ABSTRACT

Title of dissertation: ESSAYS ON THE DISTRIBUTIONAL AND WELFARE EFFECTS OF INTERNATIONAL TRADE

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International trade brings welfare gains from specialization, but generates inequality because production factors differ across industries and firms. This dissertation consists of two chapters that study the impacts of international trade on inequality and welfare. The first chapter studies the impacts of international trade and technical change on the skill premium through structural change. The second chapter investigates the effects of international trade on welfare and the production structure when heterogeneous firms can adopt more specialized technologies.

Chapter 1: International Trade, Structural Change and the Skill Premium

I develop a multi-country general equilibrium trade model to investigate the effects of international trade and technical change on structural change and the skill premium. In my three-sector framework, trade and technical change affect struc-

tural change by altering the household and intermediate expenditure shares for each sector. Sectors differ in their skill intensity, so that reallocation to skill intensive sectors increases the skill premium. I apply the framework to 37 countries, and the model replicates the changes in trade shares, production shares, consumption shares, and skill premium from 1997 to 2007. I find that (1) trade increased the skill premium in all countries; (2) trade and technical change each explains half of the increase in skill premium in countries where both channels contributed positively; (3) the underlying force of trade increasing the skill premium is higher foreign production efficiency rather than reductions in the trade costs. An application to the U.S. and China reveals that, for the U.S., (1) trade with China explains more than half of the decline in manufacturing share; and (2) trade and technical change together reallocate 1.6% of skilled workers out of the shrinking manufacturing sector, but only 0.2% of the unskilled workers.

Chapter 2: Intermediates Specialization and Welfare Gains from Trade (with Nuno Limão)

International trade increases the benefits to production specialization. In standard models this specialization occurs as production is re-allocated across firms with fixed technologies to explore economies of scale and comparative advantage. We examine the impact of international trade on welfare and the production structure when heterogeneous firms can adopt more specialized technologies—e.g. an assembly line using specialized inputs from other firms. In this setting, trade liberalization lowers the cost of intermediates and increases the return to specialized technologies, which implies a higher share of intermediates in trade and production—two features consistent with recent data. This firm specialization channel increases the aggregate welfare gains from trade but, under limited entry, it also decreases the income share of primary factors such as labor.

ESSAYS ON THE DISTRIBUTIONAL AND WELFARE EFFECTS OF INTERNATIONAL TRADE

by

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Foreword

The second chapter of this dissertation was co-authored with Nuno Limão at Department of Economics at University of Maryland and National Bureau of Economic Research.

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Chapter 1: International Trade, Structural Change and the Skill Premium

1.1 Introduction

Over the past 20 years, both developed and developing countries have experienced a rapid pace of globalization. Many of these countries have also experienced large increases in the skill premium, measured by the wage ratio of college graduates to non-college graduates.[1] Figure 1.1 illustrates that around two thirds of countries experienced rising skill premium from 1997 to 2007, including both advanced economies, such as the U.S. and Italy, and emerging ones, such as China and Brazil. While there has been considerable research on the role of trade and skill-biased technical change in skill premium, to date there is no conclusive evidence on their relative importance.

Another important feature of the global economy has been the substantial reallocation of economic activity across broad sectors, i.e., structural change. There have been substantial shifts from the agricultural to the manufacturing sector in developing countries, and from the manufacturing to the services sector in developed

[1]See, for example, Goldberg and Pavcnik (2007) for evidence of rising skill premium in developing countries in the 1990s.

countries. These structural changes may further increase the skill premium because skill intensity in production is the highest in services and the lowest in agriculture.

As such, I examine the roles of trade and technical change on the skill premium in the presence of structural change. Specifically, I address the following two questions. First, to what extent have recent fundamental shocks, which affect trade and technical change, impacted the skill premium across countries? Second, how are the impacts from these fundamental shocks affected by structural change across developed and developing countries?

I address these questions by first developing a multi-sector, multi-country general equilibrium trade model based on Eaton and Kortum (2002) and Caliendo and Parro (2015), augmented with elements of structural change. I divide the economy into agriculture, manufacturing, and services, where goods from all sectors are tradable. The production factors include skilled and unskilled labor as well as intermediate inputs from each sector, so that the model allows for input-output linkages. Structural change is driven by endogenous changes in expenditure shares. For households, it is due to nonhomothetic preferences, while for firms, it is through changes in expenditures on intermediate goods.

The framework allows me to perform a structural decomposition exercise to quantify the relative importance of alternative explanations, in the spirit of the accounting approach used in Eaton et al. (2016). Specifically, changes between any two periods can be fully explained by six types of country-specific shocks: (i) changes in the bilateral trade cost between each pair of trading partners in each sector, (ii) changes in each sector's production efficiency, (iii) changes in each sector's skill intensity, (iv) changes in the supply of skilled and unskilled labor, (v) changes in trade deficits, and (vi) changes in the model residuals.[2,3] After retrieving these shocks, I combine them into trade and technology shocks, which affect both within and between sectoral reallocations, so that I can quantify their relative importance on the changes in the skill premium.

I apply the framework to 37 countries from 1997 to 2007, a period when global trade values increased by more than 50%. I retrieve data on production, factor payments, consumption, and bilateral trade from four versions of the Global Trade Analysis Project (GTAP), corresponding to 1997, 2001, 2004, and 2007. In addition, I assemble data on skill premium from various sources for each sample country. Based on my framework, I use these data to estimate model parameters and retrieve the shocks on trade and technology.

The model generates a gravity equation that relates bilateral trade flows to country-sector price indices, which I obtain using an approach similar to that of Parro (2013) and Reyes-Heroles (2016). The gravity structure also allows me to recover sectoral bilateral trade costs and production efficiency. Since the supply of labor is exogenous in the framework, the shocks to the relative supply of skilled labor are adjusted to be consistent with the observed skill premium. I measure skill intensity by the cost share of skilled labor in total labor payments. Shocks to total employment and trade deficits are also obtained directly from the data.

[2] Trade deficits in my framework are exogenous because there are no capital accumulation and household saving decisions as in Eaton et al. (2016).

[3] The residual shocks include the ones from the estimation of household expenditures and intermediate expenditures as well as changes in the value added share.

The estimated sectoral prices allow for the calibration of parameters of household expenditure and a firm's intermediate expenditure, by matching the model-implied household expenditure share and firm intermediate expenditure share with the data counterparts. I employ an Almost Ideal Demand System (AIDS), which allows for changes in real income and relative sectoral prices to affect household expenditure shares across sectors.[4] Changing intermediate expenditure shares across sectors is possible by modeling a translog expenditure function for intermediates.[5]

These calibrated demand parameters and the shocks allow me to replicate the data on production share, household expenditure share, trade flows, and skill premium in 1997 and 2007. Instead of applying each shock individually to the model, I classify them into shocks on the labor supply, trade, technology, and model residuals so that I can attribute the observed changes in the skill premium to trade and technical change.

The trade shocks consist of three components. The first are bilateral trade costs. The second are shocks to country-specific trade deficits. The third is related to changes in the production efficiency of foreign countries, since in this framework foreign productivity growth affects the home country through trade only. On the technology side, I include shocks to skill intensity and home production efficiency, i.e., neutral technical change. By feeding each mutually exclusive group of shocks

[4] Fajgelbaum and Khandelwal (2016) also use AIDS to show that poor consumers gain more from trade as they consume more tradable goods, which are less income elastic.

[5] Two channels drive endogenous changes in intermediates expenditure share. First, each sector uses its own intermediates intensively, so any structural change is amplified through sectoral linkages, as in Cravino and Sotelo (2016) and Sposi (2015). Second, sectoral relative prices affect intermediates expenditure share through cross sectoral price elasticity terms in the translog specification.

separately into the model, I quantify the relative importance of trade and technical change on the changes in the skill premium. Several results emerge.

I find that both trade and technical change made significant contributions to the increases in the skill premium from 1997 to 2007. Trade increases the skill premium in all countries, with a median of 8% across countries. The effects of trade are larger in countries that experienced significant reductions in trade costs, such as China, and in those more exposed to the global economy, such as Ireland and Luxembourg. On the other hand, the average effects of technical change are smaller and very heterogenous across countries. The model interprets some countries that experienced decreases in the skill intensity within certain sectors, such as Peru, as negative effects from skill-biased technical change.

I gauge the relative importance of trade and technical change by focusing on two-thirds of countries in my sample, in which technical change increases the skill premium. I find that trade and technical change each explain half of the increases in the skill premium. Lastly, the changes in the relative supply of skilled labor increased during this period, contributing to a decrease in the skill premium.

This approach also allows for identifying trade as a quantitatively important conduit for foreign technical change to affect home skill premium. By feeding each type of trade shocks separately into the framework, I find that changes in foreign production efficiency are responsible for the positive effects of trade on the skill premium, while changes in the trade cost and deficits have negligible or negative effects. This implies that, in order to get a complete picture of the effects of trade on the skill premium, we have to consider the effects from foreign technical change.

To investigate the effects of structural change on the skill premium, I impose a Cobb-Douglas expenditure structure on households and firms.[6] The simple model is similar to the standard multi-sector general equilibrium trade model (e.g., Caliendo and Parro (2015)), into which I feed the same set of shocks and compare with the baseline to obtain the effects due to structural change. There are two main findings. First, the trade effects via foreign technical change are halved once structural change is shut down. The reason is that the shocks to sectoral production efficiency are the main driver of structural change in the model.[7] Second, structural change increases the skill premium more in developing countries relative to developed countries, as growth in own sectoral production efficiency has been larger in developing countries.

Finally, I apply the framework to study the effects of trade and technical change on sectoral reallocations in the U.S. and China from 1997 to 2007, by feeding in U.S. and China specific shocks. Specifically, the shocks include changes in the relative supply of skilled labor, skill intensity, production efficiency, and trade deficits in the U.S. and China, as well as changes in the bilateral trade cost between the two countries.

In the case of the U.S., the model predicts that trade with China explains more than half of the decline in the manufacturing production share, while increases in the production efficiency of the U.S. explain one-third of the decline. In terms of labor

[6]This implies that there are no endogenous changes in household and economy-wide intermediate expenditure shares.

[7]The result that structural change is mainly driven by changes in sectoral production efficiency is consistent with the work on structural change. See, for example, Swiecki (2014). In my framework, structural change is mainly due to the income effect from nonhomothetic preferences and the amplification effect from the intensive usage of own intermediates in each sector.

reallocations, trade and technical change reallocate 1.6% of the skilled workers out of the shrinking manufacturing to services, but only 0.2% of the unskilled workers. Therefore, I contribute to recent studies on the distributional impacts of imports from China on the U.S. local labor markets by providing a general equilibrium assessment.[8]

In the case of China, the model reveals that trade and technical change together explain almost all of the sectoral reallocations from agriculture to manufacturing. Labor reallocations are characterized by the unskilled workers moving from agriculture to manufacturing, leading to a 6.6% increase in the manufacturing employment share of the unskilled workers. These predictions are consistent with the process of structural transformation in China.[9]

My work bridges two recent research strands. The first focuses on quantifying the effects of trade and technical change on the skill premium, and the second focuses on structural change.

Most recent studies attempting to explain the impact of trade on the skill premium focus on within sector variation of skill intensity.[10] In this literature, international trade reallocates market share to the more productive and skill-intensive firms so that the demand for the skilled increases. In my framework, this channel is captured in the exogenous changes in the skill intensity within each sector. From

[8]See, for example, Autor et al. (2013, 2014) on the effects of imports from China on the U.S. labor markets.

[9]See, for example, Brandt et al. (2008) on structural transformation in China.

[10]See, for example, Burstein and Vogel (2016) for technology skill complementarity, Parro (2013) for capital skill complementarity, Verhoogen (2008) for quality upgrading in Mexico, and Bustos (2011a) for skill upgrading in Argentina.

the data below, increases in skill intensity are concentrated in the least tradable services sector, which casts doubt on the quantitative importance of this within channel. Nonetheless, incorporating this channel into my framework will strengthen the effects of trade on the skill premium, as some effects from skill-biased technical change are attributable to trade.

Methodologically, my work is related to Caron et al. (2014) and Fieler (2011), who also use nonhomothetic preferences. They explore nonhomotheticity to explain why rich countries trade more with each other, whereas I use it as a natural motive for structural change.

My work contributes to the literature on structural change by connecting it to the changes in the skill premium in an open economy setting. Buera et al. (2015) build a two-sector closed economy model and show that reallocations to the skill intensive services sector due to structural change explain around 30% of the observed increases in the skill premium in advanced economies, while the rest are due to skill-biased technical change. I complement their results by showing that trade also increases the skill premium through structural change, and most positive effects of trade on the skill premium come from productivity growth in foreign countries.

My work also relates to the literature that investigates the determinants of structural change. For example, Swiecki (2014) attributes the observed structural change to trade, sectoral technical change, nonhomothetic demand, and intersectoral wedges, while I find that technical change, sectoral linkages and nonhomothetic demand are relatively more important drivers of structural change.

Finally, Cravino and Sotelo (2016) also quantify the effects of trade-induced structural change on the skill premium. They find that, between 1995 and 2007, trade increased the skill premium by an average of 4% across countries. My work differs in several aspects. First, they only compute the effects of trade, while I separately identify the effects of trade and technical change. Doing so is important both because changes in production efficiency are the major drivers of structural change, and because the impacts of trade are reflected through changes in the foreign production efficiency, as my results highlight. The second key difference is that Cravino and Sotelo (2016) only allow for structural change from the goods to the services sector, whereas I also include the agricultural sector. Therefore, my framework captures the important structural change from agriculture to manufacturing in developing countries, which is an important source of the increases in skill premium.

The rest of this chapter is organized as follows. Section 1.2 presents the data on skill intensity and structural change. Section 1.3 builds the theoretical framework. Section 1.4 discusses the strategy to retrieve exogenous shocks and calibrate the model parameters. Section 1.5 uses the framework to conduct counterfactuals, which investigate the effects of trade and technical change on the changes in the skill premium. Section 1.6 presents an application of the model to study sectoral reallocations in the U.S. and China. Section 1.7 concludes the chapter.

1.2 A First Look at the Data

In this section, I present some aspects of the data that concern the evolution of the skill premium, skill intensity, and structural change in my sample countries from 1997 to 2007.

Figure 1.1 plots the observed changes in the skill premium in each country, measured by the changes in the ratio of wage of the college workers to the non-college workers, against log real GDP per worker. It shows that around two-thirds of the countries experienced increases in the skill premium, including both developed and developing countries. Moreover, the experiences across countries reveal a lot of heterogeneity. Some countries, such as China and Italy, have an increase in the skill premium of over 10%. Some other countries, like Chile and France, have a decrease in the skill premium of over 10%. In my framework, I will connect the observed changes in the skill premium to different shocks.

The reason that why structural change affects the skill premium is that sectors have different skill intensity. Table 1.1 presents the data on skill intensity (β^k) in each sector, measured as the share of wage payments to the skilled workers in total labor cost.[11] The left panel reveals that the services sector is most skill intensive while the agriculture sector is least skill intensive. The right panel shows that in OECD countries the services sector has the largest increase in skill intensity, while all three sectors in non-OECD countries experience increases in skill intensity. The changes in skill intensity within each sector are one of the shocks that affect the changes in skill premium.

Now I go to the data on structural change. I measure structural change by changes in the production share of each sector: $y^k = \frac{\text{value of output in sector } k}{\text{total value of output}}$. The first

[11] In the model the skilled and unskilled labor are combined with a Cobb-Douglas technology, so the skill intensity is directly measured by the cost share of the skilled labor.

three columns of Table 1.6 present the changes in production share in each sector from 1997 to 2007. In OECD countries, sectoral reallocation is from agriculture and manufacturing to services, while the pattern of structural change in non-OECD countries is from agriculture to manufacturing and services. Together with the observation that the services sector is most skill intensive and the agriculture sector is least skill intensive, structural change may increase the skill premium in all countries.

Changing household expenditure across sectors influences structural change. Table 1.2 shows the average household expenditure share on each sector. Looking at the levels in the left panel, OECD countries consume relatively more goods from services and less goods from agriculture than non-OECD countries. The changes in household expenditure share are mainly characterized by switching from agriculture to services. The upper panel of Figure 1.2 shows that the changes in household expenditure share are positively correlated with structural change. These observations indicate the role of income differences in explaining the consumption patterns across countries, if goods from services are more income elastic than agriculture. In my model, household preferences are nonhomothetic to capture this potential income effect.

Changes in firms' expenditure shares for intermediates across sectors also affect structural change. I define the intermediates expenditure share e^{kl} as the ratio of the cost of intermediates from sector l to sector k's total intermediates cost. Table 1.3 presents the average intermediates expenditure share in each sector. From the left panel, we see that each sector uses its own intermediates intensively. This implies that any change in production share is amplified through sectoral linkages. From the right panel, we see that each sector uses more skill-intensive services intermediates overtime.

What matters for structural change is the changes in average intermediate expenditure share for each sector e^k, defined as $e^k = y^A e^{Ak} + y^M e^{Mk} + y^S e^{Sk}$. The lower panel of Figure 1.2 illustrates that the changes in average intermediate expenditure share are highly positively correlated with structural change in each sector.

To capture the rich input-output linkages that are important for structural change, total intermediates expenditure is translog and sector specific, to incorporate both the intensive usage of own sector intermediates and to allow relative sectoral prices to influence the sectoral intermediates expenditure share.

1.3 Model

The static trade model is based on Eaton and Kortum (2002) and Caliendo and Parro (2015). The world economy has $n = 1, \ldots, N$ countries, each with three tradable sectors: agriculture (A), manufacturing (M), and services (S). Let $\Omega = \{A, M, S\}$ denotes the set of all sectors. Country n is endowed with U_n units of unskilled labor, and S_n units of skilled labor.

Output in each sector is a CES aggregate (with constant elasticity of substitution σ) of the outputs of a unit continuum of goods (different across each sector) indexed by $j \in [0, 1]$. Country n's efficiency $z_n^k(j)$ at making good j in sector k is the realization of a random variable z_n^k distributed as:

$$F_n^k(z) = \mathbf{Pr}(z_n^k \leq z) = \exp\left(-T_n^k z^{-\theta^k}\right), \tag{1.1}$$

drawn independently across each good j in country n. Here, T_n^k reflects the overall production efficiency in country n sector k, and the parameter θ^k is an inverse measure of the dispersion of productivities.

Households consume outputs from all sectors with a preference structure of the Almost Ideal Demand System (AIDS). Production of good j in each sector combines the services of each type of labor and intermediates from each of the three sectors. Technology is such that the intermediates from each sector are aggregated into a composite intermediates bundle with translog technology, and the composite bundle is further combined with two labor inputs following a Cobb-Douglas technology with constant returns to scale.

Trade in the outputs of the three sectors incurs standard iceberg costs, such that delivering one unit of output from country i to country n requires $\kappa_{ni}^k \geq 1$ units, with $\kappa_{nn}^k = 1$. Taking into account the ad valorem tariff rate $\tau_{ni}^k \geq 0$, the trade cost from country i to country n is $d_{ni}^k = \left(1 + \tau_{ni}^k\right) \kappa_{ni}^k$.[12]

1.3.1 Preferences

The preference of household h in country n is AIDS, as in Fajgelbaum and Khandelwal (2016). The preference is defined by expenditure share on goods from

[12] There is no tariff in the services sector, so $\tau_{ni}^S = 0$.

each sector, $s_n^k(h)$:

$$s_n^k(h) = \alpha_k + \delta_{kA} \ln P_n^A + \delta_{kM} \ln P_n^M + \delta_{kS} \ln P_n^S + b_k \ln\left(\frac{I_n(h)}{P_n}\right) \quad k \in \Omega,$$

where $I_n(h)$ is household h's income and P_n^k is sectoral price level. The overall price level P_n is of the translog form:

$$\ln P_n = \sum_{k\in\Omega} \alpha_k \ln P_n^k + \frac{1}{2} \sum_{k\in\Omega} \sum_{l\in\Omega} \delta_{kl} \ln P_n^k \ln P_n^l.$$

I restrict $\sum_{k\in\Omega} \alpha_k = 1$, $\sum_{k\in\Omega} \delta_{kl} = 0$, $\sum_{k\in\Omega} b_k = 0$ so that the expenditure shares add up to 1. In addition, $\sum_{l\in\Omega} \delta_{kl} = 0$ and $\delta_{kl} = \delta_{lk}$ correspond to the homogeneity and symmetry assumptions, so the AIDS is well defined.

Notice here that the substitution patterns between sectors are translog, so that it is more flexible than the usual CES considered in the structural change literature. If the income elasticity of demand $b_k \neq 0$, preferences are nonhomothetic. In sum, the AIDS specification captures complementarity across sectors and nonhomotheticity, both of which are important in explaining structural change from the side of household demand.

1.3.1.1 Aggregation

The AIDS is easily aggregated to the economy level household expenditure share s_n^k:

$$s_n^k = \alpha_k + \delta_{kA} \ln P_n^A + \delta_{kM} \ln P_n^M + \delta_{kS} \ln P_n^S + b_k \left[Th_n + \ln\left(\frac{\bar{I}_n}{P_n}\right)\right] \quad k \in \Omega, \quad (1.2)$$

where $\bar{I}_n$ is the average income of consumers in each country, and Th_n is the Theil index of inequality.[13] Note that the preferences are the same across the countries, but the expenditure shares are different because real income per capita, the Theil index and the relative prices vary. In the quantitative exercises I use those variations in the data to estimate the parameters of the demand system.

1.3.2 Technology

1.3.2.1 Composite Intermediates Bundle

In each sector, intermediates from different sectors are combined with a translog technology. The price of the composite intermediates bundle is:

$$r_n^k = \sum_{l \in \Omega} \gamma_n^{kl} \ln P_n^l + \frac{1}{2} \sum_{l \in \Omega} \sum_{m \in \Omega} \eta_{lm}^k \ln P_n^l \ln P_n^m, \tag{1.3}$$

with the restrictions $\sum_{l \in \Omega} \gamma_n^{kl} = 1$, $\sum_{l \in \Omega} \eta_{lm}^k = 0$, $\sum_{m \in \Omega} \eta_{lm}^k = 0$, and $\eta_{lm}^k = \eta_{ml}^k$ so that the translog cost function is well defined. The share of intermediates from sector l in sector k's total intermediates spending is:

$$e_n^{kl} = \gamma_n^{kl} + \sum_{m \in \Omega} \eta_{lm}^k \ln P_n^m \tag{1.4}$$

for $k, l \in \Omega$. The intermediates expenditure share differs across sectors, as the constant terms γ_n^{kl}, and the price elasticities η_{lm}^k are sector specific. Notice that if all the price elasticities equal to zero, the intermediates expenditure shares are constant, which corresponds to a Cobb-Douglas technology.

[13] See Deaton and Muellbauer (1980).

1.3.2.2 Firm's Problem

The firm producing good j in country n sector k solves the following cost minimization problem:

$$\min \ c_n^k(j) = w_n^u l_u + w_n^s l_s + r_n^k M_n^k \quad \text{s.t.} \quad z_n^k(j) \left[l_u^{1-\beta_n^k} l_s^{\beta_n^k} \right]^{v_n^k} \left(M_n^k \right)^{1-v_n^k} \geq 1,$$

where l_u, l_s, and M_n^k are the demand for unskilled labor, skilled labor, and composite intermediates bundle, respectively, v_n^k is the value added share, and w_n^u, w_n^s are the wages paid to the unskilled and skilled labor, respectively.

Perfect competition implies that the price of good j in country n sector k is:

$$p_n^k(j) = \min \left\{ p_{ni}^k(j) : \ i = 1, \ldots, N \right\},$$

where $p_{ni}^k(j) = c_i^k(j) d_{ni}^k$ is the price charged by a firm in country i shipping to country n.

1.3.3 Equilibrium Relationships

In this section, I list the equilibrium outcomes of the model that I will later take to the data.

1.3.3.1 Prices and Trade Shares

From the firm's cost minimization problem, the unit cost c_n^k of producing in country n sector k, combining labor and composite intermediates bundle is:

$$c_n^k = \left[\left(\frac{1}{v_n^k} \right)^{v_n^k} \left(\frac{1}{1 - v_n^k} \right)^{1-v_n^k} \right] \left[\left(\frac{w_n^u}{1 - \beta_n^k} \right)^{1-\beta_n^k} \left(\frac{w_n^s}{\beta_n^k} \right)^{\beta_n^k} \right]^{v_n^k} \left(r_n^k \right)^{1-v_n^k}, \tag{1.5}$$

where r_n^k is given by (1.3), and the price level in country n sector k, after combining production costs in each country, is:

$$P_n^k = \epsilon_k \left[\sum_{l=1}^{N} T_l^k \left(c_l^k d_{nl}^k \right)^{-\theta^k} \right]^{-\frac{1}{\theta^k}}, \tag{1.6}$$

where $\epsilon_k = \left[\Gamma \left(\frac{\theta^k + 1 - \sigma}{\theta^k} \right) \right]^{\frac{1}{1-\sigma}}$, and $\Gamma(\cdot)$ is the Gamma function.

The share of spending in country n sector k that goes to goods imported from country i is:

$$\pi_{ni}^k = \frac{X_{ni}^k}{X_n^k} = \frac{T_i^k \left(c_i^k d_{ni}^k \right)^{-\theta^k}}{\Phi_n^k}, \tag{1.7}$$

where $\Phi_n^k = \sum_{l=1}^{N} T_l^k \left(c_l^k d_{nl}^k \right)^{-\theta^k}$ is the multilateral resistance term.

