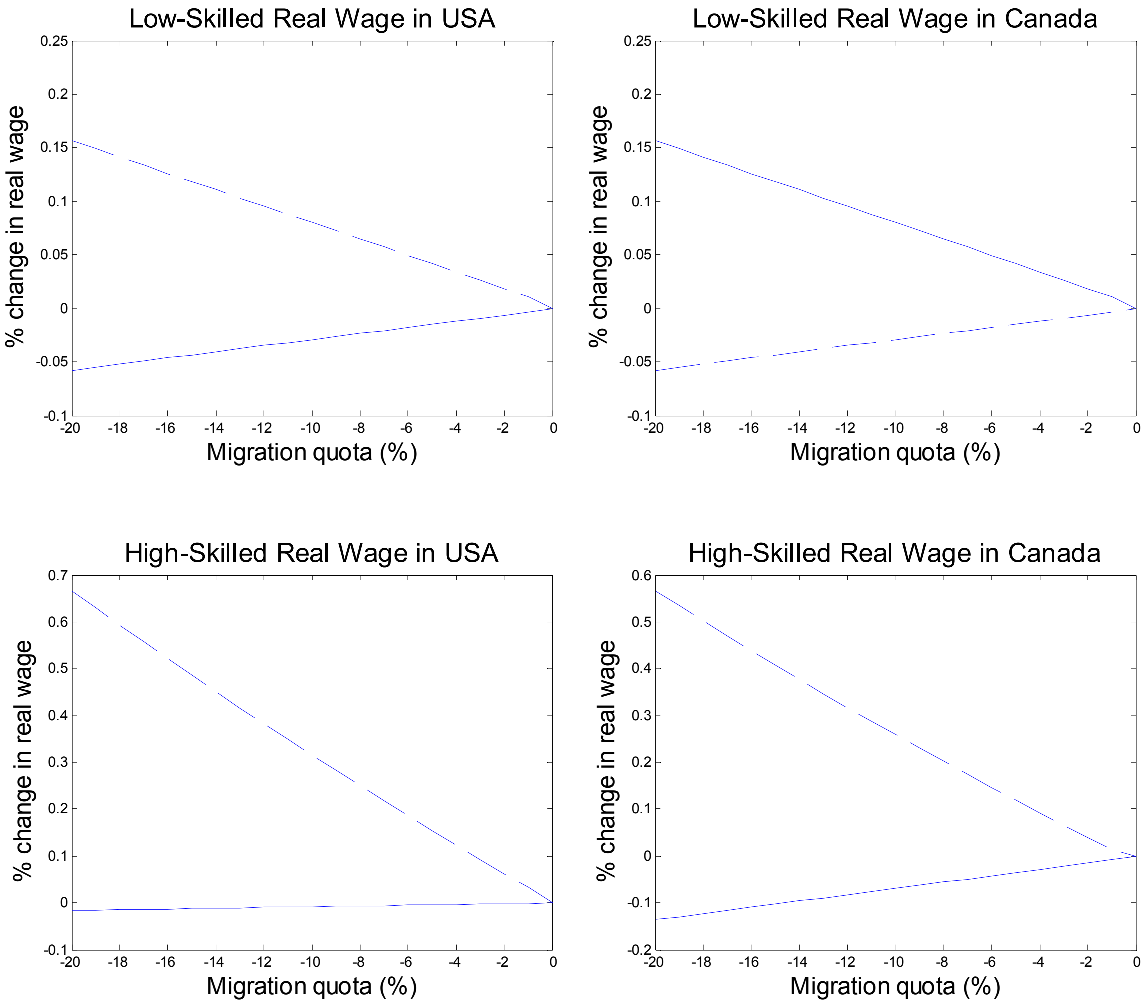


Figure 15: Income changes due to bilateral quotas for high-skilled migrants
(Solid line represents real wage of native workers and dashed line represents real wage of foreign workers)