1.3.3.2 Market Clearing

Denote X_n^k as the value of country n's total spending on sector k, and Y_n^k as the value of gross production. World goods market clearing implies that:

$$Y_n^k = \sum_{i=1}^{N} \frac{\pi_{in}^k}{1 + \tau_{in}^k} X_i^k. \tag{1.8}$$

Using (1.2) and (1.4), total spending on goods from sector k is the sum of household spending on sector k plus the use of sector k's output as intermediates in sector l:

$$X_n^k = s_n^k I_n + \sum_{l \in \Omega} (1 - v_n^l) e_n^{lk} Y_n^l, \tag{1.9}$$

where $I_n = w_n^u U_n + w_n^s S_n + D_n + \sum_{l \in \Omega} X_n^l \left(1 - \sum_{i=1}^{N} \frac{\pi_{ni}^l}{1 + \tau_{ni}^l} \right)$ is the total income of households in country n, consisting of wage payments $w_n^u U_n + w_n^s S_n$, trade deficits D_n, and tariff revenue $\sum_{l \in \Omega} X_n^l \left(1 - \sum_{i=1}^{N} \frac{\pi_{ni}^l}{1 + \tau_{ni}^l} \right)$.

Clearing in the competitive market for each type of labor implies that total labor income equals labor demand across sectors:

$$\begin{aligned} w_n^u U_n &= \sum_{k \in \Omega} (1 - \beta_n^k) v_n^k Y_n^k, \\ w_n^s S_n &= \sum_{k \in \Omega} \beta_n^k v_n^k Y_n^k. \end{aligned} \tag{1.10}$$

Finally, gross production plus trade deficits and tariff revenue equals total spending in each country:

$$\sum_{k \in \Omega} \left[Y_n^k + X_n^k \left(1 - \sum_{i=1}^{N} \frac{\pi_{ni}^k}{1 + \tau_{ni}^k} \right) \right] + D_n = \sum_{k \in \Omega} X_n^k. \tag{1.11}$$

As the model is static, trade deficits are just exogenous transfers between countries.[14]

1.3.4 The Exogenous Variables

For the purpose of the quantitative exercises, I divide exogenous variables of the model into constant parameters Θ and one time shocks Ψ:

$$\Theta = \{\alpha_k, \delta_{kl}, b_k, \gamma_n^{kl}, \eta_{lm}^k, \theta^k\} \quad \text{and} \quad \Psi = \{\kappa_{ni}^k, \tau_{ni}^k, T_n^k, \beta_n^k, v_n^k, U_n, S_n, D_n\},$$

for $k, l, m \in \Omega$, and $n, i = 1 \ldots N$. Equations (1.2) through (1.11) determine the endogenous variables, which include wages w_n^u, w_n^s, prices of intermediates bundle r_n^k, prices P_n^k, trade shares π_{ni}^k, household expenditure shares s_n^k, total spending X_n^k, output Y_n^k for sectors $k \in \Omega$, and intermediates expenditure shares e_n^{kl} for $k, l \in \Omega$.

Shocks in the framework affect structural change through their effects on sectoral prices and the real income, which in turn affect household expenditure shares

[14] When solving the model, I normalize the total world expenditure $\sum_{n=1}^{N} X_n = 1$. Trade deficits are then regarded as a constant share of total world expenditure that satisfies $\sum_{n=1}^{N} D_n = 0$.

and intermediates expenditure shares according to (1.2) and (1.4). In addition, sectoral linkages amplify the structural change due to intensive usage of own sector intermediates.

1.3.5 Connecting Shocks to the Skill Premium

In my framework, shocks affect the skill premium through four channels.

The first channel relates to the shock to skill intensity β_n^k. A larger β_n^k implies that the sector becomes more skill intensive in production, so that the relative demand for the skilled labor increases. It can be interpreted as skill-biased technical change (SBTC). The changes in β_n^k are *exogenous* to other types of shocks in the model.

The second channel comes from the shock to skill abundance $\frac{S_n}{L_n}$. An increase in the relative supply of the skilled labor $\frac{S_n}{L_n}$ decreases the skill premium.

The third channel is based on the Hechscher-Ohlin theory. Countries that are skill abundant (with high $\frac{S_n}{L_n}$) tend to be net exporters in the skill-intensive services sector, so trade increases the skill premium. On the other hand, countries that are skill scarce are likely to be net exporters in the skill-unintensive agriculture sector, so trade decreases the skill premium in these countries. Changes in trade costs $\{\kappa_{ni}^k, \tau_{ni}^k\}$, trade deficits D_n, sectoral production efficiency T_n^k, and skill abundance $\frac{S_n}{L_n}$ affect the magnitude of the Hechscher-Ohlin force.

The final channel relates to the endogenous changes in household and intermediates expenditure shares, which affect structural change directly.[15] Structural change is mainly due to shocks to sectoral production efficiency. Home technical change affects structural change in the domestic economy directly. Foreign technical change affects structural change in foreign countries, which in turn affects the home country through trade.

The effects of all shocks on the skill premium depends on the strength of each of the four channels.

1.3.6 Structural Change and the Skill Premium

How do trade and technical change affect the skill premium through structural change? In this subsection, I make some simplifying assumptions to study the effects of structural change on the skill premium. I assume that there are two countries, $N = 2$; two sectors, $k = a, b$, and sector b is the skill-intensive ($\beta_n^b > \beta_n^a$) and income-elastic ($b_b > 0 > b_a$) sector; and that the value added share is the same across sectors and countries, $v_n^k = v$. Details are provided in Appendix A.3.

With the simplifying assumptions, the equilibrium skill premium can be written as:

$$\frac{w_n^s}{w_n^u} = \frac{U_n - FCT_n(U)}{S_n - FCT_n(S)} \frac{\sum_{k=\{a,b\}} \beta_n^k \left[v s_n^k + (1-v) e_n^k \right]}{\sum_{k=\{a,b\}} (1-\beta_n^k) \left[v s_n^k + (1-v) e_n^k \right]}, \tag{1.12}$$

where $e_n^k = y_n^a e_n^{ak} + y_n^b e_n^{bk}$ is the average intermediates expenditure share on sector k, y_n^k is the production share of sector k, and $FCT_n(l) = \sum_{k=\{a,b\}} l_n^k \omega_n^k$, $l = U, S$ is the factor content of trade, with $\omega_n^k = \frac{X_{-nn}^k - X_{n-n}^k}{X_{-nn}^k + X_{nn}^k}$. If a country has a comparative

[15] Hechscher-Ohlin force relies on sectoral reallocation, and therefore it is also one channel that affects structural change.

advantage in skill-intensive sector b, then the country is a net exporter of the skilled labor ($FCT_n(S) > 0$) and a net importer of the unskilled labor ($FCT_n(U) < 0$). Therefore, international trade raises the skill premium in a country with a comparative advantage in the skill-intensive sector and decreases the skill premium in a country with comparative disadvantage in the skill-intensive sector.

Structural change at foreign country $-n$ also affects the factor content of trade at home. Given the same trade shares, if foreign households and firms have larger expenditure shares on goods from skill-intensive sector b, the home country is more likely to be a net exporter in sector b. Therefore, changes in factor content of trade of the skilled at home is positive ($\Delta FCT_n(S) > 0$), while the changes in the factor content of trade of the unskilled is negative ($\Delta FCT_n(U) < 0$), leading to an increase in the skill premium at home.

The second part on the right-hand side of (1.12) captures the effects of structural change at home on the skill premium. It includes the changes in expenditure shares due to both households and firms. As the changes in numerator and denominator are opposite in sign, I only investigate the changes in numerator (Num):

$$Num_n = \underbrace{v \sum_{k=\{a,b\}} \beta_n^k s_n^k}_{\text{consumer}} + \underbrace{(1-v) \sum_{k=\{a,b\}} \beta_n^k e_n^k}_{\text{firm}} .$$

On the side of the households:

$$\sum_{k=\{a,b\}} \beta_n^k s_n^k = \left(\beta_n^b - \beta_n^a\right) \Delta s_n^b, \tag{1.13}$$

where $\Delta s_n^k = \left(s_n^k\right)' - s_n^k$ is the difference in the household expenditure share between two periods. Over time, households demand relatively more sector b goods due to gains from trade or technology progress if preferences are nonhomothetic. This in turn implies that $\Delta s_n^b > 0$, which increases the skill premium.

I further decompose the expression on the side of firms into three parts:

$$\sum_{k=\{a,b\}} \beta_n^k e_n^k = \left(\beta_n^b - \beta_n^a\right) \Delta e_n^b$$
$$= \left(\beta_n^b - \beta_n^a\right) \left[\underbrace{\left(e_n^{aa} + e_n^{bb} - 1\right) \Delta y_n^b}_{\text{between-sector}} + \underbrace{\left(y_n^b \Delta e_n^{bb} - y_n^a \Delta e_n^{aa}\right)}_{\text{within-sector}} + \underbrace{\left(\Delta e_n^{aa} + \Delta e_n^{bb}\right) \Delta y_n^b}_{\text{interaction}} \right]. \tag{1.14}$$

The between-sector component is non-zero when the intermediates expenditure share differs across sectors.[16] If each sector uses its own intermediates intensively ($e_n^{aa}, e_n^{bb} > 1$), reallocation to skill-intensive sector b ($\Delta y_n^b > 0$) increases the skill premium. The within-sector component is active when changes in the intermediates expenditure share are non-zero within each sector. If each sector uses more skill-intensive intermediates over time ($\Delta e_n^{aa} < 0$ and $\Delta e_n^{bb} > 0$), the skill premium increases. The sign of the interaction term is in general ambiguous, and depends on which sector has the larger changes in the intermediates expenditure share.

1.4 Taking the Model to the Data

In this section, I estimate the parameters of the model and back out the shocks. I use data mainly from Global Trade Analysis Project (GTAP) versions 5 to 8, corresponding to the years 1997, 2001, 2004, and 2007, to 38 countries including the rest of the world (ROW). I use data on total expenditure $X_n^k(t)$, output $Y_n^k(t)$,

[16] By definition, $e_n^{ka} + e_n^{kb} = 1$. If different sectors use the same inputs, $e_n^{aa} = e_n^{ba}$ and $e_n^{ab} = e_n^{bb}$, such that $e_n^{aa} + e_n^{bb} = 1$.

and bilateral trade flows $X_{ni}^k(t)$ to compute production shares y_n^k and trade shares π_{ni}^k for $k \in \Omega$.[17] I take total employment $L_n(t)$ from the Penn World Tables 8.1 and the skill premium $\frac{w_n^s}{w_n^u}(t)$ from various sources. Details on how I assemble the data are provided in Appendix A.2.

The procedure of quantification involves two major steps. In the first step, I retrieve sectoral prices P_n^k from the model-implied gravity equation on trade flows. Armed with sectoral prices and other observables from the data, I estimate the demand parameters $\Theta_d = \{\alpha_k, \delta_{kl}, b_k, \gamma_n^{kl}, \eta_{lm}^k\}$ and back out the shocks Ψ. In the end, the model replicates the trade share, production share, consumption share, and skill premium in each country in 1997 and 2007.

1.4.1 Sectoral Prices

In this section I show how to get sectoral prices by estimating a model-implied gravity equation. More precisely, I identify sectoral prices relative to a base country (ROW) from the estimates of country fixed effects in the gravity equation.[18]

Starting from (1.7), dividing the trade share from country i to country n by country n's own share and taking logs, I get:

$$\ln\left(\frac{\pi_{ni}^k}{\pi_{nn}^k}\right) = \ln\left[T_i^k\left(c_i^k\right)^{-\theta^k}\right] - \ln\left[T_n^k\left(c_n^k\right)^{-\theta^k}\right] - \theta^k \ln d_{ni}^k, \tag{1.15}$$

where $d_{ni}^k = \left(1+\tau_{ni}^k\right)\kappa_{ni}^k$. As the iceberg cost κ_{ni}^k is unknown, I further parameterize it as $\kappa_{ni}^k = \bar{\kappa}_{ni}^k\zeta_{ni}^k$, where $\bar{\kappa}_{ni}^k = \bar{\kappa}_{in}^k$ is the symmetric part of the iceberg cost. I pin

[17] Specifically, $y_n^k = \frac{Y_n^k}{\sum_{l\in\Omega} Y_n^l}$ and $\pi_{ni}^k = \frac{X_{ni}^k}{X_n^k}$.

[18] The procedure I employ is similar to that used by Parro (2013) and Reyes-Heroles (2016).

down the symmetric iceberg cost $\bar{\kappa}^k_{ni}$ by adding to (1.15) the trade flow in the opposite direction $\ln\left(\frac{\pi^k_{in}}{\pi^k_{ii}}\right)$, with the assumption of no asymmetry in iceberg cost ($\zeta^k_{ni} = \zeta^k_{in} = 1$). This implies that

$$\bar{\kappa}^k_{ni} = \left(\frac{\pi^k_{ni}}{\pi^k_{ii}}\frac{\pi^k_{in}}{\pi^k_{nn}}\right)^{-\frac{1}{2\theta^k}} \left[(1+\tau^k_{ni})(1+\tau^k_{in})\right]^{-\frac{1}{2}}.$$

The only unknown parameter here is the trade elasticity θ^k, which I set as $\theta^k = 4$ for $k \in \Omega$ from the estimates of Simonovska and Waugh (2014a).[19]

Moving the part of the trade costs that is known, which includes tariff $\left(1+\tau^k_{ni}\right)$ and symmetric iceberg cost $\bar{\kappa}^k_{ni}$, to the left-hand side of (1.15), I obtain the equation to estimate:

$$\ln\left[\left(\frac{\pi^k_{ni}}{\pi^k_{in}}\frac{\pi^k_{ii}}{\pi^k_{nn}}\right)^{-\frac{1}{2\theta^k}} \left(\frac{1+\tau^k_{ni}}{1+\tau^k_{in}}\right)^{-\frac{1}{2}}\right] = \underbrace{\ln\left[\left(T^k_i\right)^{-\frac{1}{\theta^k}} c^k_i\right]}_{\text{exporter fixed effect}} - \underbrace{\ln\left[\left(T^k_n\right)^{-\frac{1}{\theta^k}} c^k_n\right]}_{\text{importer fixed effect}} + \underbrace{\ln \zeta^k_{ni}}_{\text{residual}}. \tag{1.16}$$

Everything on the left hand side of (1.16) is either taken from the data or assigned, and I estimate (1.16) by OLS for each year sector.

The sectoral relative price P^k_n for each year is identified from either the importer or exporter fixed effects $S^k_n = \left(T^k_n\right)^{-\frac{1}{\theta^k}} c^k_n$:

$$P^k_n = \frac{\epsilon_k S^k_n}{\left(\pi^k_{nn}\right)^{-\frac{1}{\theta^k}}}. \tag{1.17}$$

1.4.2 Backing out Shocks

With the equilibrium conditions (1.2) through (1.11) and data on endogenous variables $\{y^k_n, \frac{w^s_n}{w^u_n}, \pi^k_{ni}, P^k_n\}$, I can back out the following shocks without knowing the

[19] I also use $\theta^k = 3$ and $\theta^k = 5$ to check whether my results are affected.

equilibrium wages:

1. Equations (1.6) and (1.7), as it applies to $n \neq i$ relative to $n = i$, give me trade costs d_{ni}^k:
$$d_{ni}^k = \left(\frac{\pi_{ni}^k}{\pi_{ii}^k}\right)^{-\frac{1}{\theta^k}} \frac{P_n^k}{P_i^k}. \tag{1.18}$$
With data on tariffs τ_{ni}^k, iceberg costs $\kappa_{ni}^k = \frac{d_{ni}^k}{1+\tau_{ni}^k}$.[20]

2. I compute the value added shares v_n^k directly from the data, measured as the ratio of total labor payments to total production costs.

3. I compute the skill intensity β_n^k directly from the data, measured as the ratio of payments to the skill labor to total labor payments.

4. I compute the total labor force L_n directly from the data on total employment in country n.

5. Dividing the two expressions in (1.10), I retrieve the relative supply of the skilled labor given data on the skill premium $\frac{w_n^s}{w_n^u}$:
$$\frac{S_n}{U_n} = \frac{\sum_{k\in\Omega} \beta_n^k v_n^k y_n^k}{\sum_{k\in\Omega}(1-\beta_n^k) v_n^k y_n^k} \left(\frac{w_n^u}{w_n^s}\right). \tag{1.19}$$
Together with the values on L_n, I know the S_n and U_n levels.

6. I compute trade deficits D_n directly from the data.

To back out sectoral production efficiency T_n^k and estimate demand parameters Θ_d require the values of equilibrium wages w_n^u and w_n^s. This can be done by first

[20] An alternative way to recover the trade costs is to use the bilateral residuals ζ_{ni}^k from (1.16) so that $d_{ni}^k = \left(1+\tau_{ni}^k\right)\bar{\kappa}_{ni}^k \zeta_{ni}^k$. These two methods give the same trade costs.

using (1.8) and (1.11) to solve for equilibrium outputs Y_n^k and then solving for the wages using (1.9) and (1.19).

To back out sectoral production efficiency, I calculate the equilibrium values of the unit cost c_n^k from (1.5) and use expression (1.7) with $n = i$:

$$T_n^k = \left(\frac{P_n^k}{\epsilon_k c_n^k} \right)^{-\theta^k}. \tag{1.20}$$

1.4.3 Demand Parameters

I estimate the AIDS parameters $\{\alpha_k, \delta_{kl}, b_k\}$ by minimizing the distance between the model-implied household expenditure shares $\tilde{s}_n^k(t)$ from (1.2) and the expenditure shares from the data $s_n^k(t)$:

$$\{\alpha_k, \delta_{kl}, b_k\} = \text{argmin} \sum_{k\in\Omega} \sum_{n=1}^{N} \sum_{t} \left[s_n^k(t) - \tilde{s}_n^k(t) \right]^2.$$

Similarly, I estimate the translog intermediates cost parameters $\{\gamma_n^{kl}, \eta_{lm}^k\}$ by minimizing the distance between the model-implied intermediates expenditure shares $\tilde{e}_n^{kl}(t)$ from (1.4) and the respective shares from the data $e_n^{kl}(t)$ sector by sector:

$$\{\gamma_n^{kl}, \eta_{lm}^k\} = \text{argmin} \sum_{l\in\Omega} \sum_{n=1}^{N} \sum_{t} \left[e_n^{kl}(t) - \tilde{e}_n^{kl}(t) \right]^2, \quad k \in \Omega.$$

To match household expenditure shares in the data, I regard the residuals from the estimation of AIDS as another shock, which I call the preference shifters:

$$a_n^k(t) = s_n^k(t) - \tilde{s}_n^k(t), \quad k \in \Omega,\ n = 1, \ldots, N. \tag{1.21}$$

For the model to match production shares and therefore structural changes in the data, the model-implied intermediates expenditure shares have to be internally consistent with the aggregate intermediates expenditure share $e_n^k(t)$ implied by (1.9).[21] I match production shares by finding input shifters $g_n^{kl}(t)$, which minimizes the distance to the residuals from the estimation of intermediates cost parameters in each year sector:

$$g_n^{kl}(t) = \text{argmin} \sum_{l\in\Omega} \sum_{n=1}^{N} \left[e_n^{kl}(t) - \tilde{e}_n^{kl}(t) - g_n^{kl}(t) \right]^2, \tag{1.22}$$

subject to

$$\frac{\sum_{l=\in\Omega} \left[1 - v_n^l(t)\right] \left[\tilde{e}_n^{lk}(t) + g_n^{lk}(t)\right] Y_n^l(t)}{\sum_{l\in\Omega} \left[1 - v_n^l(t)\right] Y_n^l(t)} = e_n^k(t) \quad \text{and} \quad \sum_l g_n^{kl}(t) = 0,$$

where the first restriction ensures that the model matches the production shares in the data.[22]

The procedure delivers the constant parameters Θ and one time shocks $\Psi = \{\kappa_{ni}^k, \tau_{ni}^k, T_n^k, \beta_n^k, v_n^k, U_n, S_n, D_n, a_n^k, g_n^{kl}\}$ of the baseline model. By construction, the solution to the baseline model matches the trade shares π_{ni}^k, household expenditure shares s_n^k, production shares y_n^k, and skill premium $\frac{w_n^s}{w_n^u}$ in both the initial (1997) and the end (2007) equilibria.

1.4.4 Values of Exogenous Parameters

Table 1.4 and Table 1.5 summarize the baseline demand parameters.

For the AIDS parameters in Table 1.4, the values of income elasticities b_k indicate that goods from the agriculture sector are necessities, while goods from the services sector are luxuries. The estimates of income elasticities are consistent with the

[21] $e_n^k(t) = \frac{X_n^k(t) - s_n^k(t) I_n(t)}{\sum_{l\in\Omega}[1-v_n^l(t)] Y_n^l(t)}$.

[22] Simply matching the intermediates expenditure shares in the data does not work, as I do not have factors such as capital and land in the model.

estimates from the structural change literature, which find services to be the luxury sector. The estimates of price elasticities δ_{kl} reveal that goods from the agriculture and services sectors are in general complements to other sectors ($\delta_{AA}, \delta_{SS} > 0$), while goods from the manufacturing sector are substitutes ($\delta_{MM} < 0$). The estimates here are consistent with the final expenditure approach in Herrendorf et al. (2013), who find that substitutability between sectors is close to a Cobb-Douglas utility.

Table 1.5 presents the estimates on the price elasticities of the translog intermediates cost function. In general, intermediates from all sectors are complements to each other in the agriculture sector and substitutes to each other in the manufacturing and services sector.

Table 1.7 summarizes the baseline shocks. I report the cumulative changes in the shocks for each country and sector between 1997 and 2007.

The first three columns in Table 1.7 summarize the average changes in trade costs. I report the trade volume weighted trade costs for each country, as well as the average trade costs in OECD and non-OECD countries. The first observation is that the reductions in trade costs are larger in non-OECD countries, especially in the manufacturing sector. It is also interesting to note that there are significant reductions in the trade costs of the services sector. Given that the services sector often has the largest production share in each country, especially in the OECD countries, the effects of trade may be larger than trade models in which services are regarded as non-tradable.

The next three columns in Table 1.7 present the relative changes in average sectoral productivities $\left(\hat{T}_n^M\right)^{\frac{1}{\theta}}$. Again, productivity growth is much larger in non-OECD countries, especially in the manufacturing sector. As sectoral productivity growth is found to be the most important driver of structural change in the literature, the impacts of structural change on the skill premium is likely to be larger in non-OECD countries.

For the skill-biased technical change in the next three columns of Table 1.7, we see that most of the increases in skill intensity happened in the services sector. As OECD countries have larger production shares in the services sector, the impacts of skill-biased technical change on the skill premium is likely to be relatively more important than in non-OECD countries.

Finally, the last column of Table 1.7 shows the changes in the relative supply of skilled labor. On average, the share of the skilled labor increases, implying downward pressure on the skill premium.

1.4.5 External Validation

The model replicates the trade shares, production shares, consumption shares, and skill premium in the data, so I assess the fit of the model by using external data to verify some of the shocks I back out.

1.4.5.1 Labor Productivity

The first validation exercise tests whether labor productivity in the model reflects the true values in the data. Figure 1.3 plots labor productivity in the model against TFP in the data.[23] Labor productivity in each country is a production share weighted average of sectoral labor productivity. Sectoral labor productivity takes into account the effect of trade and is calculated as $\text{LP}_n^k = \frac{c_n^k}{P_n^k}$.[24] The plots show that labor productivity in each country correlates well with TFP in both years. Figure 1.4 also shows that the log changes in labor productivity correlates reasonably well with log changes in TFP.

1.4.5.2 Share of the Skilled Labor

The second exercise verifies the share of the skilled labor $\frac{S_n}{L_n}$ in each country. Figure 1.5 plots the model-implied $\frac{S_n}{L_n}$ against the share of populations with incomplete tertiary degree taken from Barro and Lee (2013).[25] The fit is reasonable with R^2 over 0.2 for both years, but the model over-estimates the share of the skilled labor for most countries. Figure 1.6 presents the model-implied changes in $\frac{S_n}{L_n}$ against the corresponding changes in the Barro and Lee (2013) measure. The slope is positive when I take into account the outliers.[26]

One reason of the coarse fit is that the skilled labor in developed countries may be of higher quality than their counterparts in developing countries. If this is the case, the share of the skilled labor I back out also reflects the quality of the

[23] I compute TFP directly from PWT 8.1 as the TFP valued at current PPPs in the corresponding years.

[24] See Finicelli et al. (2013) for detail.

[25] As data from Barro and Lee (2013) is at 5-year intervals, I compare the model-implied share in 2007 to the data in 2005, and the model share in 1997 to the data in 1995.

[26] I drop 7 countries where the deviations from the changes in the data are at least 8 percentage points.

labor force.[27] To check whether this is the case, Figure 1.7 plots the model-implied share against the TFP-adjusted data share: TFP $\times \frac{S_n}{L_n}$(data). There is a large improvement in the fit, as indicated by an increase in the R^2. The changes in the model-implied share also see a large improvement in the fit from Figure 1.8.

Finally, I regress the model-implied share of the skilled labor on observables, which help explain cross country differences in educational attainment. Restuccia and Vandenbroucke (2014) find that variations in TFP and life expectancy explain most of the differences in educational attainment across countries and over time. Therefore, I regress the model-implied share on TFP, life expectancy, and the share of government expenditure on education as a percentage of GDP to assess the model fit. Table 1.8 presents the regression results. The first observation is that for the model-implied share, all three observables are of the correct sign and the R-squares are over 0.5 in both years. Moreover, the data measure from Barro and Lee (2013) does not fit well as the model-implied share, indicating that the model share may reflect the quality difference of the skilled labor.

In sum, the validation exercises above show that the shocks on the share of the skilled labor are reasonable.

[27]Another interpretation is that the same college graduate is more productive in rich countries, as rich countries have larger capital stock.

1.4.5.3 Trade Cost

I verify the validity of the bilateral trade cost I back out by regressing it on common determinants of trade cost.[28] The observables include tariffs, log distance, and the dummy variables such as contiguity (=1 if two countries share the border), common language (=1 if two countries speak the same official language), non-reciprocal preferential trade agreements (=1 if two countries have a NRPTA), reciprocal preferential trade agreements (=1 if two countries have a RPTA), and trade agreements (=1 if two countries either are in the same currency or economic union, or in the same free trade agreement).

The left panel of Table 1.9 presents the regression results on levels of trade cost for each sector in year 1997 and 2007. The first observation is that all the coefficients on tariffs and distance are of the correct sign and statistically significant, except the tariff coefficient on agriculture in 2007. Second, all of the coefficients on contiguity and common language are negative and statistically significant, except the common language coefficient on services in 2007. In sum, the level of trade cost I back out is reasonable as it correlates well with the common determinants of trade cost.[29]

The right panel of Table 1.9 presents the regression results on changes in trade costs. Log distance is interacted with the changes in world crude oil price so that the coefficient is identified. The first observation is that the distance coefficient is

[28] As almost all country pairs in my sample have bilateral trade flows, there is no problem of zero trade flows.

[29] The exception is that some of the coefficients on the TA dummy imply higher trade costs. These may reflect an endogeneity bias since TAs are correlated with bilateral unobserved characteristics (e.g., Limão (2016)), which I can't control for in levels.

of the correct sign and statistically significant. The fit is particularly good for the changes in trade costs in the services sector, with all coefficients of the correct sign and a large R^2. In sum, the changes in trade costs are also reasonable.

1.4.6 Classifying Shocks

In this section I classify shocks Ψ into trade shocks, technology shocks, labor supply shocks, and model residuals.

For a home country n, any shocks outside country n affect the home country through trade only. These shocks include the trade cost shocks $\{\hat{\kappa}_{mi}^k, \hat{\tau}_{mi}^k\}$, shocks to trade deficits $\hat{D}_n$, and shocks to foreign sectoral production efficiency $\hat{T}_{-n}^k$, which corresponds to the definition of foreign shocks in Arkolakis et al. (2012).[30] The technology shocks at home include shocks to home production efficiency $\hat{T}_n^k$ as well as skill-biased technical change $\Delta\beta_n^k$. The shocks to home sectoral production efficiency $\hat{T}_n^k$ can be regarded as neutral technical change (NTC). I classify the shocks as follows:

1. Trade shocks consist of
   - trade cost shocks: $\{\hat{\kappa}_{mi}^k, \hat{\tau}_{mi}^k\}$,
   - trade deficits shocks: ΔD_n,
   - foreign technology shocks: $\hat{T}_{-n}^k$;
2. Technology shocks consist of:

[30] I focus on shocks that affect trade directly to study the first order effect. Other shocks, such as skill-biased technical change $\Delta\beta_{-n}^k$, affect trade flows indirectly through their effects on the unit cost c_n^k.

- skill-biased technical change: $\Delta\beta_n^k$,
- neutral technical change: $\hat{T}_n^k$;

3. Labor supply shocks: $\{\hat{L}_n, \hat{S}_n, \hat{U}_n\}$;
4. Model residuals consist of the changes in:

- value added share: Δv_n^k,
- preference shifters: Δa_n^k,
- input shifters: Δg_n^{kl}.

1.5 Counterfactuals

With the shocks that fully account for the changes that occurred from 1997 to 2007, I can provide insight on whether it is trade or technical change that drives the changes in the skill premium in each country. To do so I consider a scenario where only one set of shocks is operative, keeping other types of shocks fixed at their 1997 levels, and apply each set of shocks country by country to see the effects on the skill premium.

Table 1.10 summarizes my main findings. It shows the effects of shocks from the labor supply, trade, technology, and residuals on changes in the skill premium, with each group of shocks acting in isolation.[31][32] The first three rows present the

[31]All changes in the skill premium are relative changes: $\Delta\text{SP}\% = \frac{\text{SP}(c)-\text{SP}(97)}{\text{SP}(97)} \times 100\%$, where $\text{SP}(c)$ is the skill premium at the counterfactual.

[32]There is no reason for the effects of each shock to add up to the observed value because there are interactions between different shocks.

median values across the respective group of countries. In general, both trade and technical change increase the skill premium, while labor supply shocks decrease it.

The results for each individual country reveal that trade increases the skill premium in all countries, with a median of 8.3%. In particular, small countries, such as Ireland and Luxembourg, or countries experiencing large reductions in trade costs, such as China, have larger effects of trade on the skill premium. In general, trade increases the skill premium more in non-OECD countries than in OECD countries. The effects of technical change on the skill premium are more heterogeneous. For some countries, such as China and India, technical change increases the skill premium by over 20%, while for some other countries, such as Peru, the effects are negative and large. The heterogeneity can be explained by the average changes in skill intensity for each country, as shown in the left panel of Figure 1.9. This suggests that SBTC plays a major role in explaining the changes in skill premium due to technical change.

To gauge the relative importance of trade and technical change, I focus on the subset of countries where both forces increase the skill premium. Trade increases the skill premium by 7.5%, while technical change increases the skill premium by 5.3% in a typical country in this subset. The last two columns of Table 1.10 illustrate the contribution of each channel to the rise in the skill premium.[33] In a typical country, trade and technical change are equally important.

It is interesting to note that for Latin American countries and some Asian

[33]The contribution from trade, for example, is computed as $\frac{\Delta\text{SP(trade)}}{\Delta\text{SP(trade)}+\Delta\text{SP(tech)}} \times 100\%$.

emerging economies, the residuals are particularly large, indicating that a lot of the observed changes in the skill premium are due to neither trade nor technical change. To investigate whether the large residuals are due to changes in the value added share Δv_n^k for $k \in \Omega$, the right panel of Figure 1.9 plots the changes in the skill premium due to shocks to value added share against the skill premium predicted by residuals.[34] The shocks to value added share help explain the effects from the residuals, but a significant portion remains unexplained, especially for the Latin American countries. This shows that the channels in the model do not capture the observed changes in household expenditure shares and intermediates expenditure shares in some countries.[35]

1.5.1 Trade and Technical Change

As I have different types of trade shocks, it is worthwhile to understand which type of trade shocks is more important. The first three columns of Table 1.11 present the effects of the three types of trade shocks on the changes in skill premium. The main findings are that trade increases the skill premium due to foreign technical change but not changes in the trade cost or deficits. In general, the effects of trade cost and trade deficits are small for most of the countries. The effects of foreign technical change, on the other hand, have a median value of 6.3% on the skill premium for OECD countries and a larger value of 13% for non-OECD countries.

[34] I only focus on countries where the effects of the residuals are larger than 5% in absolute values.

[35] One reason may be that I do not have other factors of production such as land, which may be important for exporters of agricultural goods such as Argentina.

This illustrates the importance of considering foreign technical change, in addition to changes in the trade cost and deficits, when evaluating the impact of trade on the skill premium.

The last two columns of Table 1.11 illustrate the effects of NTC and SBTC on the changes in the skill premium. SBTC explains most of the increases in the skill premium, which confirms the findings in the left panel of Figure 1.9. On the other hand, the effects of NTC are mostly negative except for China, where sectoral productivity growth is exceptional. Moreover, the median effects of SBTC are larger in OECD countries. This is partially explained by the fact that SBTC are larger in the services sector in the OECD countries (from Table 1.7), and that rich countries have a larger production share in services.

1.5.2 Role of Structural Change

In this section, I investigate the effects of structural change on the skill premium by shutting down the endogenous changes in household expenditure share (s_n^k) and aggregate intermediates expenditure share (e_n^k).[36] More specifically, both the consumer utility and intermediates expenditure function are Cobb-Douglas. In addition, there are no sectoral linkages, so each sector has the same intermediates expenditure share for all sectors.[37] The no structural change model is similar to the

[36]To be precise, there is still structural change induced by international trade, which is the "net export channel" as in Uy et al. (2013), due to differences in sectoral production efficiency and skill abundance across countries. Keeping that in mind, I will call the simple framework the "no structural change model."

[37]Mathematically, $e_n^k = e_n^{Ak} = e_n^{Mk} = e_n^{Sk}$ for $k \in \Omega$.

standard multi-sector trade model considered by Caliendo and Parro (2015).

The no structural change model has two additional shocks compared to the baseline: the household expenditure share $s_n^k(t)$ and aggregate intermediates expenditure share $e_n^k(t)$ for $k \in \Omega$. The values of $s_n^k(t)$ are set to the values in the data, while the values of $e_n^k(t)$ are equal to the $e_n^k(t)$ in the baseline, which matches the structural change.[38] I match the no structural change model to the same moments in the baseline so that it yields the same exogenous variables and shocks.[39]

I apply the same groups of shocks one by one to the no structural change model and compare the results with the baseline. Table 1.12 decomposes the changes in skill premium for the no structural change model. Comparing with the baseline results in Table 1.10, the main observation is that the effects of trade on the skill premium are almost halved (from 8.3% to 4.2%). Moreover, the effects of technical change are negligible in non-OECD countries. In terms of percentage contributions, trade now explains only 35% of the increases in skill premium in a typical country, compared to 50% in the baseline. From Figure 1.10, where I plot the changes in skill premium in the no structural change model against the baseline, the effect of trade is smaller in almost every country.

To quantify the effects of structural change on the skill premium, I add up the differences implied by the labor supply, trade, and technology shocks between

[38] The shocks to consumption expenditure share and intermediates expenditure share play the same roles as preference shifters and input shifters, respectively, in the baseline model. These two shocks are counted as residuals.

[39] Shocks to production efficiency are slightly different as sectoral linkages differ, which implies a different unit cost $c_n^k(t)$. I compare the production efficiency T_n^k implied by the two models and find that they are very similar.

the baseline and no structural change model. The calculation shows that structural change increases the skill premium by 2.3% in OECD countries and 7.7% in non-OECD countries.[40] This shows that structural change has larger effects on the skill premium in non-OECD countries.

The effects of structural change come mainly from the shocks to sectoral production efficiency T_n^k, as shown in Table 1.13. Comparing to the baseline results in Table 1.11, the effects of foreign technical change decrease a lot. The reason is that sectoral technical change is the main driver of structural change in the model. Other types of shocks that have little effect on structural change, such as labor supply and SBTC, give similar results as the baseline.[41]

The finding that structural change has a larger effect in non-OECD countries is also shown in Figure 1.11, where I plot the differences in the skill premium implied by the baseline and no structural change model against income per worker in each country. Both graphs for trade and technology shocks give a negative slope, indicating that the effect of structural change is larger for non-OECD countries. This may be due to the fact that non-OECD countries have larger increases in sectoral production efficiency than do OECD countries, as shown in Table 1.7. Sectoral technical change drives structural change, leading to larger increases in the skill premium in non-OECD countries.

[40] An alternative is to calculate the increases in the effects of the residuals. This gives an increase of 1.7% in OECD countries and 7.4% in non-OECD countries.

[41] See Appendix A.4 for details on contributions of different shocks to structural change.

1.5.3 Robustness

In this section, I check whether my main results are sensitive to alternative values of trade elasticity and separate estimation of expenditure functions for OECD and non-OECD countries. In all the exercises, I recalibrate the parameters and back out the shocks so that the model with alternative specifications match the same data as the baseline.

1.5.3.1 Trade Elasticity

The upper part of Table 1.14 presents the results under $\theta = 3$ and $\theta = 5$. Comparing with the baseline, we see that the results under alternative values of trade elasticity imply different effects of trade and technical change on the skill premium. Moreover, the results on non-OECD countries are more sensitive to different values of trade elasticity. The reason that why my results are sensitive to the values of trade elasticity is that it affects the values of the shocks I back out. In particular, I back out sectoral prices conditional on the value of trade elasticity from the estimation of (1.16), and shocks to sectoral production efficiency and trade cost depend on sectoral prices.

To gauge whether the value of trade elasticity of $\theta = 4$ is reasonable, I estimate the elasticities in agriculture and manufacturing, following the triple difference method used by Caliendo and Parro (2015).[42] From (1.7), I multiply the trade flows from country i to country h, from country h to country n, and finally from country

[42]The method utilizes variation in tariffs, so it is not applicable to the services sector.

n to country i, and then divide the trade flows in the opposite directions. The procedure gives the flowing estimation equation:

$$\ln\left(\frac{X_{in}^k X_{nh}^k X_{hi}^k}{X_{ih}^k X_{hn}^k X_{ni}^k}\right) = -\theta^k \ln\left(\frac{\tau_{in}^k \tau_{nh}^k \tau_{hi}^k}{\tau_{ih}^k \tau_{hn}^k \tau_{ni}^k}\right) + \varepsilon^k, \tag{1.23}$$

and I estimate it by OLS. Table 1.15 presents the estimates for each year of GTAP data for 37 countries in my sample. We see that the trade elasticity in manufacturing ranges from 1.5 to 4.5, while the estimates in the agriculture sector are too small. The reason may be due to the fact that variation in tariffs provide little information on identifying trade elasticity, as pointed out by Simonovska and Waugh (2014b). Therefore, I use $\theta = 4$ from Simonovska and Waugh (2014a), which is the standard value of trade elasticity for models with broad sectors.[43]

1.5.3.2 Separate Estimation of Expenditure Functions

The bottom part of Table 1.14 shows the results when AIDS and translog intermediates expenditure functions are estimated separately for OECD and non-OECD countries. Comparing with the baseline, estimating translog intermediates expenditure function separately does not have much effect on the results. However, a separate estimation of AIDS reduces (increases) the effects of technical change on OECD (non-OECD) countries and reduces the residuals in non-OECD countries.[44] Overall, the effects are similar to the baseline results.

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[43]In the future, I plan to use sectoral price data to estimate the trade elasticity consistent with my framework. As pointed out by Simonovska and Waugh (2014b), different trade models imply different sectoral prices conditional on the same trade flows, so different model-consistent trade elasticities can be identified from variation in sectoral prices.

[44]The residuals for Latin American countries are still very large.

1.6 Structural Change in the U.S. and China

In this section, I apply the framework to investigate the effects of trade and technical change on structural change in the U.S. and China. The motivation comes from the fact that since 2001, the U.S. has experienced a huge increase in manufacturing imports from China.[45] The influx of cheap Chinese goods has profound influences on the U.S. labor markets, such as a declining manufacturing employment share in trade-exposed regions and larger earning losses for unskilled manufacturing workers.[46] Meanwhile, China is able to transform from an agricultural economy to a world manufacturing factory through its export-oriented growth strategy.[47]

There is a growing body of literature analyzing the effects of imports from China on the U.S. labor markets, both at the levels of industry and local labor markets. Autor et al. (2013) find that there is a larger decline in employment in commuting zones that are more exposed to imports from China. At the industry level, Acemoglu et al. (2016) find that manufacturing industries that face greater import penetration from China face larger employment losses.

Based on my structural model, I can investigate the effects of imports from China on the U.S. labor market at the sector level, using the trade shocks that I back out. Though I do not have industry and local labor market variation, one advantage of my approach is that it does not suffer from the potential endogeneity

[45]See, for example, Handley and Limão (2013).

[46]See, for example, Autor et al. (2013, 2014) and others.

[47]See, for example, Brandt et al. (2008) on structural transformation in China.

problem of the instrument used in these papers.[48] In addition, the structural model incorporates the general equilibrium effects of trade shocks from China, which are in general hard to estimate using a reduced form approach.

My framework can also shed light on whether it is trade or technical change that is driving the changes in the U.S. labor markets. Autor et al. (2015) uses exposure to computerization as technology shock, together with imports from China as trade shock, to investigate the effects of trade and technical change on the employment at the commuting zone level. Given that I have different types of trade and technology shocks that are independent, I can separately identify the effects of each shock on the U.S. economy.

1.6.1 Shocks

I use the baseline specification to focus on the effects of shocks that involve only the U.S. and China. These shocks include $\hat{T}_n^k$, $\Delta\beta_n^k$, ΔD_n, and $\{\hat{L}_n, \hat{S}_n, \hat{U}_n\}$ in the U.S. and China, as well as trade cost shocks $\{\hat{\kappa}_{ni}^k, \hat{\tau}_{ni}^k\}$ involving only the U.S.–China pair. Shocks for other countries are kept at 1997 values.

Suppose the U.S. is the home country. Shocks on the trade deficits in the U.S. reflect only the effects of trade with China, which is given by:

$$\Delta D_{\text{US}} = \Delta X_{\text{US CHN}} - \Delta X_{\text{CHN US}}.$$

[48] These papers often instrument imports from China in the U.S. by imports from China in other high-income countries in order to correct for factors affecting imports originated in the U.S. The instruments are invalid if shocks in the home country that affect imports from China correlate across high-income countries. To the extent that the patterns of structural change are similar across high-income countries, the identifying assumption of the instrument is likely to fail.

From the perspective of the U.S., foreign technical change refers only to changes in the production efficiency in China, $\hat{T}^k_{\text{CHN}}$. This implies that the trade shocks for the U.S. in the counterfactual are:

1. trade cost shock: $\{\hat{\kappa}^k_{\text{CHN US}}, \hat{\tau}^k_{\text{CHN US}}\}$,

2. trade deficits shock: ΔD_{US},

3. changes in production efficiency in China: $\hat{T}^k_{\text{CHN}}$.

A similar set of trade shocks can be grouped for China. The technology and labor supply shocks are the same as the counterfactuals on the skill premium.

1.6.2 Counterfactuals

I first compare the effects of trade between the U.S. and China on the skill premium to the effects of trade between all countries (baseline) in Table 1.16. We see that U.S.–China trade has larger effects on the skill premium in China, contributing to 34% of the rise in skill premium due to trade. For the U.S., the contribution is smaller at 13%. The reason for this finding is that the U.S. is a very important trading partner for China during the period, while the U.S. trades mostly with developed countries.

In the following, I present the effects of trade and technical change on the production share and labor reallocations in the U.S. and China.

1.6.2.1 Sectoral Reallocation

Figure 1.12 shows the effects of trade and technical change on the changes in production share in the U.S.. The main findings are that trade with China explains more than half of the decline in the manufacturing share, and NTC explains around one-third of the decline. Moreover, the main effect of NTC is to reallocate economic activity from agriculture to the services sector. These results are consistent with the findings of Autor et al. (2015), who find that trade with China mainly affects the manufacturing sector, while computerization has wider effects on the whole economy.

Comparing the left and right panel gives us the general equilibrium effects from structural change. The negative effects of trade with China are smaller under the standard model. The effects of NTC are mainly due to structural change, which is important in explaining the expansion of the services sector. Moreover, NTC decreases the manufacturing share through structural change, as the effects of NTC are opposite in sign under the standard model.

In the case of China, Figure 1.13 illustrates that the effect of trade with the U.S. and NTC is to shift resources from the agriculture to the manufacturing sector. From Table 1.17, Trade and technical change together completely explain the rise in the manufacturing share. This is consistent with the experience in China that a lot of resources are shifting from agriculture-based rural villages to industrialized city coasts. Similar to the case of the U.S., most of the effects of NTC on sectoral reallocation come from structural change.

1.6.2.2 Labor Reallocation

In the following, I investigate the differential effects of trade and technical change across the skilled and unskilled workers, through the angle of labor reallocation across sectors.

Figure 1.14 presents the effects of trade and technical change on the sectoral employment share in the U.S. From the left panel, the skilled worker switches out of the manufacturing into the services sector. The contributions from trade with China, NTC, and SBTC are similar in magnitude. For the reallocation of the unskilled worker, the effects of trade and NTC are similar as in the case of the skilled worker, but the effects of SBTC are opposite. The reason for this is that most SBTC occurs in the services sector in the U.S., as can be seen from Table 1.7. From Table 1.18, the net effect of trade with China and technical change is to reduce the manufacturing employment share of skilled workers by 1.6%, but only 0.2% for the unskilled workers. This is consistent with the findings of Autor et al. (2014) that workers with low qualifications are more likely to remain in trade-exposed manufacturing sector and subject to further trade shocks. Moreover, NTC has wider impacts than trade in that some unskilled workers from agriculture switch out to services.

The above results suggest that the distributional impacts on workers with different skills come mainly from SBTC but not NTC. As computerization has both the neutral and skill-biased components of technical change, the results from Autor et al. (2015) probably capture a mixture of these two types of technical change. In particular, the authors find that computerization has no significant impact on the net manufacturing employment, which can be reconciled from the above findings that NTC and SBTC has the opposite effect on the manufacturing employment shares of the skilled and unskilled workers.

In the case of China from Figure 1.15, most of the labor reallocation is characterized by unskilled workers switching out of agriculture to manufacturing, with a net increase in the manufacturing employment share of the unskilled workers at 6.6%. From Table 1.18, trade with the U.S. increases the manufacturing employment share of the unskilled by 4.9%, while the effect of NTC is smaller at 3.8%. Relative to trade with the U.S., NTC induces more unskilled workers in agriculture to move to services. The skilled workers mainly move out of manufacturing to services, and most of this pattern is due to skill-biased technical change.

1.7 Conclusion

This paper quantifies the effects of trade and technical change on the changes in skill premium in the presence of structural change. I find that trade and technical change each contributes 50% to the rise in the skill premium from 1997 to 2007. Moreover, the positive effects of trade on the skill premium come from changes in foreign production efficiency but not changes in the trade cost.

The key mechanism behind the positive effects of trade on the skill premium is structural change, driven by endogenous changes in household expenditure and a firm's intermediates expenditure. The household side is due to nonhomothetic preferences, and the firm side is due to intensive usage of own sector intermediates. Once structural change is shut down, the effects of trade on the skill premium are halved. My results therefore highlight a quantitatively important channel by which foreign productivity growth increases the skill premium at home through reallocation to skill-intensive sectors and international trade.

My framework also sheds light on the shrinking of the manufacturing sector in the U.S. The quantitative exercise on the U.S. and China reveals that in the U.S., more than half of the decline in the manufacturing production share is attributable to trade with China. Moreover, 1.6% of the skilled workers have moved out of the shrinking manufacturing sector, but only 0.2% of the unskilled workers are able to do so. On the other hand, trade with the U.S. explains most of the rise in the manufacturing production share in China. Moreover, 6.6% of the unskilled workers move from agriculture to manufacturing.

My results point to the fact that, to the extent that most of the increases in the skill premium are driven by technical changes (whether through skill-biased technical change or foreign productivity growth), inequality is a byproduct of economic development. This underlines the importance of designing policies such that the people with low skill also benefit from technological progress.

Tables

Table 1.1: Average skill intensity (%)

	β^k in 1997			$\Delta\beta^k$		
	A	M	S	A	M	S
OECD	15.9	30.9	43.9	-0.07	0.05	2.35
Non-OECD	5.66	16.6	38.4	1.65	0.70	0.62

Notes: A=Agriculture, M=Manufacturing, S=Services. $\Delta x = x(07) - x(97)$ is simple difference between the two periods. Skill intensity is measured by share of total wage payments to the skilled.

Table 1.2: Average consumption expenditure share (%)

	s^k in 1997			Δs^k		
	A	M	S	A	M	S
OECD	14.5	18.9	66.7	-3.16	1.06	2.10
Non-OECD	30.2	22.8	47.0	-8.40	-2.34	10.74

Table 1.3: Average intermediates expenditure share (%)

	e^{kl} in 2007			Δe^{kl}		
	A	M	S	A	M	S
Agriculture	56.3	17.5	26.3	-2.10	0.58	1.52
Manufacturing	2.00	71.6	26.4	-1.17	0.77	0.40
Services	5.91	30.1	64.0	0.95	-1.95	1.01

Table 1.4: Calibrated AIDS parameters

α_A	α_M	α_M	b_A	b_M	b_S
0.065	0.176	0.759	-0.062	-0.008	0.070
δ_{AA}	δ_{AM}	δ_{AS}	δ_{MM}	δ_{MS}	δ_{SS}
0.034	0.032	-0.067	-0.059	0.027	0.040

Table 1.5: Calibrated intermediates cost share parameters

	η^k_{AA}	η^k_{AM}	η^k_{AS}	η^k_{MM}	η^k_{MS}	η^k_{SS}
Agriculture	0.059	-0.045	-0.014	0.041	0.004	0.010
Manufacturing	-0.029	0.063	-0.035	-0.126	0.063	-0.028
Services	-0.083	0.096	-0.013	-0.103	0.007	0.006

Table 1.6: Structural change: 1997 to 2007 (%)

	Production share			Consumption share			Intermediates share		
	A	M	S	A	M	S	A	M	S
OECD	-2.9	-1.6	4.5	-3.2	1.1	2.1	-1.4	0.1	1.2
Non-OECD	-5.8	1.9	3.9	-8.4	-2.3	10.7	-3.7	0.0	3.7
AUS	-2.7	-2.5	5.2	-3.0	0.8	2.1	0.4	-9.0	8.6
AUT	-1.0	5.7	-4.7	-2.1	2.4	-0.3	-0.3	11.7	-11.4
BEL	-2.6	-1.7	4.3	-0.5	4.2	-3.7	-3.5	0.7	2.8
CAN	-2.4	-6.0	8.4	-1.9	-4.2	6.1	-1.4	-3.3	4.7
DEU	-0.9	4.9	-4.1	-1.0	3.5	-2.5	-1.0	1.4	-0.5
DNK	-3.3	1.2	2.1	-1.1	6.4	-5.3	-2.3	5.1	-2.8
ESP	-3.4	-0.3	3.7	-1.2	-3.6	4.8	-3.6	1.5	2.1
FIN	-2.4	3.5	-1.1	-3.3	5.9	-2.5	-1.5	9.8	-8.4
FRA	-1.3	-2.7	4.0	-2.8	1.6	1.2	1.0	1.9	-2.9
GBR	-1.8	-5.0	6.8	-0.2	4.5	-4.3	-1.5	-5.4	6.9
GRC	-7.2	-0.5	7.8	-19.6	-3.4	23.0	2.4	21.1	-23.5
IRL	-6.5	-5.8	12.3	-0.4	0.7	-0.4	-2.0	-15.4	17.4
ITA	-1.2	0.8	0.4	-0.6	4.7	-4.1	-1.0	2.1	-1.1
JPN	-1.5	0.0	1.5	-2.0	-2.8	4.8	-0.4	-1.5	1.9
KOR	-3.9	1.1	2.8	-10.5	-6.0	16.5	-2.2	1.7	0.6
LUX	-7.7	-16.0	23.7	-2.1	0.5	1.6	-9.7	-23.7	33.5
NLD	-1.7	-5.0	6.6	1.7	1.9	-3.6	-0.6	-2.8	3.4
PRT	-2.3	-1.6	3.9	-10.2	-5.9	16.1	1.9	6.4	-8.3
SWE	-2.1	-0.4	2.5	-1.2	10.0	-8.8	-1.2	-1.2	2.4
USA	-1.3	-1.6	2.9	-1.2	-0.1	1.3	-0.2	0.8	-0.6
ARG	-5.6	-14.3	19.9	-12.4	-11.9	24.4	-6.7	-18.6	25.4
BRA	-4.0	-4.4	8.4	-9.0	-9.2	18.1	-3.5	-5.2	8.7
CHL	-9.7	4.2	5.5	-11.4	-3.8	15.2	-6.6	-1.3	7.9
CHN	-6.9	3.6	3.3	-19.1	-5.7	24.8	-2.8	0.2	2.6
CZE	-6.8	6.5	0.3	-8.8	-7.9	16.7	-4.9	5.4	-0.5
HUN	-4.3	11.5	-7.2	4.4	-1.1	-3.3	-3.8	11.0	-7.2
IDN	-5.4	4.9	0.6	-9.1	1.4	7.7	-3.7	5.0	-1.3
IND	-7.3	-1.1	8.4	-10.7	-3.2	13.9	-3.1	0.8	2.3
MEX	-6.9	-6.5	13.4	-7.7	-5.8	13.5	-6.4	-8.1	14.5
PER	-1.8	11.2	-9.4	1.9	4.7	-6.7	-1.9	3.8	-1.9
PHL	-8.3	10.8	-2.5	-15.7	4.0	11.7	-2.0	4.0	-2.0
POL	-6.4	2.0	4.4	-9.5	0.5	9.0	-3.9	1.2	2.7
SVK	-9.4	0.4	9.0	-11.0	-0.2	11.2	-6.9	-1.6	8.5
SVN	-6.9	-1.7	8.6	-11.7	2.6	9.1	-4.1	-2.1	6.1
THA	-1.2	8.1	-6.9	-1.8	-5.3	7.0	-0.8	6.3	-5.5
URY	-5.9	-1.8	7.6	-12.8	0.3	12.6	-4.1	-1.6	5.7
VEN	-1.1	-1.2	2.2	1.4	0.8	-2.3	1.6	1.0	-2.6

Notes: The first two rows present the simple averages for the OECD and non-OECD countries respectively. OECD and non-OECD countries are separated by a horizontal line.