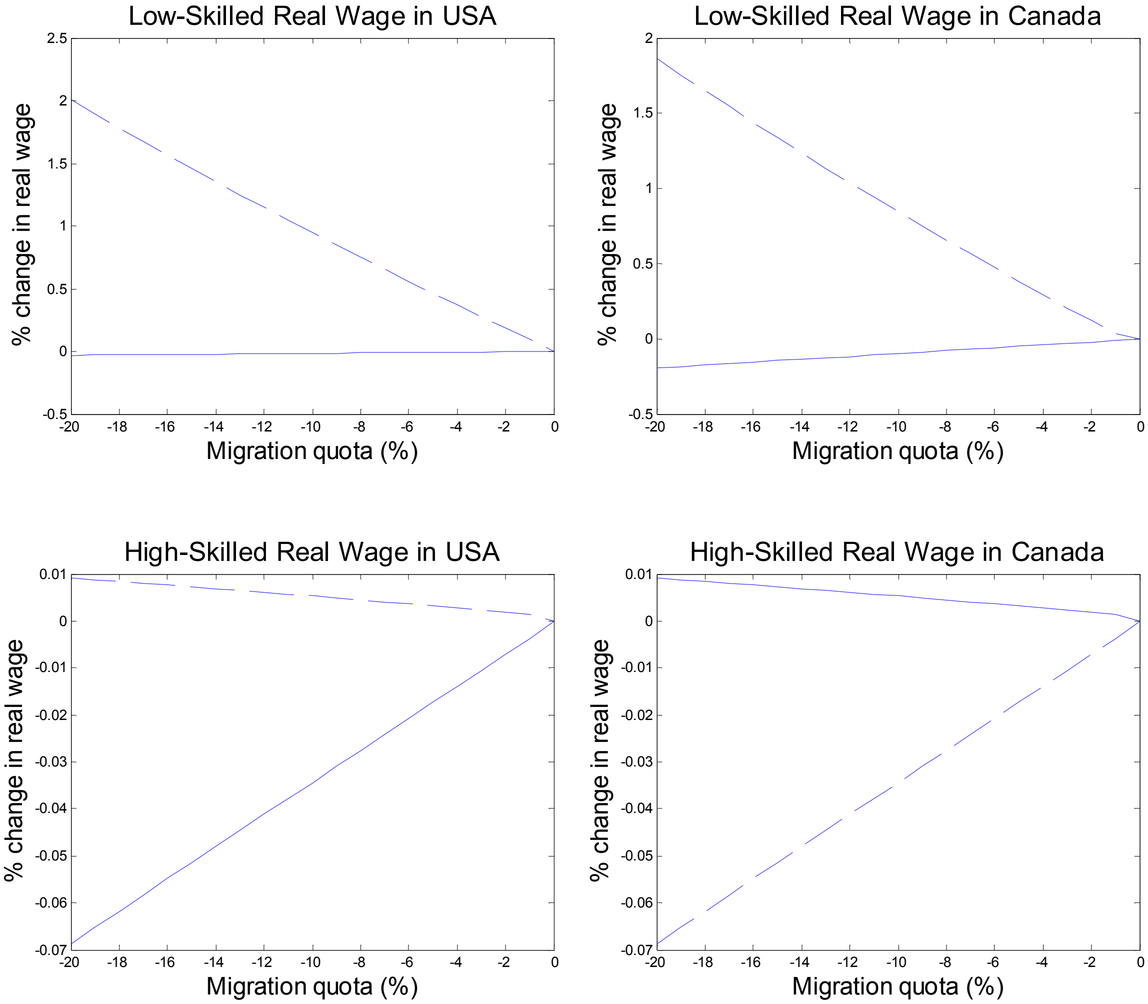
Low-Skilled Real Wage in USA

Low-Skilled Real Wage in Canada

High-Skilled Real Wage in USA

High-Skilled Real Wage in Canada

Figure 16: Income Changes due to bilateral quotas for low-skilled migrants
(Solid line represents real wage of native workers and dashed line represents real wage of foreign workers)