Table 1.7: Values of shocks 1997 to 2007 (%)

	$\hat{d}_n^A$	$\hat{d}_n^M$	$\hat{d}_n^S$	$\left(\hat{T}_n^A\right)^{\frac{1}{\theta}}$	$\left(\hat{T}_n^M\right)^{\frac{1}{\theta}}$	$\left(\hat{T}_n^S\right)^{\frac{1}{\theta}}$	$\Delta\beta_n^A$	$\Delta\beta_n^M$	$\Delta\beta_n^S$	$\Delta\left(\frac{S_n}{L_n}\right)$
OECD	-6.1	-0.2	-5.4	44.6	16.1	4.9	-0.05	-0.62	2.64	1.58
Non-OECD	-11.7	-10.3	-7.0	37.8	31.6	7.6	0.68	-0.05	1.73	2.54
AUS	-8.9	-7.1	-0.7	46.7	34.3	17.5	0.59	0.36	-1.45	-1.91
AUT	-18.9	-4.6	-3.8	41.5	16.3	-1.4	0.10	-0.10	8.52	5.78
BEL	-3.7	1.7	-2.8	16.8	-3.4	-14.4	-2.35	0.86	3.82	2.72
CAN	-7.4	6.8	-2.4	40.3	23.0	29.1	1.01	0.48	10.66	7.87
DEU	-7.1	-4.8	-9.2	53.8	18.2	0.9	-0.33	0.19	1.96	0.29
DNK	-6.4	0.7	-18.7	39.3	33.1	13.2	-1.51	-0.01	4.54	2.57
ESP	-5.6	0.1	-11.7	52.0	23.9	14.1	-0.49	0.43	-0.59	-0.40
FIN	-6.0	1.8	-10.2	43.1	27.8	13.8	-0.90	0.64	3.80	1.55
FRA	-0.1	0.3	2.8	39.1	7.7	-5.4	-0.40	-0.41	5.54	7.19
GBR	-3.3	3.8	-10.2	60.0	36.3	13.3	0.43	0.01	1.20	4.54
GRC	-5.0	-7.4	-22.6	80.9	40.6	11.6	3.89	-1.18	1.52	4.45
IRL	-5.3	-1.0	-28.5	49.4	33.8	27.6	-0.11	2.18	-2.90	-0.35
ITA	-3.0	-0.5	-0.5	37.1	16.4	-9.9	1.49	0.21	2.10	-2.96
JPN	-0.6	-4.0	5.3	28.8	2.7	-14.2	0.26	0.70	-0.28	0.12
KOR	3.4	-5.7	-6.9	35.2	24.1	21.8	0.83	0.75	1.09	2.22
LUX	-25.4	-10.0	-47.2	13.9	47.9	16.4	-3.99	-0.83	0.14	-4.82
NLD	0.9	13.6	-1.7	39.4	28.0	2.8	1.02	-1.84	5.10	3.05
PRT	-9.1	1.8	-8.9	51.3	30.9	21.4	-2.40	-0.22	-1.71	-2.18
SWE	-12.7	1.1	-12.0	49.8	8.4	-1.1	1.00	-0.96	1.29	2.72
USA	-7.7	-0.2	1.3	44.2	24.8	13.8	0.51	-0.23	2.64	1.08
ARG	-13.1	-19.8	-5.4	27.4	2.1	-16.2	-0.32	0.93	1.93	4.40
BRA	-4.4	-12.3	-5.6	42.9	26.0	4.2	1.66	0.07	-1.26	-0.85
CHL	-13.5	-15.6	-1.8	44.5	39.1	8.3	1.47	-0.10	-0.17	2.86
CHN	-9.9	-11.0	-12.6	90.9	42.4	18.4	0.55	0.15	5.62	2.07
CZE	-20.9	-9.0	-3.6	31.0	28.2	20.3	1.75	1.75	-2.46	-1.53
HUN	-11.0	-4.5	-13.1	51.5	44.5	27.9	2.04	1.53	3.54	-0.57
IDN	-15.0	-1.9	12.9	39.0	33.2	1.7	1.13	0.50	-4.46	-0.48
IND	-17.4	-18.7	-22.7	123.6	39.0	7.6	2.51	-0.06	5.36	5.26
MEX	-14.7	0.2	3.4	61.5	29.3	37.4	4.27	0.68	3.33	2.75
PER	-3.6	-14.5	0.6	38.5	23.5	2.5	3.42	-0.13	-10.23	-5.51
PHL	-3.1	1.3	45.3	36.5	17.2	-8.0	1.30	3.32	-6.08	-1.86
POL	-19.6	-12.8	-9.2	67.7	48.4	24.8	0.85	1.12	4.64	4.27
SVK	-23.7	-6.3	-11.0	37.3	33.0	32.6	1.31	1.08	0.59	3.06
SVN	-16.0	-7.4	-12.8	33.3	31.2	11.5	1.39	1.36	-2.71	0.63
THA	-7.6	-6.1	-3.3	47.9	22.6	-17.3	1.66	0.99	0.09	-0.58
URY	0.3	-8.5	9.0	43.8	25.8	-14.9	1.32	-0.67	10.44	6.82
VEN	7.2	-3.1	19.1	59.5	47.2	21.1	1.77	-0.64	2.30	6.43

Notes: The weights to compute the average changes in trade costs, sectoral technology, skill biased technology and share of the skilled labor are trade volumes, sectoral output, sectoral output and total employment respectively.

Table 1.8: Validation on the share of the skilled labor

	2007 $\frac{S_n}{L_n}$		1997 $\frac{S_n}{L_n}$	
	model	data	model	data
TFP	15.14*	29.08*	15.60*	16.06
	(2.19)	(2.25)	(2.06)	(1.46)
Life expectancy	0.173	-0.0228	0.194	0.182
	(0.52)	(-0.04)	(0.55)	(0.35)
$\frac{\text{Education expenditure}}{\text{GDP}}$	1.570	-1.472	1.253	0.446
	(1.62)	(-0.81)	(1.81)	(0.44)
N	33	33	35	35
R^2	0.543	0.271	0.507	0.265

Notes: t statistics in parentheses: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. The model column uses the model implied $\frac{S_n}{L_n}$ as the dependend variable, while the data column uses the share of incomplete teriary from Barro and Lee (2013).

Table 1.9: Validation on the trade cost

	2007			1997			Change		
	$\ln d_{ni}^A$	$\ln d_{ni}^M$	$\ln d_{ni}^S$	$\ln d_{ni}^A$	$\ln d_{ni}^M$	$\ln d_{ni}^S$	$\Delta \ln d_{ni}^A$	$\Delta \ln d_{ni}^M$	$\Delta \ln d_{ni}^S$
$\ln\left(1+\tau_{ni}^k\right)$	0.113	1.743***		0.201**	0.961***		0.036	-0.004	
	(1.00)	(5.43)		(2.69)	(4.61)		(0.57)	(-0.06)	
distance	0.320***	0.286***	0.079***	0.257***	0.230***	0.008*	0.036***	0.013*	0.065***
	(27.90)	(29.39)	(12.86)	(22.40)	(24.55)	(2.29)	(6.18)	(2.46)	(15.86)
contig	-0.128***	-0.028	-0.208***	-0.158***	-0.109***	-0.032**			
	(-3.60)	(-0.92)	(-10.60)	(-4.91)	(-3.93)	(-3.18)			
comlang	-0.113***	-0.108***	0.011	-0.104***	-0.102***	-0.023**			
	(-4.10)	(-4.67)	(0.72)	(-4.12)	(-4.71)	(-2.93)			
NRPTA	-0.024	0.053*	-0.072***	-0.086***	-0.034	-0.004	-0.041	-0.022	-0.021
	(-0.76)	(2.01)	(-4.20)	(-3.48)	(-1.60)	(-0.48)	(-1.53)	(-0.92)	(-1.11)
RPTA	0.071	0.035	-0.036	0.069	0.076	-0.028	-0.027	0.025	-0.175***
	(1.10)	(0.65)	(-1.02)	(1.46)	(1.86)	(-1.87)	(-0.73)	(0.77)	(-6.81)
TA	0.015	0.068**	0.050***	-0.033	-0.190***	-0.010	0.095***	0.022	-0.011
	(0.62)	(3.24)	(3.68)	(-1.09)	(-7.82)	(-1.19)	(4.41)	(1.15)	(-0.74)
N	1322	1332	1332	1324	1330	1330	1317	1330	1330
R^2	0.797	0.799	0.836	0.801	0.839	0.931	0.356	0.310	0.697

Notes: t statistics in parentheses: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. The independent variable, from top to bottom, reads log tariff, log distance, common border, common language, non-reciprocal preferential trade agreement, reciprocal PTA, and trade agreement capturing currency union, economic union, and free trade agreement. All regressions with exporter and importer fixed effects. There are a total of 37 countries, so that the total number of bilateral pairs is 1332. Data on distance and the dummy variables comes from Limão (2016). For the specification on changes in the trade cost, log distance is interacted with changes in the crude oil price.

Table 1.10: Decomposition of changes in the skill premium (%): baseline

	Actual	Labor supply	All trade shocks	All tech shocks	Residual	Trade	Tech
All	2.30	-10.72	8.31	1.74	0.30		
All(tech>0)	2.30	-16.63	7.45	5.31	1.07	49.9%	50.1%
OECD	2.45	-8.78	7.31	2.29	-0.25		
Non-OECD	-0.64	-14.48	10.57	1.74	3.33		
AUS	6.48	9.01	5.62	-5.11	-1.52		
AUT	-1.45	-24.13	4.91	20.77	0.24	19.1%	80.9%
BEL	2.30	-11.52	8.27	5.31	-0.63	60.9%	39.1%
CAN	0.27	-34.24	2.82	43.52	0.30	6.1%	93.9%
DEU	4.91	-1.57	4.06	3.63	0.13	52.8%	47.2%
DNK	2.60	-10.72	8.45	8.48	-2.41	49.9%	50.1%
ESP	4.08	1.81	10.89	-5.15	-0.73		
FIN	4.52	-6.84	7.45	9.95	-3.65	42.8%	57.2%
FRA	-11.91	-28.79	7.02	11.67	2.23	37.6%	62.4%
GBR	-14.46	-19.38	6.92	1.36	-0.85	83.6%	16.4%
GRC	-4.65	-18.73	23.44	1.39	1.07	94.4%	5.6%
IRL	1.29	2.54	13.10	-11.06	0.35		
ITA	14.91	13.73	7.29	1.20	-5.71	85.9%	14.1%
JPN	-0.30	-0.60	1.16	-1.06	0.98		
KOR	-2.84	-12.12	4.95	5.16	3.00	49.0%	51.0%
LUX	34.20	24.42	17.03	-8.40	-3.66		
NLD	5.01	-13.01	9.27	3.19	2.24	74.4%	25.6%
PRT	5.82	12.28	9.12	-7.43	-2.81		
SWE	-6.08	-11.19	7.32	0.75	0.20	90.7%	9.3%
USA	4.82	-5.14	2.01	9.62	-1.01	17.3%	82.7%
ARG	-0.64	-25.97	4.25	1.74	29.03	71.0%	29.0%
BRA	12.83	6.24	3.13	-4.52	9.87		
CHL	-10.82	-20.45	6.80	-4.67	14.79		
CHN	20.92	-14.48	20.28	24.64	1.15	45.1%	54.9%
CZE	2.72	10.07	7.71	-9.27	-6.98		
HUN	8.73	3.68	13.46	4.10	-14.69	76.7%	23.3%
IDN	-6.22	3.00	11.49	-11.21	-6.14		
IND	10.52	-33.60	8.31	24.65	27.97	25.2%	74.8%
MEX	8.26	-18.22	9.38	16.51	10.24	36.2%	63.8%
PER	-10.24	42.85	10.57	-26.78	-25.17		
PHL	-2.97	8.62	29.11	-30.70	3.33		
POL	-2.31	-20.35	19.39	8.28	4.14	70.1%	29.9%
SVK	-2.47	-16.63	9.01	3.92	1.39	69.7%	30.3%
SVN	-3.93	-4.23	13.63	-10.60	-1.22		
THA	4.58	2.85	18.29	-21.24	8.34		
URY	6.05	-38.22	12.23	15.57	23.55	44.0%	56.0%
VEN	-24.30	-33.34	3.46	5.21	1.93	39.9%	60.1%

Notes: The second row presents the median values for the subset of countries where technical change increases the skill premium. The last two columns compute the contributions from trade and technical change to the increase in skill premium for countries where the effects of both are positive.

Table 1.11: Effects of trade and technical change on the skill premium (%): baseline

	Trade costs	Deficits	Foreign tech	NTC	SBTC
All	-0.25	0.07	8.03	-3.82	5.85
OECD	-0.10	0.28	6.31	-2.98	5.91
Non-OECD	-1.40	-0.38	13.02	-4.79	4.07
AUS	-1.01	0.13	6.07	-1.07	-4.24
AUT	0.28	-0.55	5.48	-4.24	29.57
BEL	-0.34	1.07	7.40	-4.91	12.22
CAN	-0.34	0.07	2.83	-0.26	43.23
DEU	-0.38	-0.60	4.59	-2.03	5.97
DNK	-0.91	0.66	7.25	-4.10	14.44
ESP	0.20	1.87	8.18	-3.52	-1.63
FIN	-0.52	0.97	5.96	-1.75	12.33
FRA	-0.08	0.87	6.54	-4.13	17.35
GBR	0.14	0.74	5.53	-2.26	3.87
GRC	3.66	0.95	14.41	-4.22	5.85
IRL	-1.74	-7.12	10.86	-6.29	-5.31
ITA	-0.13	0.63	6.79	-5.45	7.31
JPN	0.04	0.07	1.11	-0.68	-0.40
KOR	-0.17	-0.12	5.29	0.37	4.82
LUX	4.95	1.59	10.70	-6.74	-1.99
NLD	0.16	-0.42	8.04	-8.65	15.29
PRT	0.27	-0.15	8.03	-1.95	-5.64
SWE	0.29	0.24	5.38	-2.45	3.19
USA	-0.12	0.33	1.66	0.47	9.02
ARG	-2.32	-1.01	5.24	-3.82	6.31
BRA	-0.25	-1.06	4.05	-1.29	-3.43
CHL	-1.44	-3.98	11.57	-5.30	0.56
CHN	3.18	2.81	10.04	7.10	16.45
CZE	-5.70	0.13	17.06	-6.71	-3.51
HUN	-1.40	-1.59	15.17	-8.30	13.96
IDN	-1.40	0.56	12.09	-0.62	-11.92
IND	-1.82	-1.09	6.80	-0.21	25.72
MEX	0.66	-0.33	9.91	1.14	15.23
PER	-0.73	-2.09	13.02	-4.79	-24.42
PHL	-3.90	8.16	32.18	-23.03	-13.30
POL	1.08	-0.03	16.42	-5.75	15.55
SVK	-4.76	-0.60	17.67	-0.10	4.07
SVN	-2.48	1.15	14.87	-7.07	-4.77
THA	0.56	-1.22	17.02	-24.51	2.55
URY	-2.83	0.32	14.33	-12.35	39.13
VEN	0.63	-0.38	6.28	-1.69	7.86

Table 1.12: Decomposition of changes in the skill premium (%): no structural change

	Actual	Labor supply	All trade shocks	All tech shocks	Residual	Trade	Tech
All	2.30	-10.71	4.24	3.07	3.04		
All(tech>0)	2.30	-16.79	3.96	6.92	3.30	34.7%	65.3%
OECD	2.45	-8.77	4.00	3.27	1.42		
Non-OECD	-0.64	-14.58	4.52	0.24	10.71		
AUS	6.48	9.09	2.28	-5.84	2.29		
AUT	-1.45	-24.16	3.40	23.24	0.48	12.8%	87.2%
BEL	2.30	-11.52	5.58	6.38	1.02	46.7%	53.3%
CAN	0.27	-34.25	1.39	42.55	2.00	3.2%	96.8%
DEU	4.91	-1.53	2.04	3.89	1.13	34.4%	65.6%
DNK	2.60	-10.71	5.40	10.14	-0.21	34.7%	65.3%
ESP	4.08	1.91	6.61	-4.42	3.04		
FIN	4.52	-6.83	3.96	10.17	-0.87	28.0%	72.0%
FRA	-11.91	-28.84	3.79	13.37	3.30	22.1%	77.9%
GBR	-14.46	-19.39	4.04	1.33	1.70	75.2%	24.8%
GRC	-4.65	-18.69	14.03	0.76	8.19	94.9%	5.1%
IRL	1.29	2.37	7.63	-8.75	4.58		
ITA	14.91	13.84	3.94	3.07	-5.15	56.2%	43.8%
JPN	-0.30	-0.62	0.49	-0.62	0.78		
KOR	-2.84	-12.13	2.21	3.46	5.81	39.0%	61.0%
LUX	34.20	24.85	13.41	-7.35	2.87		
NLD	5.01	-13.05	5.60	7.95	3.31	41.3%	58.7%
PRT	5.82	12.39	5.13	-8.16	0.10		
SWE	-6.08	-11.19	4.24	1.45	1.14	74.4%	25.6%
USA	4.82	-5.13	0.90	8.44	0.81	9.6%	90.4%
ARG	-0.64	-25.93	0.64	3.58	28.22	15.1%	84.9%
BRA	12.83	6.30	1.03	-5.35	12.24		
CHL	-10.82	-20.50	1.01	-4.36	17.49		
CHN	20.92	-14.58	10.04	13.61	19.71	42.4%	57.6%
CZE	2.72	10.59	4.89	-9.36	-1.15		
HUN	8.73	3.91	8.59	5.34	-5.73	61.7%	38.3%
IDN	-6.22	3.10	4.42	-13.99	2.34		
IND	10.52	-33.69	1.30	21.51	35.61	5.7%	94.3%
MEX	8.26	-18.27	3.57	13.22	15.54	21.2%	78.8%
PER	-10.24	43.63	3.33	-27.13	-20.59		
PHL	-2.97	9.58	12.92	-24.68	7.36		
POL	-2.31	-20.62	10.65	6.92	10.71	60.6%	39.4%
SVK	-2.47	-16.79	5.15	0.24	13.06	95.6%	4.4%
SVN	-3.93	-4.20	8.23	-9.77	6.46		
THA	4.58	3.00	9.90	-11.32	7.77		
URY	6.05	-38.28	4.52	23.70	21.73	16.0%	84.0%
VEN	-24.30	-33.39	1.21	4.29	5.86	22.0%	78.0%

Notes: the subset of countries where technical change increases the skill premium are the same as the baseline.

Table 1.13: Effects of trade and technical change on the skill premium (%): no structural change

	Trade costs	Deficits	Foreign tech	NTC	SBTC
All	-0.16	0.02	4.44	-3.10	5.98
OECD	-0.06	0.14	3.46	-2.78	6.00
Non-OECD	-0.70	-0.29	5.32	-3.92	4.06
AUS	-0.77	0.07	2.90	-1.79	-4.27
AUT	0.32	-0.22	3.37	-3.07	30.15
BEL	-0.21	0.76	4.92	-4.40	12.43
CAN	-0.15	0.01	1.40	-0.68	43.80
DEU	-0.31	-0.37	2.41	-1.81	6.01
DNK	-0.76	0.42	4.27	-3.16	14.72
ESP	0.14	1.08	4.44	-2.85	-1.64
FIN	-0.38	0.55	3.11	-1.77	12.49
FRA	-0.05	0.47	3.55	-2.91	17.56
GBR	0.06	0.46	3.06	-2.34	3.91
GRC	2.84	0.12	7.78	-4.88	5.98
IRL	-2.20	-5.24	6.38	-3.47	-5.41
ITA	-0.08	0.35	3.65	-3.76	7.32
JPN	0.01	0.02	0.50	-0.27	-0.39
KOR	-0.19	-0.04	2.49	-1.29	4.84
LUX	2.54	1.01	7.21	-5.55	-1.70
NLD	0.17	-0.27	5.11	-5.47	15.64
PRT	0.09	-0.13	4.56	-2.71	-5.69
SWE	0.09	0.15	2.94	-1.71	3.25
USA	-0.08	0.17	0.75	-0.42	9.01
ARG	-1.66	-0.65	2.51	-2.41	6.36
BRA	-0.16	-0.65	1.90	-2.16	-3.41
CHL	-1.07	-2.63	5.32	-4.89	0.47
CHN	1.26	1.76	4.48	-2.36	16.63
CZE	-2.68	0.26	9.36	-6.32	-3.99
HUN	-0.60	-0.97	8.41	-7.50	14.22
IDN	-0.70	0.50	5.07	-3.02	-12.28
IND	-1.94	-1.29	2.96	-3.19	25.91
MEX	0.01	-0.29	4.16	-1.70	15.03
PER	-0.56	-1.04	5.31	-3.92	-24.96
PHL	-0.76	5.01	14.24	-13.87	-14.36
POL	0.88	-0.02	7.87	-7.22	15.88
SVK	-2.67	-0.27	9.49	-3.76	4.06
SVN	-1.39	0.77	8.28	-5.68	-5.05
THA	0.30	-0.68	8.66	-14.09	2.38
URY	-2.42	0.40	7.36	-8.54	40.24
VEN	0.56	-0.30	2.68	-3.10	7.92

Table 1.14: Decomposition of changes in the skill premium (%): robustness

	Actual	Labor supply	All trade shocks	All tech shocks	Residual
			Baseline		
All	2.30	-10.72	8.31	1.74	0.30
OECD	2.45	-8.78	7.31	2.29	-0.25
Non-OECD	-0.64	-14.48	10.57	1.74	3.33
			$\theta = 3$		
All	2.30	-10.73	6.07	3.87	0.10
OECD	2.45	-8.78	5.62	4.19	-0.70
Non-OECD	-0.64	-14.52	7.24	3.87	2.93
			$\theta = 5$		
All	2.30	-10.72	10.87	-0.71	0.24
OECD	2.45	-8.78	8.95	-0.60	-0.30
Non-OECD	-0.64	-14.45	14.61	-0.71	3.96
			Different intermediates expenditure		
All	2.30	-10.72	8.73	2.36	0.42
OECD	2.45	-8.78	7.32	1.70	0.06
Non-OECD	-0.64	-14.49	11.00	2.69	3.51
			Different AIDS		
All	2.30	-10.70	7.92	1.84	1.28
OECD	2.45	-8.76	6.67	0.75	1.25
Non-OECD	-0.64	-14.56	10.64	4.38	1.28

Table 1.15: Estimates of trade elasticity: triple difference

	pool	2007	2004	2001	1997
Agriculture	0.09	0.03	-0.27	-0.34	0.99
s.e.	(0.02)	(0.06)	(-0.05)	(-0.04)	(0.05)
Manufacturing	2.81	2.93	4.48	3.59	1.48
s.e.	(0.07)	(0.17)	(0.16)	(0.14)	(0.10)

Notes: The table presents the estimates of trade elasticity (negative value of the coefficients in front of $-\theta^k$) in agriculture and manufacturing, using the triple difference method as in Caliendo and Parro (2015). The first column presents the estimates when pooling four years of data together.

Table 1.16: Changes in the skill premium (%): U.S. and China

	Trade	NTC	SBTC	Labor supply	Trade (baseline)	
CHN	6.83	7.10	16.45	-14.61	20.28	33.7%
USA	0.27	0.47	9.02	-5.15	2.01	13.4%

Notes: The last column computes the contribution from the trade between the U.S. and China to the total increase in the skill premium due to trade in these two countries.

Table 1.17: Changes in production share (%): U.S. and China

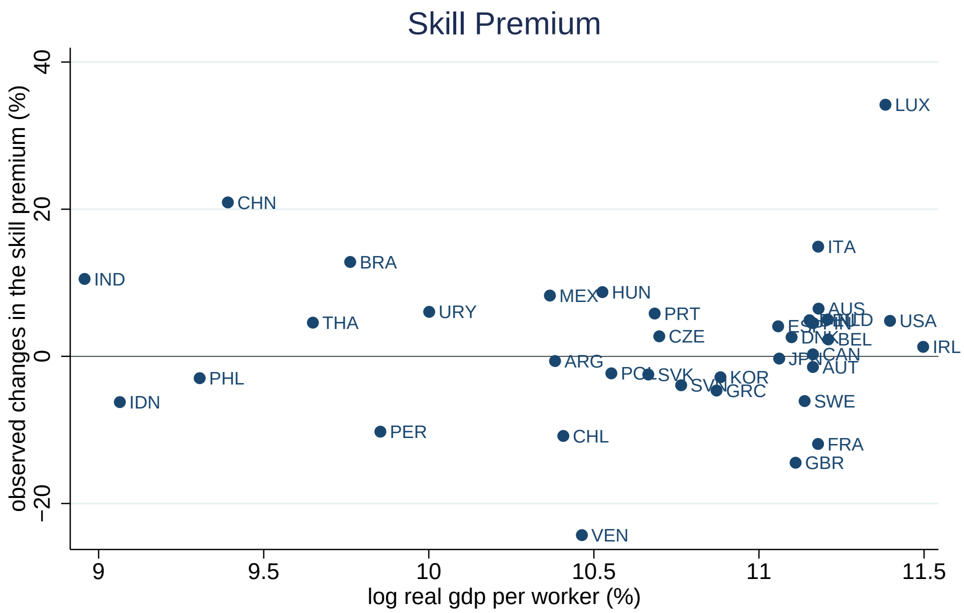
	Actual	Trade +tech	Trade	NTC	SBTC	Labor supply
			U.S.			
A	-1.30	-0.98	-0.20	-0.83	-0.07	0.04
M	-1.59	-1.06	-0.98	-0.57	0.21	0.04
S	2.90	2.04	1.18	1.40	-0.14	-0.08
			China			
A	-6.91	-5.18	-4.49	-4.05	0.06	0.01
M	3.60	4.62	4.42	3.28	0.13	-0.08
S	3.32	0.56	0.07	0.77	-0.19	0.07

Table 1.18: Changes in manufacturing employment share (%): U.S. and China

	Trade +tech	Trade	NTC	SBTC	Labor supply
			U.S.		
Skilled	-1.63	-0.70	-0.51	-0.68	0.03
Unskilled	-0.22	-0.79	-0.53	0.90	0.03
			China		
Skilled	-1.29	1.82	0.96	-2.67	-0.07
Unskilled	6.57	4.93	3.81	1.12	-0.07

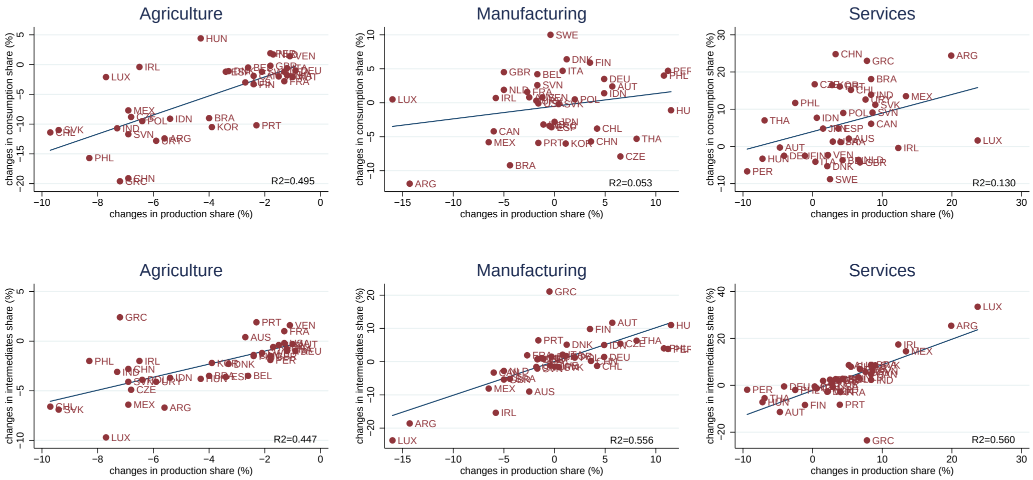
Figures

Figure 1.1: Observed changes in the skill premium: 1997–2007



Notes: The skill premium is defined as the ratio of wage payments to a college educated worker relative to a non-college educated worker. Source: EU KLEMS, SEDLAC (CEDLAS and The World Bank), see Appendix A.2 for details on how I compute the skill premium.

Figure 1.2: Observed structural change: 1997–2007



Notes: The upper panels plot the changes in the consumption expenditure share against the changes in production share in each sector. The bottom panels plot the changes in the average intermediates expenditure share against the changes in production share in each sector.

Figure 1.3: Labor productivity: model VS data

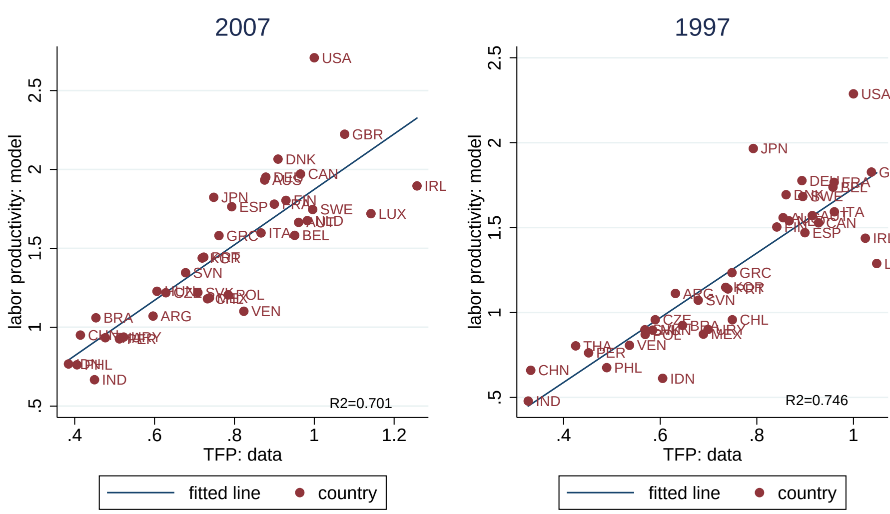


Figure 1.4: Log change in labor productivity: model VS data

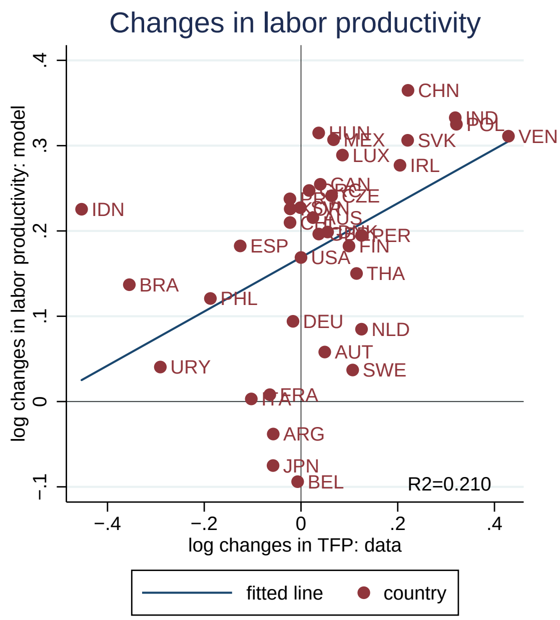


Figure 1.5: Share of skill abundance: model VS data

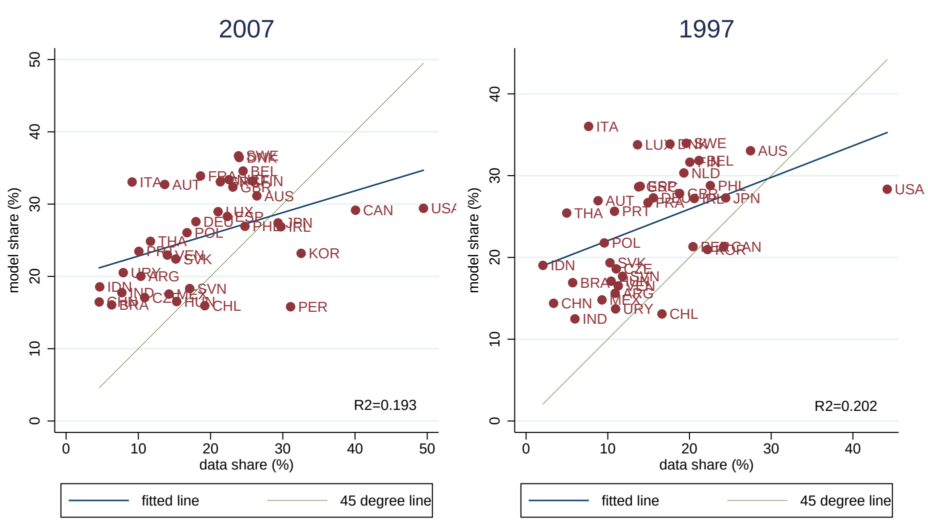


Figure 1.6: Change in share of skill abundance: model VS data

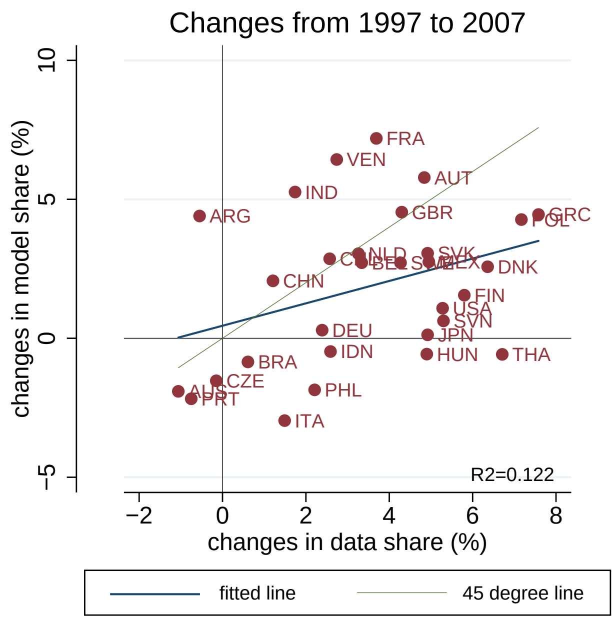


Figure 1.7: Share of skill abundance: model VS TFP-adjusted data

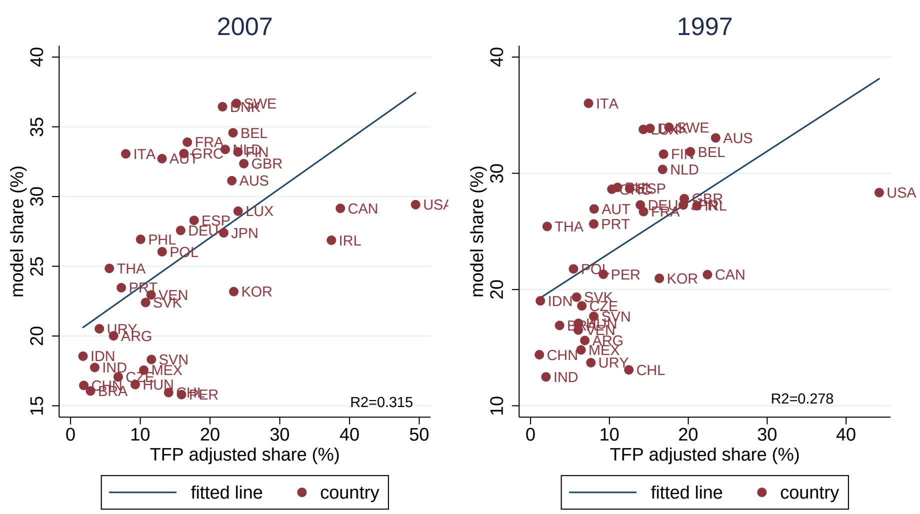


Figure 1.8: Change in share of skill abundance: model VS TFP-adjusted data

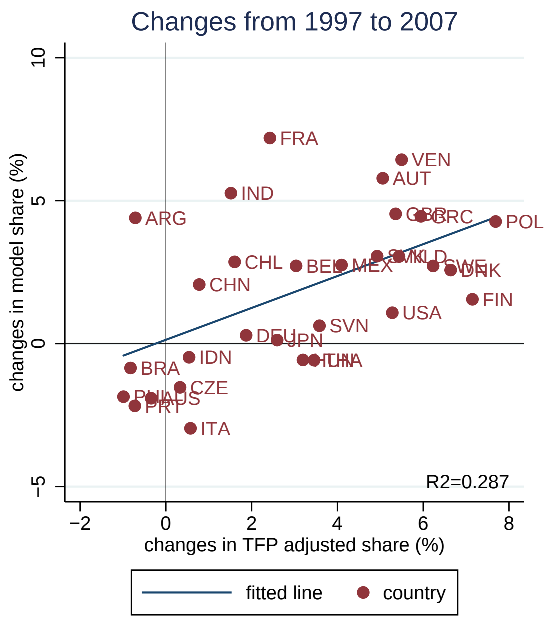
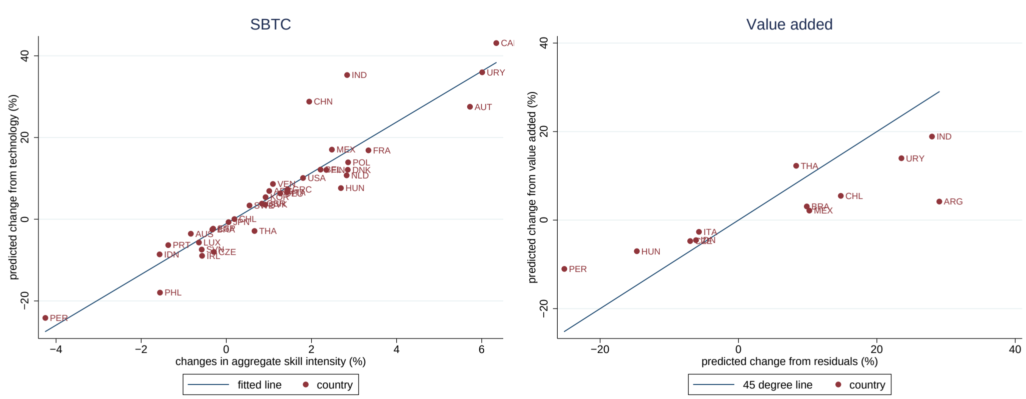


Figure 1.9: Changes in the skill premium: baseline



Notes: The left panel plots the skill premium due to technical change against the average changes in the skill intensity, which is weighted by the production shares in 1997. The right panel plots the skill premium due to changes in value added share against that of the model residuals.

Figure 1.10: Changes in the skill premium: baseline VS standard model

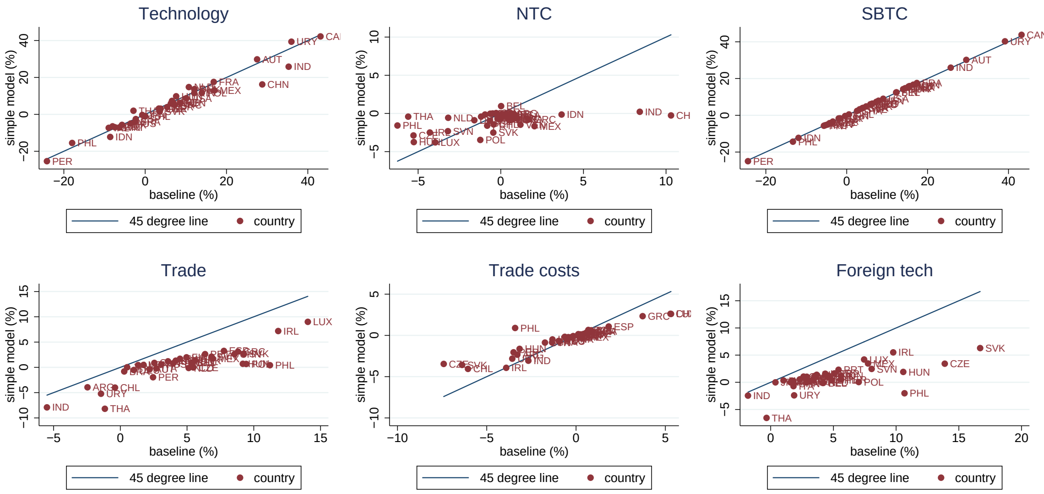
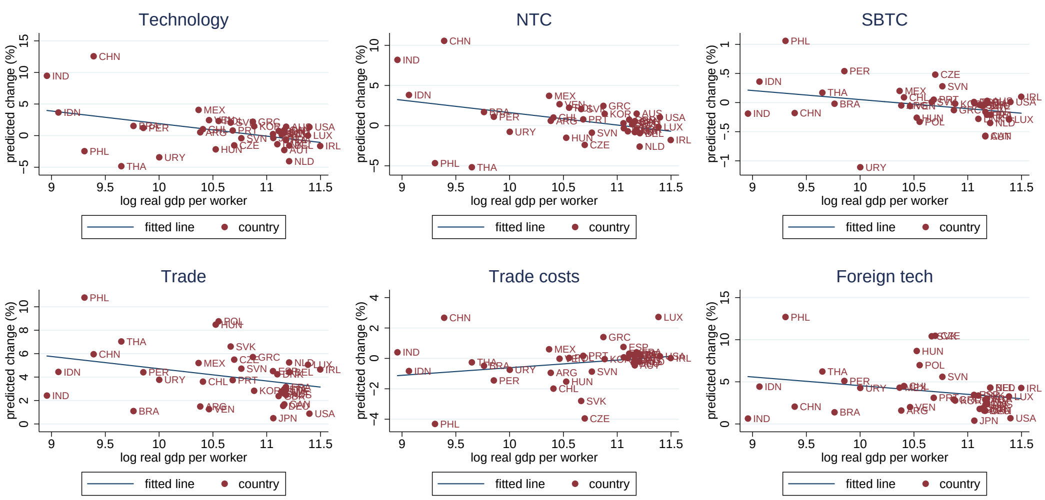


Figure 1.11: Effects of structural change on the skill premium



Notes: The upper panels plot the differences in the skill premium between the baseline and standard model implied by technology shocks, against the log real income per worker in 2007. The lower panels plot the differences implied by trade shocks.

Figure 1.12: Changes in production share: US

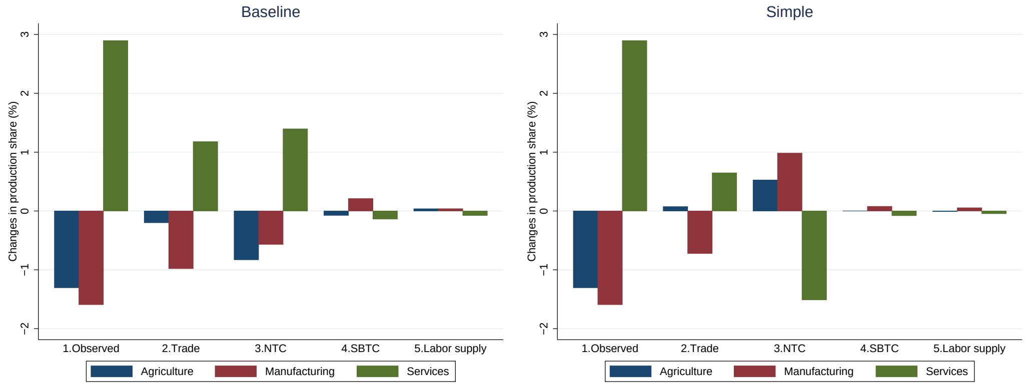


Figure 1.13: Changes in production share: China

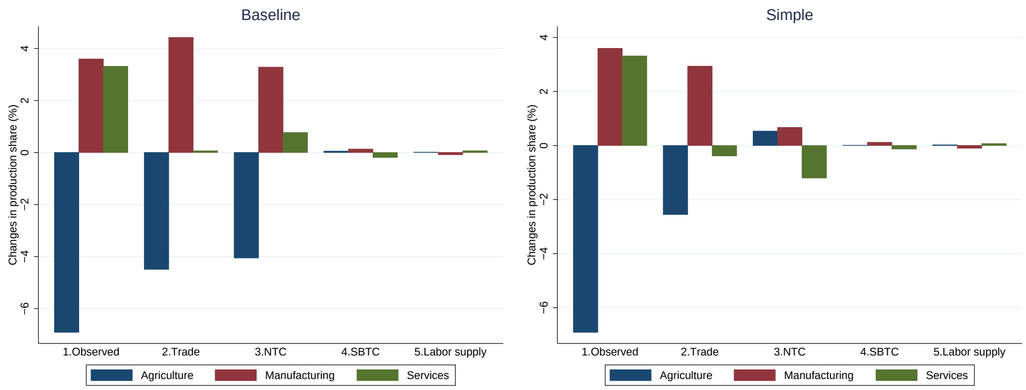


Figure 1.14: Labor reallocation: baseline US

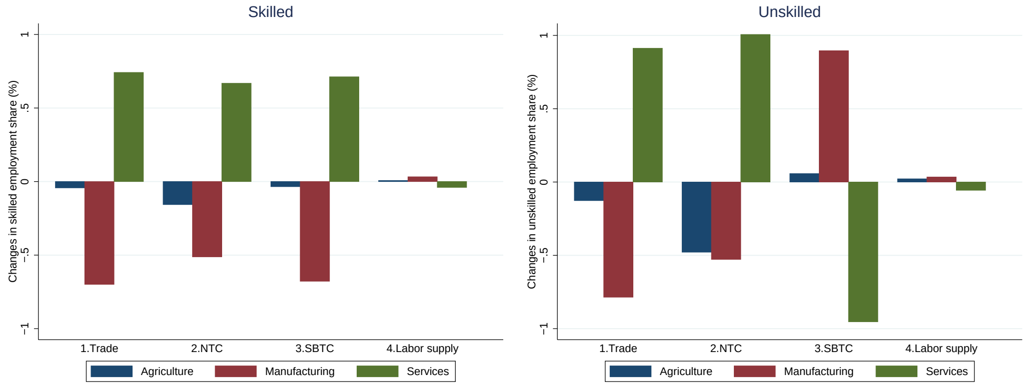
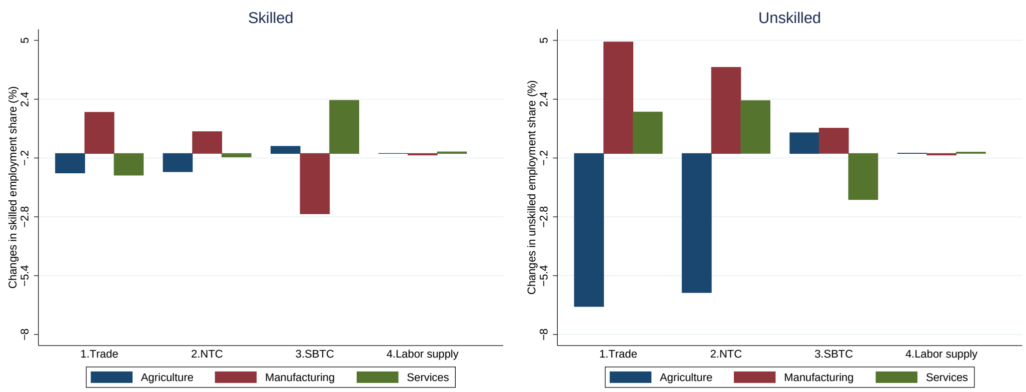


Figure 1.15: Labor reallocation: baseline China



Chapter 2: Intermediates Specialization and Gains from Trade

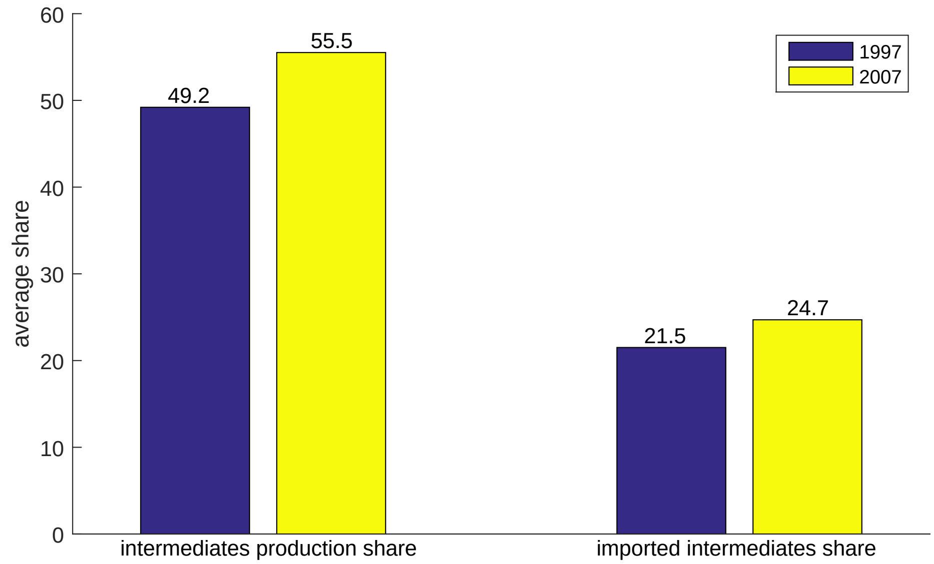
2.1 Introduction

The extensive trade liberalization in the last two decades has been characterized by a large increase in trade in intermediate inputs.[1] A related but less explored fact is the rise in intermediates cost share in production, which we document in Figure 2.1. This share increased from 49.2% to 55.5% worldwide for manufacturing between 1997 and 2007. Figure 2.1 also reveals that the imported intermediates share—defined as the ratio of expenditures on imported intermediates to total intermediates—has increased worldwide from 21.5% to 24.7%. These facts suggest that international trade may play a role in the growth in intermediates production share.