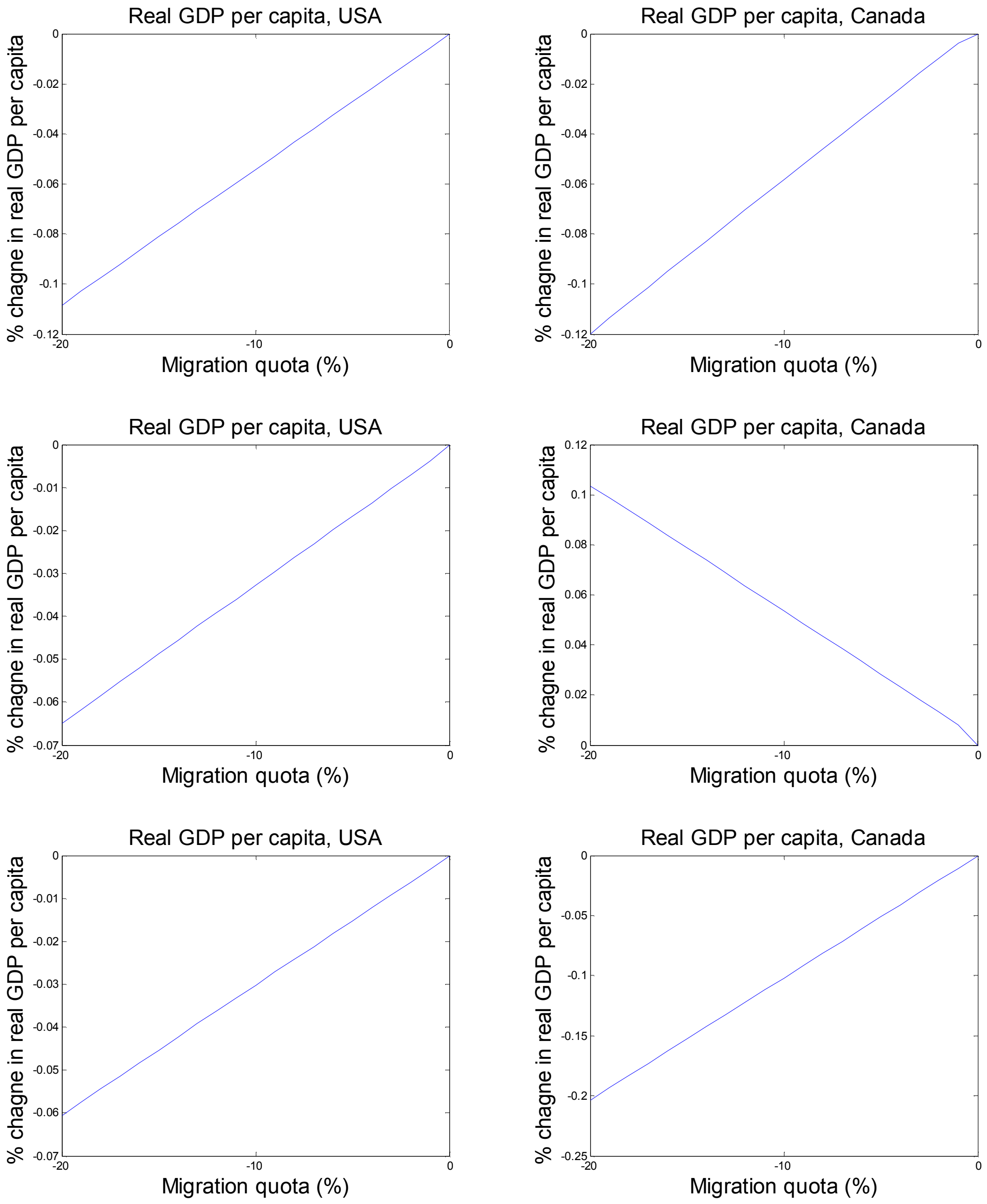
Low-Skilled Real Wage in USA

Low-Skilled Real Wage in Canada

High-Skilled Real Wage in USA

High-Skilled Real Wage in Canada

Figure 17: Change in real per capita GDP due to migration quotas
Row 1 – Bilateral migration quotas are implemented for all migrants
Row 2 – Bilateral migration quotas are implemented only for high-skilled migrants
Row 3 – Bilateral migration quotas are implemented only for low-skilled migrants



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