It is well known that international trade increases the benefits to production specialization. In standard models this specialization occurs as production is reallocated *across* firms with fixed technologies to explore economies of scale and comparative advantage. In this paper, we examine the impact of international trade on welfare and the production structure when heterogeneous firms can adopt more

[1] See for example Johnson and Noguera (2012, 2016).

Figure 2.1: Intermediates production and imported intermediates share in world manufacturing



Source: Global Trade Analysis Project (GTAP) v5 and v8.

Notes: The figure plots the average intermediates production and imported intermediates share in manufacturing across countries in the GTAP (a total of 67). The weights are total production costs for intermediates production share and total intermediates expenditure for imported intermediates share.

specialized technologies so that there is specialization *within* a firm. To this end, we first develop a theoretical framework where reductions in trade costs increase the average intermediates production share in the economy. Second, we study the implications of our framework on trade share of intermediates and the welfare gains from trade.

Our framework builds on the heterogeneous firm trade model à la Melitz (2003). Firms choose between two types of production technology, one utilizes only primary factors such as labor, and the other utilizes both primary factors and intermediate inputs sourced from other firms. We assume that the intermediates technology has lower unit cost but requires the firm to pay a higher fixed cost.[2] [3] Therefore only firms that are productive enough use intermediates in production.[4]

The key feature of our framework is that the productivity advantage of using intermediates, henceforth the *specialization premium*, is endogenous to the available intermediate inputs in the economy via the love of variety setup. Reductions in trade costs bring in new imported intermediates, which lowers the price of intermediates in the economy. All else equal, this increases the specialization premium so that more firms find it profitable to use intermediates. Moreover, overall demand for intermediates increases in the economy both because there is an increase in the fraction of adopters and the most productive firms that already upgraded expands. This further induces more firms to adopt the intermediates technology so that the average intermediates' production share in the economy increases.

Therefore, a reduction in trade cost generates an increase in the trade share of intermediates relative to final consumption goods because the intermediates production share rises. Thus, welfare gains from trade are larger relative to a model in which the unit cost saving from the advanced technology is fixed.

In addition, the flexibility of our framework allows us to look at the effects

[2] This is similar to models with technology upgrading where firms pay a fixed cost to use a lower unit cost technology.

[3] There are two reasons why the unit cost of the intermediates technology is lower. First, firms can source cheaper imported intermediate inputs. Second, utilizing imported intermediates increases firm productivity, as documented by Amiti and Konings (2007) for Indonesia, and Halpern et al. (2015) for Hungary.

[4] One interpretation of this technology is that the less productive firms must use their primary input for all tasks (for e.g., producing their own intermediates and assembling them), whereas the more productive ones can afford a technology that uses more efficient purchased intermediates so that its primary input can specialize in certain tasks (e.g. assembly).

of trade liberalization on non-exporters. To do so we focus on the case where all exporters already use intermediates so that trade costs can affect the technology decisions of purely domestic firms.

In order to assess the quantitative relevance of the endogenous specialization premium generated in our framework, we calibrate our two symmetric country, one sector setting to the U.S. manufacturing sector from 2000 to 2007. In our calibrated model, the evolution of the intermediates production share can be well explained by variations in import penetration during this period.

To gauge how much additional gains from trade is due to the endogenous specialization premium, we contrast the impact of trade cost reductions relative to a model where the specialization premium is fixed. We find that endogenous specialization premium contributes to around 20% of the overall welfare gains from trade relative to autarky in our framework.

Closely related to our paper is the work by Yi (2003, 2010), who uses multi-stage production to explain the growth in world trade volumes since the 1980s and the home bias in trade. Instead of using multi-stage production, in our framework all goods are used both for final consumption and intermediates as in most quantitative trade models. While both approaches imply an increase in the trade share of intermediates after a reduction in trade costs, our framework also implies an increase in the average intermediates' production share in the economy, whereas in the models with multi-stage production it is fixed.[5]

[5]The intermediates' production share is also fixed in the work by Fieler et al. (2014), where firms substitute high quality for low quality intermediates due to lower price of high quality intermediates after trade with high income countries.

Our paper also relates to the recent literature that studies firm heterogeneity in importing. For example, Antras et al. (2014) builds a framework where firms differ in the number of destinations they source for intermediates, and Ramanarayanan (2014) develops a framework where firms differ in the share of intermediates that are imported. Our framework does not have firm heterogeneity in the above two dimensions, but firms are different in terms of total share of intermediates used in production.

Moreover, our paper relates to the recent literature that focuses on the welfare gains from trade. We highlight the role of endogenous specialization premium in generating larger welfare gains from trade by comparing to a special case of our model with a fixed specialization premium. In the spirit of Melitz and Redding (2015), we show that the same reductions in trade costs imply larger welfare gains under endogenous specialization premium when the two frameworks have the same initial aggregate outcomes. Using the sufficient statistics approach as in Arkolakis et al. (2012), we also show that in the fixed specialization premium framework the gains from trade can be represented as a simple function of three sufficient statistics: the degree of openess, the trade elasticity, and the fixed share of intermediates in production. However, in our setting with an endogenous specialization premium that is no longer possible; we now require information on the specialization premium. Moreover, in the fixed specialization model, trade liberalization leaves the wage share of national income unchanged since real wages and profits (due to restricted entry) increase at similar rates, but with an endogenous premium, profits increase faster than wages. Thus the endogenous specialization channel implies a lower share of wages in national income due to liberalization, which is consistent with recent declines in that share for some countries.[6]

Finally, our framework implies that an increase in market size increases the specialization premium. Therefore, a larger market size increases the degree of specialization within the firm, as illustrated in Chaney and Ossa (2013). This also implies that welfare gains from trade depend on the size of initial market. In a version of our framework with free entry, we show that a reduction in trade cost increases the number of potential entrants and generates larger welfare gains than our fixed number of entrants benchmark. This result is consistent with the findings by Goldberg et al. (2010) that lower import tariffs in India accounted for on average 31% of the new products introduced by domestic firms (captured in our framework by new entry) through firm's access to new imported varieties.

The rest of the paper is organized as follows. Section 2.2 presents some cross country evidence on changes in intermediates production share and imported intermediates share. Section 2.3 and 2.4 develop the theoretical framework and solve for the equilibrium. Section 2.5 derives some comparative statics on trade share of intermediates and welfare gains from trade. Section 2.6 takes our theoretical framework to the data on U.S. manufacturing. Section 2.7 investigates the robustness of the implications of our framework under alternative model specifications. Section 2.8 concludes.

[6]This channel implies a potential for distributional impacts if we allow profits to be unevenly redistributed across households. We implicitly assume profits are evenly redistributed to all households but conjecture that the aggregate results (other than income distribution) would be similar under uneven shares.

2.2 Cross Country Evidence

In this section we provide some cross country evidence on the rising shares of intermediates in manufacturing production and trade from 1997 to 2007. This will provide some motivation for our focus on intermediates and for certain elements of the model.

The changes in intermediates production share, defined as the ratio of intermediates expenditure to total production cost for 67 countries is shown in Table 2.1. The first column decomposes the data in Figure 2.1 into 9 manufacturing industries.

Table 2.1: Changes in intermediates production share: 1997-2007 (%)

	intermediates production share	within	between
All manu	6.3	3.7	2.6
Food	-0.7	-2.2	1.5
Textile	3.1	0.2	2.9
Wood	3.5	1.3	2.2
Chemical	11.2	9.1	2.1
Metal	6.2	3.3	3.0
Motor	5.8	4.7	1.2
Electronic	8.7	2.9	5.8
Machine	7.9	4.5	3.4
Rest manu	2.2	1.2	1.0

Notes: The table presents the average percentage changes in intermediates production share from 1997 to 2007 across 67 countries in the manufacturing sector, weighted by total production costs. Intermediates production share in the first column is defined as the total expenditure on intermediates over total production cost. The last two columns decompose the changes in the 1st column into within and between industry changes.

First, we note that the share increased by at least 2 percentage points in all but one industry.

Second, we decompose the change into growth within countries and production reallocation towards countries with higher share of intermediates using the following formula:

$$\begin{aligned}\Delta\alpha^k &= \sum_i w_i^k(07)\alpha_i^k(07) - \sum_i w_i^k(97)\alpha_i^k(97) \\ &= \underbrace{\sum_i \bar{w}_i^k \left[\alpha_i^k(07) - \alpha_i^k(97)\right]}_{\text{within}} + \underbrace{\sum_i \bar{\alpha}_i^k \left[w_i^k(07) - w_i^k(97)\right]}_{\text{between}},\end{aligned} \tag{2.1}$$

where k stands for industry, i stands for country, and $\bar{w}_i^k = \frac{1}{2}\left[w_i^k(07) + w_i^k(97)\right]$, $\bar{\alpha}_i^k = \frac{1}{2}\left[\alpha_i^k(07) + \alpha_i^k(97)\right]$ denote the average weights and intermediates share between the two periods. In the penultimate column of Table 2.1 we see that the within change accounts for nearly 60% of the effect for manufacturing as a whole and it is positive for all industries except food. The last column shows that in each industry there is production reallocation towards countries with higher intermediate production share.

Third, instead of computing the weighted average, the first three columns of Table 2.2 present the median and simple average changes in intermediates production share across countries. The main observation is that the magnitudes of the increases in intermediates production share are significantly smaller for almost all industries under the median and simple average. The reason is that large countries tend to have larger increases in intermediates production share, suggesting that firms need to reach some scale to utilize intermediates.

Having established the fact that the aggregate intermediates production share in manufacturing has increased over the period, we then ask what factors might be driving this rise. The fourth column of Table 2.2 reveals that for all industries

Table 2.2: Intermediates production share and imported intermediates share (%)

	%Δ in production share			%Δ in imported int share			
	weighted avg	median	simple avg	weighted avg	median	simple avg	correlation
All manu	6.3	0.6	0.4	3.2	0.8	0.1	17.2
Food	-0.7	-2.0	-3.2	0.1	1.2	0.3	7.7
Textile	3.1	-1.3	-2.3	-1.7	2.0	1.5	29.2
Wood	3.5	0.2	0.0	0.0	0.3	-0.4	26.6
Chemical	11.2	6.2	5.3	6.1	1.0	0.8	27.4
Metal	6.2	4.0	3.2	4.5	3.9	3.6	23.3
Motor	5.8	0.6	0.2	3.7	0.6	1.5	53.9
Electronic	8.7	-1.4	-2.1	0.3	-5.9	-5.7	53.8
Machine	7.9	2.7	1.1	0.9	-0.8	-2.4	44.6
Rest manu	2.2	4.2	1.4	1.8	0.8	1.7	50.8

Notes: The last column presents the correlation between the weighted average changes in intermediates production share and imported intermediates share across 67 countries in the sample.

except textiles, the imported intermediates share, defined by the ratio of expenditures on imported intermediates to total intermediates, has increased. It suggests that international trade may be responsible for the rising intermediates production share. The last column of Table 2.2 further supports the hypothesis by computing the simple correlation between changes in intermediates production share and imported intermediates share across countries, which is positive for all industries.

The positive correlations in table 2.2 may be driven by specific countries that have liberalized and adopted more intermediates. Column two of table 2.3 presents the regression results when we control for country specific changes. The positive correlation is still there. The result is also robust to industry specific changes and removing outliers. To address the concern that some of the correlation is mechanical, the last two columns of table 2.3 presents the results when we instrument the changes

Table 2.3: Changes in intermediates production share and imported intermediates share from 1997 to 2007: pooled estimation

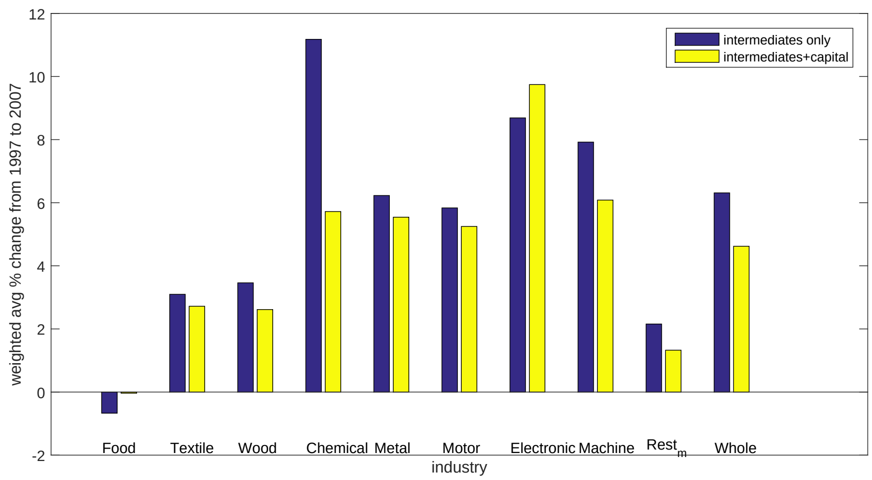
	Δ Intermediates production share					
	OLS				2SLS	1st stage
Δ Imported intermediates share	0.35	0.49	0.49	0.38	0.32	
	(0.06)	(0.04)	(0.04)	(0.03)	(0.19)	
Δ Tariff						0.19
						(0.08)
Country FE		Yes	Yes	Yes	Yes	Yes
Industry FE			Yes	Yes	Yes	Yes
No outliers				Yes		
N	603	603	603	603	603	603

Notes: robust standard errors in parentheses. The table presents the coefficients of regressing changes in intermediates production share on imported intermediates share pooled across 9 manufacturing industries and 67 countries. The unit of observation is the change in intermediates production share from 1997 to 2007 in a country industry. The instrument for changes in imported intermediates share is the average changes in destination country tariff weighted by 1997 bilateral import share. The last column shows the first stage results. The coefficients of the third column differ from the second column in the third decimal place.

in imported intermediates share with average changes in import tariffs. We see that the positive correlation remains and the first stage result indicates the validity of the instrument.

Finally, we investigate whether substitution of production factors is between intermediates and labor, capital or both. We compute changes in capital augmented intermediates production share, defined as the sum of expenditures on intermediates and capital over total production cost, and compare to our previous measure of intermediates share in Figure 2.2. We see that the two measures give similar

Figure 2.2: Changes in intermediates production share (%): robustness to capital



Notes: The figure compares the average percentage changes in intermediates production share under two definitions. The ones that include capital (right bar) is computed as the sum of expenditures on intermediates and capital over total production cost in each industry.

magnitudes in changes in all industries except chemicals.[7] Therefore in our theoretical framework we focus only on substitution between labor and intermediates and abstract from capital.

2.3 Theoretical Framework

The trade model with one sector and two symmetric countries is based on Melitz (2003) and Chaney (2008). Each country is endowed with L units of labor.

[7]We provide additional evidence for the U.S. manufacturing when we conduct quantitative exercise.

2.3.1 Preferences

Consumers in each country have the same preferences over the differentiated varieties according to the standard CES aggregator

$$U = \left(\int\limits_{\omega \in \Omega} q(\omega)^{\frac{\sigma-1}{\sigma}} d\omega \right)^{\frac{\sigma}{\sigma-1}}, \quad \sigma > 1, \tag{2.2}$$

where Ω is the set of domestically produced and imported varieties available to consumers. This gives rise to the following consumer demand for variety ω:

$$q(\omega) = EP^{\sigma-1} p(\omega)^{-\sigma}, \tag{2.3}$$

with the associated price index

$$P = \left(\int_{\omega \in \Omega} p(\omega)^{1-\sigma} d\omega \right)^{1/(1-\sigma)}, \tag{2.4}$$

where $p(\omega)$ is the price of variety ω and E is the aggregate consumer expenditure.

2.3.2 Technology

There is a measure M of potential entrants in each country and the market structure is monopolistic competition. Each firm j owns a blueprint to produce a single variety with productivity $\varphi(j)$, which is the realization of a random variable φ distributed as pareto:

$$G(\varphi) = \mathbf{Pr}(\varphi(j) \leq \varphi) = \begin{cases} 1 - \left(\frac{\varphi_{\min}}{\varphi} \right)^k & \varphi \geq \varphi_{\min}, \\ 0 & \text{otherwise,} \end{cases} \tag{2.5}$$

drawn independently across each firm in each country. Here, the location parameter $\varphi_{\min}$ reflects the lower bound of the productivity distribution, and the shape parameter k is an inverse measure of the dispersion of productivities.

After productivity $\varphi(j)$ is realized, each firm chooses between two types of production technologies with constant returns to scale and decides whether to enter the market. The inferior technology uses only labor and requires the firm to pay a fixed cost of f_n units of labor. The advanced technology combines the services of both labor and *intermediates* sourced from other firms, but requires the firm to pay a larger fixed cost of $f_n + f_a$ units of labor. We assume that the intermediates' bundle is the same as the consumption bundle, which implies that both have the same price P.[8] [9] This gives rise to the following unit cost function:

$$c_v(\varphi) = \begin{cases} \frac{1}{\varphi\phi} w^{1-\alpha} P^{\alpha} & v = a, \text{ pays } f_n + f_a, \\ \frac{w}{\varphi} & v = n, \text{ pays } f_n, \end{cases} \tag{2.6}$$

where w is the wage rate and ϕ is the fixed productivity change from using intermediates. We assume that $c_a(\varphi) < c_n(\varphi)$ so that firms trade off lower variable costs from using intermediates with larger fixed cost of production.

This formulation is isomorphic to one where the firm pays f_n and uses a fraction of labor to produce inputs in house using a linear technology and the remaining fraction, $1 - \alpha$, to assemble it. Thus we can interpret the technology adoption as one where labor is released from producing less efficient intermediates to specializing in other tasks. In appendix B.2, we show that our framework is invariant to a model with two-stage production where firms have the option to specialize in more productive tasks within the firm.

[8]It can be rationalized with competitive intermediates bundle producers assembling available varieties $\omega \in \Omega$ using a CES technology with elasticity of substitution σ.

[9]Comparing with the literature on firm importing, we ignore firm heterogeneity on importing and assume that all firms using intermediates import all varieties exported by another country.

Firms also decide whether to export by paying a fixed cost of f_x units of labor and incurring a per unit iceberg cost of τ. In equilibrium, firms maximize profits by choosing technology type and deciding whether to export.

2.4 Equilibrium

In this section we solve for the equilibrium of the model in two steps. First, we solve for the firm's optimal decisions on technology adoption and exporting. Second, we solve for the general equilibrium of the economy by aggregating firm-level decisions.

2.4.1 Optimal Firm Behavior

We solve for the firm's optimal technology choice by first describing its optimal profits conditional on any given technology adoption decisions. Technology adoption decisions involve only firms serving the domestic market because we focus on the equilibrium where all exporters optimally specialize.

A firm's domestic profit given technology choice v is

$$\pi_d^v(\varphi) = [p_d(\varphi) - c_v(\varphi)]\, q_d(\varphi) - w f_v, \;\; v = n, a, \tag{2.7}$$

where $q_d(\varphi) = \left[E + \alpha \int c_a(\varphi) q(\varphi)\right] P^{\sigma-1} p_d(\varphi)^{-\sigma}$ is firm φ's demand, which is the sum of household demand for consumption and other firms' demand for intermediates. Due to CES demand the optimal price is a constant markup over unit cost:

$$p_d^v(\varphi) = \frac{\sigma}{\sigma - 1} c_v(\varphi). \tag{2.8}$$

Substituting into (2.7) gives the optimal domestic profit:

$$\pi_v(\varphi) = \frac{1}{\sigma - 1}\left(\frac{\sigma}{\sigma - 1}\right)^{-\sigma} AP^{\sigma-1}[c_v(\varphi)]^{1-\sigma} - w(f_d + \mathbf{1}(v = a)f_a), \ \ v = n, a, \quad (2.9)$$

where $A = E + \alpha \int c_a(\varphi)q(\varphi)$.

Conditional on its underlying productivity, each firm chooses the technology which yields larger profit. As the intermediates technology has strictly lower variable cost ($c_a(\varphi) < c_n(\varphi)$) but larger fixed cost of production, only firms that are productive enough have the incentive to adopt. The adoption threshold $\bar{\varphi}_a$ is the productivity at which firms are indifferent between using intermediates or not:

$$\pi_d^n(\bar{\varphi}_a) = \pi_d^a(\bar{\varphi}_a). \quad (2.10)$$

Substituting in the optimal profits (2.9) and simplifying, the adoption threshold can be expressed as:

$$\bar{\varphi}_a = \frac{(c_a^{1-\sigma} - w^{1-\sigma})^{\frac{1}{1-\sigma}}}{P}\left(\frac{wf_a}{A\tilde{\sigma}}\right)^{\frac{1}{\sigma-1}}, \quad (2.11)$$

where $c_a = \frac{c_a(\varphi)}{\varphi}$ and $\tilde{\sigma} = \frac{1}{\sigma}\left(\frac{\sigma-1}{\sigma}\right)^{\sigma-1}$. The adoption threshold is lower the larger the reductions in variable cost from using intermediates ($\frac{c_a}{w}$) and the smaller the fixed cost of adoption (f_a).

Firms also have the choice of exporting to the other country. The profit from exports given fixed exporting cost f_x and variable iceberg cost τ is

$$\pi_x(\varphi) = [p_x(\varphi) - \tau c_a(\varphi)]\, q_x(\varphi) - wf_x. \quad (2.12)$$

Constant markup pricing still holds so that

$$p_x(\varphi) = \frac{\tau\sigma}{\sigma - 1}c_a(\varphi). \quad (2.13)$$

This gives rise to the export profit of firm φ:

$$\pi_x(\varphi) = \frac{1}{\sigma - 1}\left(\frac{\sigma}{\sigma - 1}\right)^{-\sigma} AP^{\sigma-1}[\tau c_a(\varphi)]^{1-\sigma} - wf_x. \tag{2.14}$$

Lastly, the presence of fixed costs of production (exporting) implies that not all firms sell domestically (export). The productivity threshold of domestic producers $\bar{\varphi}_n$ is given by firms who just break even:

$$\pi_d^n(\bar{\varphi}_n) = 0. \tag{2.15}$$

Simplifying, the domestic threshold is

$$\bar{\varphi}_n = \frac{w}{P}\left(\frac{wf_n}{A\tilde{\sigma}}\right)^{\frac{1}{\sigma-1}}. \tag{2.16}$$

Similarly, the export threshold $\bar{\varphi}_x$ is given by the firms who break even in the export market:

$$\pi_x(\bar{\varphi}_x) = 0. \tag{2.17}$$

Simplifying we have

$$\bar{\varphi}_x = \frac{\tau c_a}{P}\left(\frac{wf_x}{A\tilde{\sigma}}\right)^{\frac{1}{\sigma-1}}. \tag{2.18}$$

We focus our analysis on the equilibrium in which $\bar{\varphi}_n < \bar{\varphi}_a < \bar{\varphi}_x$ because we want to investigate the effects of trade liberalization on the production structure of a large set of firms, not only the relatively small share that engage in international trade. Both the adoption threshold and most implications of our framework depend crucially on the specialization premium:

Definition 2.4.1. *The specialization premium, which captures the unit cost savings from adoption, is defined as*

$$s_a = \frac{w}{c_a} = \phi\left(\frac{w}{P}\right)^{\alpha}. \tag{2.19}$$

The specialization premium is increasing in the fixed productivity effects from adoption (ϕ) and in the relative cost of labor to intermediates ($\frac{w}{P}$). It is *endogenous* in our framework because it depends on the price of the intermediates bundle.

2.4.2 General Equilibrium

We now aggregate the firm-level optimal decisions and derive the market clearing conditions. We normalize $w = 1$.

Total sales in a given country are given by the sum of sales of domestic producers and exporters:

$$
\begin{aligned}
Y &= Y_n + Y_a + Y_x \\
&= M \left[\int_{\bar{\varphi}_n}^{\bar{\varphi}_a} p_d^n(\varphi) q_d^n(\varphi) dG(\varphi) + \int_{\bar{\varphi}_a}^{\infty} p_d^a(\varphi) q_d^a(\varphi) dG(\varphi) + \int_{\bar{\varphi}_x}^{\infty} p_x(\varphi) q_x(\varphi) dG(\varphi) \right].
\end{aligned}
\tag{2.20}
$$

By goods market clearing this must equal total expenditure (X) in that market, which is the sum of household and firm expenditures:

$$Y = X = L + \Pi + \alpha \frac{\sigma - 1}{\sigma} (Y - Y_n), \tag{2.21}$$

where Π is total profits of all firms, $L + \Pi = E$ is total household expenditure, and $\alpha \frac{\sigma-1}{\sigma}(Y - Y_n) = \alpha \int c_a(\varphi) q(\varphi)$ is total firm expenditure. So we have in the equilibrium $X = A = E + \alpha \int c_a(\varphi) q(\varphi)$.

Labor market clearing implies that total payments to labor equals the labor production and fixed costs:

$$L = \frac{\sigma - 1}{\sigma}[Y_n + \alpha(Y - Y_n)] + M\left[f_d \int_{\bar{\varphi}_n}^{\bar{\varphi}_a} dG(\varphi) + f_a \int_{\bar{\varphi}_a}^{\infty} dG(\varphi) + f_x \int_{\bar{\varphi}_x}^{\infty} dG(\varphi)\right] \tag{2.22}$$

The two countries are symmetric so trade balance always holds.

The static trade equilibrium is defined as follows: Given price index P and total sales X:

1. Consumers maximize the utility in (2.2);
2. Firms maximize profits by deciding whether to produce, adopt or export;
3. Goods and labor markets clear.

2.4.3 Existence and Uniqueness of Equilibrium

The rankings of productivity thresholds $\bar{\varphi}_n < \bar{\varphi}_a < \bar{\varphi}_x$ place restrictions on the specialization premium. First, $\bar{\varphi}_n < \bar{\varphi}_a$ implies that the specialization premium cannot be too large, else all firms become adopters. Simplifying $\bar{\varphi}_n < \bar{\varphi}_a$ we have

$$s_a < \left(\frac{f_n + f_a}{f_n}\right)^{\frac{1}{\sigma - 1}}. \tag{2.23}$$

Second, $\bar{\varphi}_a < \bar{\varphi}_x$ implies that the specialization premium is large enough to induce pure domestic firms to adopt. Therefore,

$$s_a > \left(\frac{\tau^{\sigma-1} f_x}{\tau^{\sigma-1} f_x - f_a}\right)^{\frac{1}{\sigma - 1}} > 1. \tag{2.24}$$

Observe that the last inequality is the necessary condition for the existence of specialization premium. We summarize the above findings in the following lemma:

Lemma 2.4.1. *A necessary and sufficient condition for the existence of equilibrium in which $\bar{\varphi}_n < \bar{\varphi}_a < \bar{\varphi}_x$ is for the specialization premium to be bounded as follows:*

$$\left(\frac{\tau^{\sigma-1} f_x}{\tau^{\sigma-1} f_x - f_a}\right)^{\frac{1}{\sigma-1}} < s_a < \left(\frac{f_n + f_a}{f_n}\right)^{\frac{1}{\sigma-1}}. \tag{2.25}$$

In the following we derive a sufficient condition for the existence and uniqueness of equilibrium in our framework. We can write the equilibrium of the model in terms of only the price index and specialization premium.

$$\begin{aligned} P = &\Big(\Lambda_2 \left[\lambda_l(s_a,\tau)\right]^{1-\frac{k}{\sigma-1}} \\ &\times \left\{(f_n)^{1-\frac{k}{\sigma-1}} + \left[(s_a)^{\sigma-1} - 1\right]^{\frac{k}{\sigma-1}} (f_a)^{1-\frac{k}{\sigma-1}} + \tau^{-k}(s_a)^k (f_x)^{1-\frac{k}{\sigma-1}}\right\}\Big)^{-\frac{1}{k}}, \end{aligned} \tag{2.26}$$

$$P_s \equiv P = \left(\frac{\phi}{s_a}\right)^{\frac{1}{\alpha}}, \tag{2.27}$$

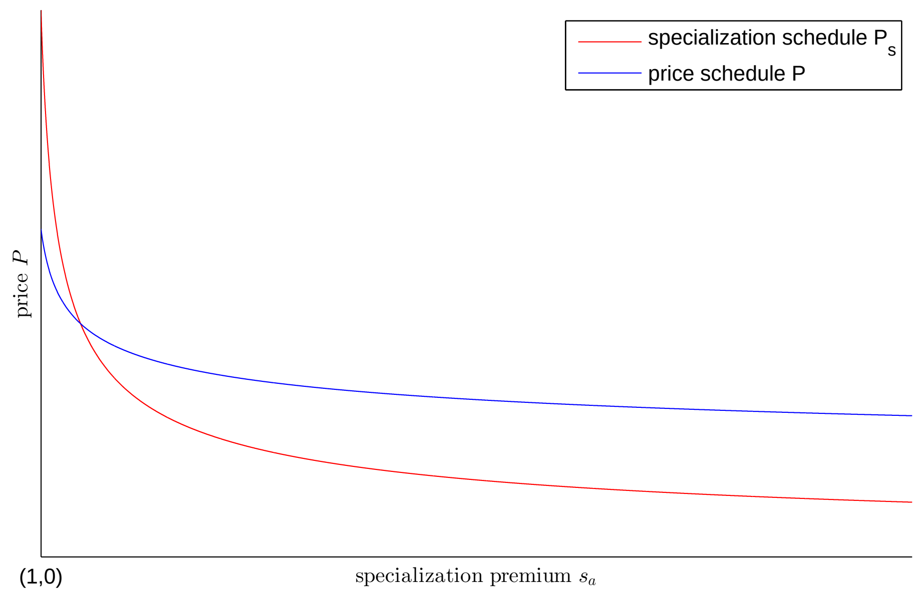
where $\lambda_l(s_a,\tau) = \frac{\sigma-1}{\sigma}\left(\frac{(f_n)^{1-\frac{k}{\sigma-1}} - \left[(s_a)^{\sigma-1}-1\right]^{\frac{k}{\sigma-1}-1}(f_a)^{1-\frac{k}{\sigma-1}}}{(f_n)^{1-\frac{k}{\sigma-1}} + \left[(s_a)^{\sigma-1}-1\right]^{\frac{k}{\sigma-1}}(f_a)^{1-\frac{k}{\sigma-1}} + \tau^{-k}(s_a)^k (f_x)^{1-\frac{k}{\sigma-1}}}\right)\alpha + \frac{\sigma-1}{\sigma}(1-\alpha) + \frac{k-\sigma+1}{\sigma k}$ is the labor share and $\Lambda_2 = (\tilde{\sigma})^{\frac{k}{\sigma-1}-1} L^{\frac{k}{\sigma-1}-1}\left(\frac{\sigma}{\sigma-1}\right)^{1-\sigma} \frac{k}{k-\sigma+1} M\left(\varphi_{\min}\right)^k$.[10] In Figure 2.3, we plot the equilibrium of the model using two curves involving the price schedule (2.26) and the specialization schedule (2.27). Therefore to prove existence and uniqueness we need to show that the intersection in Figure 2.3 is unique. The following proposition provides sufficient conditions for this to hold.

Existence

For existence, first note that both the price schedule (P) and specialization schedule (P_s) are continuous in s_a for $s_a \geq 1$.

[10]See appendix B.3.2 for details.

Figure 2.3: Existence and uniqueness of equilibrium



Second, when $s_a \to \infty$, the price schedule is bounded above 0, since for a large enough specialization premium $\bar{s}_a > 0$, all firms use intermediates and in such an economy $P(\bar{s}_a) > 0$ because further increases in specialization premium do not affect the price schedule. Moreover, the specialization schedule approaches 0 as $s_a \to \infty$. Thus there exists a $b > 0$ such that $P(s_a) > P_s(s_a)$ when $s_a > b$.

Third, both the price schedule and specialization schedule are bounded at $s_a = 1$. Therefore, a sufficient condition for the existence of equilibrium is $P(1) < P_s(1)$, which is ensured if ϕ is large enough because $P_s(1) = \phi^{\frac{1}{\alpha}}$ and the price schedule does not involve ϕ.

Uniqueness

For uniqueness, in addition to the conditions that ensure the existence of equilibrium, we require that at any intersection we have $\frac{\partial \ln P}{\partial \ln s_a} > \frac{\partial \ln P_s}{\partial \ln s_a}$ as shown in Figure 2.3. Using (2.27), a sufficient condition for the uniqueness of equilibrium is

$$\frac{\partial \ln P}{\partial \ln s_a} > -\frac{1}{\alpha}, \quad \text{for } s_a \geq 1. \tag{2.28}$$

Thus when $\alpha \to 0$, there always exists a unique equilibrium because the slope of the price schedule is finite and independent of α given s_a.

We summarize the results above in the following lemma:

Lemma 2.4.2. *There exists a* $\bar{\phi} > 0$ *such that the model has an equilibrium with* $s_a > 1$*. Moreover, this equilibrium is unique for any* $\alpha < \bar{\alpha}$*.*

From now on, we assume that the sufficient condition for existence of a unique equilibrium (2.28) holds and proceed to derive some comparative statics.

2.5 Trade Flows and Welfare

What are the effects of reductions in trade costs on trade flows and welfare? We answer this question by deriving some comparative statics and comparing with other quantitative trade models.

Because most implications of our framework arise from endogenous specialization premium, we first derive a restricted version of our model where the specialization premium is fixed. We then highlight the implications of endogenous specialization premium on trade share of intermediates, trade elasticity, and welfare following a reduction in trade cost. Finally, we discuss the effect of initial market size on the welfare gains from trade.

2.5.1 Fixed Specialization Premium Framework

We construct the fixed specialization premium model as the following:

Definition 2.5.1. *The fixed specialization premium framework has the same settings and parameters as our framework (f_n, f_a, f_x, τ, M, L, σ, k, $\varphi_{\min}$), except for the unit cost function:*

$$c_v^e(\varphi) = \begin{cases} \frac{1}{\varphi e T} w^{1-\beta} P^\beta & v = a, \text{ pays } f_n + f_a, \\ \frac{1}{\varphi e} w^{1-\beta} P^\beta & v = n, \text{ pays } f_n, \end{cases} \tag{2.29}$$

where β is the fixed intermediates production share, T is the fixed productivity advantage of adopters, and e is a parameter which adjusts the size of the economy.

Notice that the fixed specialization premium model is the Bustos (2011b) type framework extended to allow all firms to use a constant β share of intermediate inputs. We can therefore parameterize the fixed specialization premium model to have the same initial equilibrium as our framework.

Proposition 2.5.1. *The fixed specialization premium model with $\beta = \alpha\lambda_a(0)$, $T = s_a(0)$, and $e = \left(\frac{P(0)}{w(0)}\right)^\beta$ has the same equilibrium as our framework, where $x(0)$ denotes an endogenous variable in the initial equilibrium of our framework. In particular, the two models have the same initial productivity thresholds, labor shares, outputs, and welfare.*

Proof. The two models have the same average intermediates production share as $\beta = \alpha\lambda_a(0)$, implying that they have the same initial sales $Y(0)$. From $T = s_a(0)$ as well as the same adoption and exporting costs, the two models have the same fractions of adopters and exporters from the definitions of productivity thresholds (2.15), (2.10), (2.17). These arguments imply that productivity thresholds are the same. Finally, the scale parameter e ensures the fixed specialization premium model to have the same price index $P(0)$ according to the definition of $\bar{\varphi}_n^e$:

$$\bar{\varphi}_n^e = \frac{e^{-1} w^{1-\beta} P^{\beta}}{P} \left(\frac{w f_n}{Y \tilde{\sigma}} \right)^{\frac{1}{\sigma - 1}}.$$

$\square$

In essence, proposition 2.5.1 generates a 1-1 mapping between our framework and the fixed specialization premium model.

2.5.2 Endogenous Specialization Premium

We now derive the effects of reductions in trade costs on various model outcomes by emphasizing the role of endogenous specialization premium. To fix ideas, effects of changes in τ on any outcome x operate through two separate channels:

$$\frac{d \ln x}{d \ln \tau} = \underbrace{\left. \frac{\partial \ln x}{\partial \ln \tau} \right|_{s_a}}_{\text{direct}} + \underbrace{\frac{\partial \ln x}{\partial \ln s_a} \frac{d \ln s_a}{d \ln \tau}}_{\text{indirect}}.$$

The first term represents the direct effect of changes in trade cost on the economy holding the specialization premium fixed, which is the only channel operating in the fixed specialization framework. Under endogenous specialization, there is also an indirect effect if trade costs affects the specialization premium, which in turn affects outcome x.

First, we show that declines in trade costs increase the specialization premium.

Lemma 2.5.1. *Declines in variable or fixed trade costs increase the specialization premium:*

$$\frac{d\ln s_a}{d\ln \tau} < 0, \quad \frac{d\ln s_a}{d\ln f_x} < 0. \tag{2.30}$$

Proof. From definition 2.4.1, $s_a = \phi\left(\frac{1}{P}\right)^{\alpha}$ thus we have

$$\frac{d\ln s_a}{d\ln \tau} = -\alpha \frac{d\ln P}{d\ln \tau}.$$

Therefore it is equivalent to show that $\frac{d\ln P}{d\ln \tau} > 0$. The effect of changes in trade cost on price index can be written as

$$\frac{d\ln P}{d\ln \tau} = \left.\frac{\partial \ln P}{\partial \ln \tau}\right|_{s_a} + \frac{\partial \ln P}{\partial \ln s_a}\frac{d\ln s_a}{d\ln \tau},$$

where the first term, $\left.\frac{\partial \ln P}{\partial \ln \tau}\right|_{s_a}$ captures the direct effect of trade costs on price given specialization premium, and the second term is the indirect effect from changes in specialization premium. Using $\frac{d\ln s_a}{d\ln \tau} = -\alpha \frac{d\ln P}{d\ln \tau}$ and re-arranging the above expression, we have

$$\frac{d\ln P}{d\ln \tau} = \left.\frac{\partial \ln P}{\partial \ln \tau}\right|_{s_a} \Bigg/ \left(1 + \alpha \frac{\partial \ln P}{\partial \ln s_a}\right).$$

The direct effect, $\left.\frac{\partial \ln P}{\partial \ln \tau}\right|_{s_a} > 0$ because reductions in trade costs decrease the price index due to lower price of existing varieties and availability of new ones. From the sufficient condition of the existence of an unique equilibrium (2.28), $1+\alpha\frac{\partial \ln P}{\partial \ln s_a} > 0$. Therefore $\frac{d\ln P}{d\ln \tau} > 0$. □

Lemma 2.5.1 implies that if changes in specialization premium also affect an economic outcome, the indirect effect is non-zero. The next lemma shows that endogenous specialization premium amplifies the changes in fractions of adopters and exporters.

Lemma 2.5.2. *Declines in variable or fixed trade costs increase both the fractions of adopters and exporters:*

$$\begin{aligned} \frac{d\ln\chi_a}{d\tau} < 0, \quad \frac{d\ln\chi_a}{df_x} < 0; \\ \frac{d\ln\chi_x}{d\tau} < 0, \quad \frac{d\ln\chi_x}{df_x} < 0. \end{aligned} \tag{2.31}$$

Moreover, the responses are larger under endogenous specialization premium given the same reductions in trade costs.

Proof. By definition, $\chi_a = \frac{1-G(\bar{\varphi}_a)}{1-G(\bar{\varphi}_n)}$ and $\chi_x = \frac{1-G(\bar{\varphi}_x)}{1-G(\bar{\varphi}_n)}$. Utilizing the expressions for pareto (2.5) and productivity thresholds (2.11), (2.16), (2.18), we get

$$\begin{aligned} \chi_a &= \left(\frac{\bar{\varphi}_a}{\bar{\varphi}_n}\right)^{-k} = \left[(s_a)^{\sigma-1} - 1\right]^{\frac{k}{\sigma-1}} \left(\frac{f_a}{f_n}\right)^{-\frac{k}{\sigma-1}}, \\ \chi_x &= \left(\frac{\bar{\varphi}_x}{\bar{\varphi}_n}\right)^{-k} = \left(\frac{\tau}{s_a}\right)^{-k} \left(\frac{f_x}{f_n}\right)^{-\frac{k}{\sigma-1}}. \end{aligned}$$

Therefore,

$$\begin{aligned} \frac{d\ln\chi_a}{d\ln\tau} &= \left.\frac{\partial\ln\chi_a}{\partial\ln\tau}\right|_{s_a} + \frac{\partial\ln\chi_a}{\partial\ln s_a}\frac{d\ln s_a}{d\ln\tau} \\ &= 0 + k\frac{(s_a)^{\sigma-1}}{(s_a)^{\sigma-1}-1}\frac{d\ln s_a}{d\ln\tau} \\ &< 0, \end{aligned}$$

$$\begin{aligned} \frac{d\ln\chi_x}{d\ln\tau} &= \left.\frac{\partial\ln\chi_x}{\partial\ln\tau}\right|_{s_a} + \frac{\partial\ln\chi_x}{\partial\ln s_a}\frac{d\ln s_a}{d\ln\tau} \\ &= (-k) + k\frac{d\ln s_a}{d\ln\tau} \\ &< 0, \end{aligned}$$

where last steps we use $\frac{ds_a}{d\tau} < 0$ from lemma 2.5.1. Because the indirect effects (terms involving $\frac{d \ln s_a}{d \ln \tau}$) are negative, endogenous specialization premium reinforces the direct effects. $\square$

Intuitively, lemma 2.5.2 says that after a reduction in trade cost, a larger fraction of firms use intermediates as the specialization premium goes up.[11] There is also a larger share of exporters due to lower unit cost for exporters generated by larger specialization premium. Both effects are absent under fixed specialization premium. Moreover, the indirect effect is the only force that generates an increase in the fraction of adopters so that endogenous specialization premium has the possibility to generate more domestic adopters.

Endogenous specialization premium also generates larger increase in the sales share of adopters as we show in the following lemma:

Lemma 2.5.3. *Declines in variable or fixed trade costs increase the sales share of adopters* λ_a*:*

$$\frac{d \ln \lambda_a}{d \ln \tau} < 0, \quad \frac{d \ln \lambda_a}{d \ln f_x} < 0. \tag{2.32}$$

Moreover, the response is larger under endogenous specialization premium.

Proof. It is equivalent to show that $\frac{d \ln(1-\lambda_a)}{d \ln \tau} > 0$. Aggregating firm-level sales and using the expression for pareto (2.5), sales share of non-adopters can be expressed

[11] Lemma 2.5.2 does not imply that the productivity threshold of adopters $\bar{\varphi}_a$ *decreases*. There is an effect of tougher market competition which tends to increase the threshold. In Melitz (2003), the same effect decreases the sales of the marginal exporter.

as

$$\lambda_n = 1 - \lambda_a = \frac{1 - \left[(s_a)^{\sigma-1} - 1\right]^{\frac{k}{\sigma-1}-1} (f_a/f_n)^{1-\frac{k}{\sigma-1}}}{1 + \left[(s_a)^{\sigma-1} - 1\right]^{\frac{k}{\sigma-1}} (f_a/f_n)^{1-\frac{k}{\sigma-1}} + (s_a)^k \tau^{-k} (f_x/f_n)^{1-\frac{k}{\sigma-1}}}.$$

We can again decompose it into the direct and indirect effect:

$$\frac{d\ln\lambda_n}{d\ln\tau} = \left.\frac{\partial\ln\lambda_n}{\partial\ln\tau}\right|_{s_a} + \frac{\partial\ln\lambda_n}{\partial\ln s_a}\frac{d\ln s_a}{d\ln\tau}.$$

The direct effect is $\left.\frac{\partial\ln\lambda_n}{\partial\ln\tau}\right|_{s_a} = k$. The indirect effect can be written as

$$\begin{aligned}
\frac{\partial\ln\lambda_n}{\partial\ln s_a} &= \lambda_1\frac{\partial\ln}{\partial\ln s_a}\left\{\left[(s_a)^{\sigma-1} - 1\right]^{\frac{k}{\sigma-1}-1}\right\} - \lambda_2\frac{\partial\ln}{\partial\ln s_a}\left\{\left[(s_a)^{\sigma-1} - 1\right]^{\frac{k}{\sigma-1}}\right\} \\
&\quad - \lambda_3\frac{\partial\ln}{\partial\ln s_a}\left[(s_a)^k\right] \\
&= (k-\sigma+1)\lambda_1\frac{(s_a)^{\sigma-1}}{(s_a)^{\sigma-1}-1} - k\lambda_2\frac{(s_a)^{\sigma-1}}{(s_a)^{\sigma-1}-1} - k\lambda_3 \\
&< 0,
\end{aligned}$$

where $\lambda_1 < 0$, $\lambda_2 > 0$, and $\lambda_3 > 0$ are the constant shares. Because $\frac{d\ln s_a}{d\ln\tau} < 0$, the indirect effect $\frac{\partial\ln\lambda_n}{\partial\ln s_a}\frac{d\ln s_a}{d\ln\tau} > 0$, therefore it reinforces the direct effect. □

Intuitively, sales share of intermediates users increases when trade costs fall both because exporters sell more and some domestic firms upgrade to use intermediates. Because in our framework, only the adopters use intermediates, so that the intermediates production share $\alpha\lambda_a$ also increases. Under fixed specialization framework, the intermediates production share is fixed at β. One immediate implication of proposition 2.5.3 is that the labor share is increasing in trade costs.

Lemma 2.5.4. *Declines in variable or fixed costs decrease the labor share:*

$$\frac{d\ln\lambda_l}{d\ln\tau} > 0, \quad \frac{d\ln\lambda_l}{d\ln f_x} > 0. \tag{2.33}$$

Proof. We can simplify the labor market clearing condition (2.22) with the pareto distribution (2.5), to express the labor share as:

$$\lambda_l = \frac{L}{Y} = \frac{\sigma - 1}{\sigma}\left(1 - \alpha\lambda_a\right) + \frac{k - \sigma + 1}{k\sigma}.$$ [12]

This implies that $\frac{d\lambda_l}{d\tau} = -\frac{\sigma-1}{\sigma}\alpha\frac{d\lambda_a}{d\tau}$. Together with $\frac{d\lambda_a}{d\tau} < 0$ from lemma 2.5.3, we obtain $\frac{d\lambda_l}{d\tau} > 0$. Similar reasoning gives $\frac{d\lambda_l}{df_x} > 0$. □

2.5.3 Trade Flows

We now derive the effects of changes in trade costs on the trade share of intermediates.

Proposition 2.5.2. *Declines in variable or fixed trade costs increase the trade share of intermediates, v:*

$$\frac{d\ln v}{d\ln \tau} < 0, \quad \frac{d\ln v}{d\ln f_x} < 0. \tag{2.34}$$

Proof. Since the consumption bundle is the same as the intermediates bundle, the trade share of intermediates equals their share in expenditures:

$$v = \frac{\alpha\left[(\sigma - 1)/\sigma\right]\lambda_a Y}{Y} = \frac{\sigma - 1}{\sigma}\alpha\lambda_a,$$

where $\lambda_a Y$ is the total sales of intermediates users. Applying lemma 2.5.3 completes the proof. □

The trade share of intermediates increases after reductions in trade costs because of the rising sales share of firms that use intermediates. Note that under fixed

[12] See appendix B.3 for details of the derivation.

specialization premium $v = \frac{\sigma-1}{\sigma}\beta$ is fixed because all firms use the same share of intermediate inputs.

Our framework also implies a different trade elasticity due to endogenous specialization premium. We can derive the import domestic expenditure ratio as

$$\begin{aligned}\gamma = \frac{Y_x}{Y_d + Y_a} &= \frac{(\tau/s_a)^{-k} (f_x/f_n)^{1-\frac{k}{\sigma-1}}}{1 + [(s_a)^{\sigma-1} - 1]^{\frac{k}{\sigma-1}} (f_a/f_n)^{1-\frac{k}{\sigma-1}}} \\ &= \tau^{-k} \left(\frac{f_x}{f_n}\right)^{1-\frac{k}{\sigma-1}} \left\{\frac{(s_a)^k}{1 + [(s_a)^{\sigma-1} - 1]^{\frac{k}{\sigma-1}} x}\right\},\end{aligned} \tag{2.35}$$

where $x = (f_a/f_n)^{1-\frac{k}{\sigma-1}}$. The trade elasticity, defined as the elasticity of import relative to domestic demand with respect to trade costs holding income constant, can be written as

$$\eta_\tau = \left|\frac{\partial \ln \gamma}{\partial \ln \tau}\right| = k - \left.\frac{\partial \ln S}{\partial \ln \tau}\right|_{s_a} - \frac{\partial \ln S}{\partial \ln s_a}\frac{\partial \ln s_a}{\partial \ln \tau}, \tag{2.36}$$

where $S = \frac{(s_a)^k}{1+[(s_a)^{\sigma-1}-1]^{\frac{k}{\sigma-1}} x}$.

We can interpret the first term as the partial trade elasticity in a Chaney (2008) type framework, in which the specialization premium is fixed at $s_a = 1$. The second term can be interpreted as the elasticity allowing for upgrading given a fixed $s_a > 1$. The last term captures the effect from endogenous changes in the specialization premium, which only our framework possesses.

First observe that the effect of upgrading given the specialization premium, is zero: $\frac{\partial \ln S}{\partial \ln \tau} = 0$. This is because the marginal adopter is a pure domestic firm so that changes in trade costs only affect them through the specialization premium.[13]

[13]If the marginal adopter is an exporter, this is no longer the case.

Second, the effect from endogenous specialization can be expressed as

$$\begin{aligned}\frac{\partial \ln}{\partial \ln s_a}\left\{\frac{(s_a)^k}{1+\left[(s_a)^{\sigma-1}-1\right]^{\frac{k}{\sigma-1}}x}\right\} &= k-\lambda_a^d\frac{\partial \ln}{\partial \ln s_a}\left\{\left[(s_a)^{\sigma-1}-1\right]^{\frac{k}{\sigma-1}}\right\} \\ &= k\left[1-\frac{(s_a)^{\sigma-1}}{(s_a)^{\sigma-1}-1}\lambda_a^d\right] \\ &> 0,\end{aligned} \tag{2.37}$$

where $\lambda_a^d = \frac{\left[(s_a)^{\sigma-1}-1\right]^{\frac{k}{\sigma-1}}x}{1+\left[(s_a)^{\sigma-1}-1\right]^{\frac{k}{\sigma-1}}x}$ and the inequality is derived from $\frac{(s_a)^{\sigma-1}}{(s_a)^{\sigma-1}-1}\lambda_a^d = \frac{Y_a}{Y_d+Y_a} < 1$. Because $\frac{d\ln s_a}{d\ln\tau} < 0$, endogenous specialization increases the trade elasticity. We summarize the findings in the following proposition:

Proposition 2.5.3. *The trade elasticity, defined as the elasticity of import relative to domestic demand with respect to trade costs holding income constant, can be written as*

$$\eta_\tau = \left|\frac{\partial \ln \gamma}{\partial \ln \tau}\right| = k + k\left[\frac{(s_a)^{\sigma-1}}{(s_a)^{\sigma-1}-1}\lambda_a^d - 1\right]\frac{d\ln s_a}{d\ln\tau} > k, \tag{2.38}$$

which is larger than the elasticity under no intermediates or a fixed specialization premium.

Proposition 2.5.3 shows that our framework implies a *larger* and *non-constant* trade elasticity. The intuition is that an increase in the specialization premium increases the sales of adopters, because not all domestic firms adopt and use intermediates, the trade share increases. Therefore our work complements the study by Yi (2003) and provides another explanation from the side of production for the growth of world trade.

Another implication of proposition 2.5.3 is that for gravity type estimation trying to retrieve the value of k by regressing γ on $\ln\tau$, we get biased estimates because of the omitted specialization term $\frac{(s_a)^k}{1+[(s_a)^{\sigma-1}-1]^{\frac{k}{\sigma-1}}x}$ in (2.5.3), which is decreasing in trade costs. Therefore, estimate of k from gravity equation is biased upward.

We finish the discussion on trade flow by breaking it into the intensive and extensive margins. Fernandes et al. (2017) documented that around 50% of the variations in trade flows across countries operate in the intensive margin, for which the Melitz (2003) model with pareto distribution cannot explain. In our framework, total exports can be expressed as

$$Y_x = \frac{\sigma k}{k-\sigma+1} (\varphi_{\min})^k M f_x (\bar{\varphi}_x)^{-k}, \tag{2.39}$$

and the number of firms that export, or the extensive margin is

$$N_x = M (\varphi_{\min})^k (\bar{\varphi}_x)^{-k}. \tag{2.40}$$

Therefore, average exports per firm, or the intensive margin is

$$y_x = \frac{Y_x}{N_x} = \frac{\sigma k}{k-\sigma+1} f_x. \tag{2.41}$$

This is the same expression as the Melitz (2003) model so that our framework also implies all adjustments are in the intensive margin if fixed export costs are source or destination specific. The intuition is that changes in specialization premium uniformly affect all exporters because they all use intermediates.[14]

[14] If the marginal adopter is an exporter, this is no longer the case.

2.5.4 Welfare

Larger sales share of intermediates users after reductions in trade costs not only imply larger percentage growth in trade flows, but also larger welfare gains from trade compared to trade models without the possibility of intermediates adoption. We show this first by deriving sufficient statistics for welfare gains from trade, in the spirit of Arkolakis et al. (2012) and then compare with existing trade models.

Because in our current setting the number of potential entrants, M is fixed, in equilibrium firms generate positive profits which are redistributed to households. This may imply that the share of wage income in total household income is not constant.

Lemma 2.5.5. *The share of wage income in total household income, $\lambda_w = \frac{L}{L+\Pi}$ is increasing in trade cost*

$$\frac{d\lambda_w}{d\tau} > 0, \quad \frac{d\lambda_w}{df_x} > 0. \tag{2.42}$$

Moreover, λ_w is constant if average intermediates production share, $\alpha\lambda_a$ is constant.

Proof. The aggregate profits, Π is the difference between the variable profits and fixed costs:

$$\Pi = \frac{1}{\sigma}Y - F = \left(\frac{1}{\sigma} - \frac{k-\sigma+1}{\sigma k}\right)Y.$$ [15]

Utilizing simplified labor market clearing condition as in the proof of lemma 2.5.4,

[15] See Appendix B.3 for detailed derivation of $F = \frac{k-\sigma+1}{\sigma k}Y$.

we get

$$\lambda_w = \left[\frac{\sigma-1}{\sigma}(1-\alpha\lambda_a) + \frac{k-\sigma+1}{k\sigma}\right] / \left[\frac{\sigma-1}{\sigma}(1-\alpha\lambda_a) + \frac{1}{\sigma}\right].$$

Clearly, λ_w is constant if the average intermediates production share, $\alpha\lambda_a$ is constant. Because $\frac{k-\sigma+1}{k\sigma} < \frac{1}{\sigma}$ and λ_a is decreasing in trade cost from lemma 2.5.3, we get λ_w is increasing in trade cost. □

Lemma 2.5.5 has two implications. First, in standard trade models without the possibility of intermediates adoption, welfare gains from trade in terms of relative changes in real wage and real household income are the same. Therefore they cannot explain the changes in labor income share due to trade liberalization. Second, there are additional gains in our framework due to limited entry if welfare is measured in terms of relative change in real household income. To better compare the welfare gains from trade to models with free entry, we *measure changes in welfare in terms of real wage.*

We start from the expression for the adoption cutoff (2.11). Welfare in terms of real wage is

$$W = \frac{1}{P} = \left[(s_a)^{\sigma-1} - 1\right]^{\frac{1}{\sigma-1}} \left(\frac{Y\tilde{\sigma}}{f_a}\right)^{\frac{1}{\sigma-1}} \bar{\varphi}_a. \tag{2.43}$$

Utilizing $Y = \frac{L}{\lambda_l}$, changes in welfare due to reductions in trade costs can be expressed as

$$\hat{W} = [\widehat{(s_a)^{\sigma-1}} - 1]^{\frac{1}{\sigma-1}} (\hat{\lambda}_l)^{\frac{1}{1-\sigma}} (\hat{\bar{\varphi}}_a), \tag{2.44}$$

where $\hat{x} = \frac{x'}{x}$ denotes the relative change of variable x. We can further simplify the last term and obtain the following proposition:

Proposition 2.5.4. *The effect of changes in trade costs on welfare is*

$$\hat{W} = (\hat{\lambda}_l)^{-\frac{k-\sigma+1}{k(\sigma-1)}} \left(\hat{\lambda}_d \hat{\lambda}_x\right)^{-\frac{1}{k}} [\widehat{(s_a)^{\sigma-1}-1}]^{\frac{k-\sigma+1}{k(\sigma-1)}} (\hat{s}_a)^{\frac{\sigma-1}{k}}, \tag{2.45}$$

where λ_x is the domestic expenditure share and λ_d denotes the domestic sales share of intermediates users.

Proof. By definition,

$$\lambda_x = \frac{f_n (\bar{\varphi}_n)^{-k} + f_a (\bar{\varphi}_a)^{-k}}{f_n (\bar{\varphi}_n)^{-k} + f_a (\bar{\varphi}_a)^{-k} + f_x (\bar{\varphi}_x)^{-k}},$$

$$\lambda_d = \frac{(s_a)^{\sigma-1} / [(s_a)^{\sigma-1} - 1] f_a (\bar{\varphi}_a)^{-k}}{f_n (\bar{\varphi}_n)^{-k} + f_a (\bar{\varphi}_a)^{-k}}.$$

We can therefore write domestic sales of adopters as

$$Y_a = \lambda_d \lambda_x Y = \frac{\sigma k}{k-\sigma+1} (\varphi_{\min})^k M f_a \frac{(s_a)^{\sigma-1}}{(s_a)^{\sigma-1}-1} (\bar{\varphi}_a)^{-k}.$$

Utilizing $Y = \frac{wL}{\lambda_l}$ we can obtain

$$(\bar{\varphi}_a)^{-k} = \frac{\lambda_d \lambda_x}{\Lambda_2 \lambda_l} \frac{(s_a)^{\sigma-1} - 1}{(s_a)^{\sigma-1}}$$

where $\Lambda_2 = \frac{\sigma k}{k-\sigma+1} \frac{M}{L} (\varphi_{\min})^k f_a$ is a constant. Substituting it back to expression (2.44) yields the welfare expression. □

Proposition 2.5.4 shows that changes in welfare depend on five sufficient statistics: (i) the share of labor payments in total income, λ_l; (ii) the domestic expenditure share, λ_x; (iii) the domestic sales share of adopters, λ_d; (iv) the dispersion of productivity distribution, k; and (v) the specialization premium, s_a.

The observation that the specialization premium is one of the sufficient statistics for welfare gains is what distinguishes our framework with the fixed specialization premium model, in which the welfare formula as described in Arkolakis et al. (2012) still holds:

Proposition 2.5.5. *The effect of changes in trade costs on the welfare of fixed specialization premium model is*

$$\hat{W}_e = \left(\hat{\lambda}_x\right)^{-\frac{1}{(1-\beta)k}}. \tag{2.46}$$

Proof. Again starting from the definition of productivity threshold for adopters $\bar{\varphi}_a^e$:

$$(W_e)^{1-\beta} = \left(\frac{1}{P}\right)^{1-\beta} = \left(T^{\sigma-1} - 1\right)^{\frac{1}{\sigma-1}} \left(\frac{Y\tilde{\sigma}}{f_a}\right)^{\frac{1}{\sigma-1}} \bar{\varphi}_a^e,$$

implying that $\hat{W}_e = \widehat{(\bar{\varphi}_a^e)}^{\frac{1}{1-\beta}}$. Following similar steps of the proof of Proposition 2.5.4, we have:

$$(\bar{\varphi}_a^e)^{-k} = \frac{\lambda_d \lambda_x}{\Lambda_2 \lambda_l} \frac{T^{\sigma-1} - 1}{T^{\sigma-1}},$$

where $\lambda_d = \frac{T^{\sigma-1}/\left(T^{\sigma-1}-1\right) f_a (\bar{\varphi}_a^e)^{-k}}{f_n (\bar{\varphi}_n^e)^{-k} + f_a (\bar{\varphi}_a^e)^{-k}}$ and $\lambda_l = \frac{\sigma-1}{\sigma}(1-\beta) + \frac{k-\sigma+1}{k\sigma}$. Clearly, changes in the labor share $\hat{\lambda}_l = 1$. There is also no change in the domestic sales share of adopters as

$$\frac{\bar{\varphi}_a^e}{\bar{\varphi}_n^e} = \left(T^{\sigma-1} - 1\right)^{-\frac{1}{\sigma-1}} \left(\frac{f_a}{f_n}\right)^{\frac{1}{\sigma-1}}.$$

Therefore, $\hat{\bar{\varphi}}_a^e = \left(\hat{\lambda}_x\right)^{-\frac{1}{k}}$ and substituting back to $\hat{W}_e = \widehat{(\bar{\varphi}_a^e)}^{\frac{1}{1-\beta}}$ gives the result. □

Intuitively, there is no amplification on the specialization premium and labor share in the fixed specialization premium model because the labor share and fraction of adopters do not respond to changes in trade costs. Moreover, the amplification from endogenous specialization premium increases the welfare gains from trade, as illustrated in the following proposition:

Proposition 2.5.6. *Given the same reductions in trade costs, endogenous specialization implies larger welfare gains from trade than the fixed specialization premium model under the same initial equilibria:*

$$\frac{d\ln W}{d\ln \tau} < \frac{d\ln W_e}{d\ln \tau}, \quad \frac{d\ln W}{d\ln f_x} < \frac{d\ln W_e}{d\ln f_x} \tag{2.47}$$

Proof. It is equivalent to show that $\frac{d\ln P}{d\ln \tau} > \frac{d\ln P_e}{d\ln \tau}$. First observe that the price index under fixed specialization premium can be written as

$$P_e = \left(\Lambda_e \left\{(f_n)^{1-\frac{k}{\sigma-1}} + \left(T^{\sigma-1}-1\right)^{\frac{k}{\sigma-1}} (f_a)^{1-\frac{k}{\sigma-1}} + \tau^{-k}T^k(f_x)^{1-\frac{k}{\sigma-1}}\right\}\right)^{-\frac{1}{k(1-\beta)}},$$

where $\Lambda_e = (\tilde{\sigma})^{\frac{k}{\sigma-1}-1}[\lambda_l(0)]^{1-\frac{k}{\sigma-1}} L^{\frac{k}{\sigma-1}-1}\left(\frac{\sigma}{\sigma-1}\right)^{1-\sigma}\frac{k}{k-\sigma+1}M(\varphi_{\min})^k$ and $T = s_a(0)$, $\beta = \alpha\lambda_a(0)$ from proposition 2.5.1. Let $X = (f_n)^{1-\frac{k}{\sigma-1}} + (T^{\sigma-1}-1)^{\frac{k}{\sigma-1}}(f_a)^{1-\frac{k}{\sigma-1}} + \tau^{-k}T^k(f_x)^{1-\frac{k}{\sigma-1}}$ so that welfare gains under fixed specialization premium can be expressed as

$$\frac{d\ln P_e}{d\ln \tau} = -\frac{1}{k(1-\beta)}\frac{d\ln X}{d\ln \tau}.$$

From the proof of proposition 2.5.1, effects of changes in trade costs on the price index can be written as

$$\frac{d\ln P}{d\ln \tau} = \left.\frac{\partial \ln P}{\partial \ln \tau}\right|_{s_a} \bigg/ \left(1 + \alpha\frac{\partial \ln P}{\partial \ln s_a}\right).$$

The direct effect in the numerator can be further decomposed into the effects on productivity thresholds and labor share:

$$\left.\frac{\partial \ln P}{\partial \ln \tau}\right|_{s_a} = -\frac{1}{k}\frac{\partial \ln X}{\partial \ln \tau} + \left[\frac{k-\sigma+1}{k(\sigma-1)}\right]\frac{\partial \ln \lambda_l}{\partial \ln \tau} > -\frac{1}{k}\frac{\partial \ln X}{\partial \ln \tau} = (1-\beta)\frac{d\ln P_e}{d\ln \tau},$$

where the inequality follows from proposition 2.5.4 that labor share is increasing in trade costs. Note that the direct effect on X is the same as the fixed specialization premium model so the direct effect under our framework is larger.

The indirect effect from endogenous specialization premium can also be decomposed into the effects on productivity thresholds and labor share:

$$\frac{\partial \ln P}{\partial \ln s_a} = -\frac{1}{k}\frac{\partial \ln X}{\partial \ln s_a} + \left[\frac{k-\sigma+1}{k(\sigma-1)}\right]\frac{\partial \ln \lambda_l}{\partial \ln s_a} < -\frac{1}{k}\frac{\partial \ln X}{\partial \ln s_a},$$

where the inequality is from λ_a is increasing in specialization premium (proposition 2.5.3) so that λ_l is decreasing in s_a (proposition 2.5.4). Finally,

$$\begin{aligned}\frac{\partial \ln X}{\partial \ln s_a} &= \frac{s_a}{X}\frac{\partial X}{\partial s_a} \\ &= \frac{s_a}{X}\left\{k(s_a)^{\sigma-2}\left[(s_a)^{\sigma-1}-1\right]^{\frac{k}{\sigma-1}-1}(f_a)^{1-\frac{k}{\sigma-1}} + k\tau^{-k}(s_a)^{k-1}(f_x)^{1-\frac{k}{\sigma-1}}\right\} \\ &= k\lambda_a(0).\end{aligned}$$

Therefore,

$$\frac{d\ln P}{d\ln \tau} > \frac{1-\beta}{1-\alpha\lambda_a(0)}\frac{d\ln P_e}{d\ln \tau} = \frac{d\ln P_e}{d\ln \tau},$$

and we utilize $\beta = \alpha\lambda_a(0)$ from proposition 2.5.1. □

Intuitively, our framework yields larger welfare gains because the labor share λ_l is increasing in trade cost. Both the direct effect of reductions in trade cost and the indirect effect from endogenous specialization premium on the labor share amplify the welfare gains.

2.5.5 Market Size

Under fixed specialization premium, potential number of entrants M and labor supply L do not affect the welfare gains from trade. From (2.5.5), welfare depends only on changes in domestic expenditure share, which the size of the market does not affect. However, under our framework a larger market size implies a larger specialization premium and magnifies the welfare gains from trade, as illustrated in the following proposition:

Proposition 2.5.7. *An increase in the market size increases the specialization premium.*

$$\frac{d\ln s_a}{d\ln M} > 0, \quad \frac{d\ln s_a}{d\ln L} > 0. \tag{2.48}$$

Proof. This proof is very similar to the proof of proposition 2.5.1. We take out the terms relating to market size and re-write the price equation as

$$P = \left(\Lambda_3 L^{\frac{k}{\sigma-1}-1} M \left[\lambda_l(s_a, M, L)\right]^{1-\frac{k}{\sigma-1}} X\right)^{-\frac{1}{k}},$$

where $\Lambda_3 = (\tilde{\sigma})^{\frac{k}{\sigma-1}-1}\left(\frac{\sigma}{\sigma-1}\right)^{1-\sigma}\frac{k}{k-\sigma+1}(\varphi_{\min})^k$ is a constant. Using $s_a = \phi\left(\frac{1}{P}\right)^{\alpha}$ and we get $\frac{d\ln s_a}{d\ln M} = -\alpha\frac{d\ln P}{d\ln M}$, so it is equivalent to show that $\frac{d\ln P}{d\ln M} < 0$. The effect of changes in market size on price index can be written as

$$\frac{d\ln P}{d\ln M} = \left.\frac{\partial \ln P}{\partial \ln M}\right|_{s_a} + \frac{\partial \ln P}{\partial \ln s_a}\frac{d\ln s_a}{d\ln M},$$

where the first term, $\left.\frac{\partial \ln P}{\partial \ln M}\right|_{s_a}$ captures the direct effect of market size on price given specialization premium, and the second term is the indirect effect from changes in specialization premium. Using $\frac{d\ln s_a}{d\ln M} = -\alpha\frac{d\ln P}{d\ln M}$ and re-arranging the above expression, we have

$$\frac{d\ln P}{d\ln M} = \left.\frac{\partial \ln P}{\partial \ln M}\right|_{s_a} \Big/ \left(1 + \alpha\frac{\partial \ln P}{\partial \ln s_a}\right).$$

The direct effect, $\left.\frac{\partial \ln P}{\partial \ln M}\right|_{s_a} = -\frac{1}{k}$ because $\left.\frac{\partial \ln \lambda_l}{\partial \ln M}\right|_{s_a} = \left.\frac{\partial \ln X}{\partial \ln M}\right|_{s_a} = 0$. Using the sufficient condition of the existence of an unique equilibrium, $1+\alpha\frac{\partial \ln P}{\partial \ln s_a} > 0$, we get $\frac{d\ln P}{d\ln M} < 0$. In a similar fashion we can show that $\frac{d\ln P}{d\ln L} < 0$. □

Intuitively, a larger market size implies larger sales for every firm, therefore more firms have an incentive to use intermediates so that the specialization premium increases. Proposition 2.5.7 also implies that an increase in market size increases the fractions of adopters and exporters, sales share of adopters, and trade share of intermediates, because all these variables are increasing in the specialization premium.

Moreover, welfare gains from trade depend on initial market size in our framework. Because a larger market size implies a larger specialization premium, it is possible that given the same reductions in trade costs, a larger initial market size implies larger welfare gains.[16] Later we show that in a version of our framework with free entry, a reduction in trade cost increases the number of potential entrants, and implies larger welfare gains from trade.

2.6 Quantification

In this section, we use our two symmetric country model and perform a simple quantitative exercise using US manufacturing data from 2000-2007. We have three objectives. First, we check if our simple framework can match any of the changes in intermediates production share in U.S. manufacturing. Second, we carry out counterfactuals by varying the levels of trade costs in order to quantitatively assess the model's predictions on trade share of intermediates and welfare gains from trade.

[16] Note that propositions 2.5.4 and 2.5.7 are not sufficient to ensure a larger market size generates larger welfare gains because an increase in domestic sales share of adopters (λ_d) decreases the welfare gains from (2.5.4).

Third, we compare these liberalization outcomes to those in the fixed specialization premium model.

2.6.1 Data

We use data from NBER CES database. Ideally, we want to measure intermediates production share as expenditure on intermediates over total production costs. However, as payments to some factors are not observable, such as capital, total production cost cannot be computed directly from the data. Instead we assume that the production function utilizes some specific factor that is unobserved (k) with share β for all firms:

$$y = \begin{cases} k^{\beta} \left(l^{1-\alpha} x^{\alpha}\right)^{1-\beta} & \text{pays } f_n + f_a, \\ k^{\beta} l^{1-\beta} & \text{pays } f_n, \end{cases} \tag{2.49}$$

where l is the amount of observed factor (labor in the model) and x is the amount of intermediates. If we know the share of this unobserved factor β, we can then compute the intermediates production share as $\alpha(1-\beta)$. This can be done by utilizing data on total expenditure on observed factors to sales. By definition,

$$\frac{E_{nk}}{Y} = \frac{E_{nk}}{(E_{nk} + E_k)\eta} = \frac{1}{(1 + E_k/E_{nk})\eta}, \tag{2.50}$$

where E_{nk} is total expenditure on observed factors, E_k is total expenditure on unobserved factors, Y is total sales, and η is the markup.[17] Utilizing $\frac{E_k}{E_{nk}} = \frac{\beta}{1-\beta}$ and

[17] In appendix B.1.2, we show that the observed expenditure to sales ratio has not changed much since 2000, implying that there was little substitution between intermediates and unobserved factors (for e.g. capital).

the model's constant markup $\eta = \frac{\sigma}{\sigma-1}$, we have

$$1 - \beta = \frac{\sigma}{\sigma - 1} \frac{E_{nk}}{Y}. \tag{2.51}$$

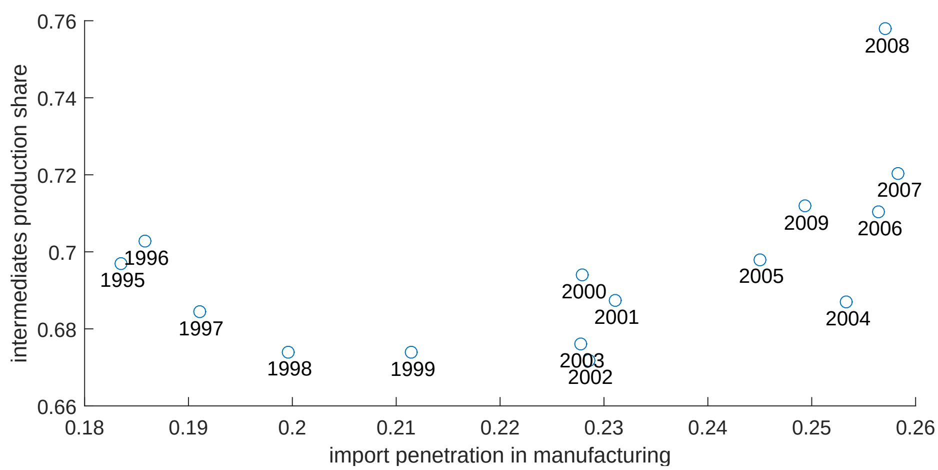
Therefore we can compute the true intermediates production share $\alpha(1-\beta)$ as

$$\alpha(1 - \beta) = \frac{\sigma}{\sigma - 1} \frac{E_x}{Y}, \tag{2.52}$$

where E_x is intermediates expenditure constructed as material costs minus energy costs. We use $\sigma = 4$ to compute the constant markup.

Figure 2.4 plots the intermediates production share against import penetration in the U.S. manufacturing sector. We see that there is an increase in intermediates

Figure 2.4: Import penetration and intermediates production share: 1995-2009



Notes: Import penetration is computed as ratio of total manufacturing import values to total manufacturing absorption.

production share post 2000 following the increase in import penetration. We discipline our model based on this period of increasing intermediates production share between 2000 and 2007.

2.6.2 Calibration

In the framework, two types of shocks affect intermediates production share. The first type relates to shocks to export costs: variable τ and fixed f_x, while the second type relates to shocks to technology adoption: fixed boost ϕ and fixed adoption cost f_a. Because at the industry level we only observe changes in import penetration but not firm heterogeneity on intermediates usage, we make the strong assumption that changes in intermediates production share in the data are driven by trade shocks only.[18] In essence, we are asking whether changes in trade costs alone can explain the rise in intermediates production share using our framework. The quantitative effects from changes in trade cost are an upper bound, as some of them may be due to technological change.

Because we only observe one data moment relating to trade costs, which is the import penetration, we make further assumptions that all changes in trade costs are due to the iceberg cost τ. Doing it instead for fixed export cost f_x gives the same quantitative results as changes in trade costs affect firm's specialization decision indirectly through changes in the specialization premium.

In sum, the only time-varying parameter in our framework is the iceberg cost τ. Fixed exporting cost f_x, fixed boost ϕ, technology intermediates share α, and the fixed adoption cost f_a are time-invariant.

[18] An example of shocks to f_a is computerization.

2.6.2.1 Assigned Parameters

The pareto shape parameter $k = 4$ and the elasticity of substitution $\sigma = 4$. The parameters relating to the scale of the economy are also assigned as they do not affect levels of intermediates production share and welfare gains. Following Melitz and Redding (2015), we normalize $f_n = \varphi_{\min} = 1$, and let total labor force L to be total manufacturing employment in 2000, and potential entrants are kept fixed at $M = \frac{\sigma-1}{\sigma k}L$.[19]

2.6.2.2 Technology Adoption

The most important steps of the calibration involves finding the values of parameters relating to technology adoption: α, ϕ, and f_a. We utilize variations in intermediates production share and TFP growth from 2000 to 2007 to estimate them. Intuitively, a reduction in variable trade cost increases the sales share of adopters, so that sector intermediates production share increases. On the other hand, sector TFP also increases because some firms upgrade and some least productive firms drop out.

As in the NBER CES database, real output in each sector is computed using industry price deflators, the model counterpart of sector TFP is the harmonic firm

[19] In the Melitz model, the number of potential entrants is proportional to total labor force and given by this expression if fixed cost of entry f_e is normalized to 1.

average TFP weighted by firm sales:

$$
\begin{aligned}
(\bar{\varphi})^{-1} &= \frac{\int_{\bar{\varphi}_n}^{\infty} p(\varphi)q(\varphi)\varphi^{-1}dG(\varphi)}{\int_{\bar{\varphi}_n}^{\infty} p(\varphi)q(\varphi)dG(\varphi)} \\
&= \left(\frac{\sigma-k-1}{\sigma-k-2}\right)\frac{(\bar{\varphi}_n)^{\sigma-k-2}+\left[(s_a)^{\sigma-1}-1\right](\bar{\varphi}_a)^{\sigma-k-2}+\tau^{1-\sigma}(s_a)^{\sigma-1}(\bar{\varphi}_x)^{\sigma-k-2}}{(\bar{\varphi}_n)^{\sigma-k-1}+\left[(s_a)^{\sigma-1}-1\right](\bar{\varphi}_a)^{\sigma-k-1}+\tau^{1-\sigma}(s_a)^{\sigma-1}(\bar{\varphi}_x)^{\sigma-k-1}}
\end{aligned}
\tag{2.53}
$$

In each year, the model perfectly matches the observed import penetration and targets intermediates production share in the data. Moreover, we also target TFP growth in the U.S. manufacturing between 2000 and 2007. In essence, we find the parameters of the model by minimizing the distance between the model-implied intermediates production share as well as TFP growth and their data counterparts as the following:

$$
\Upsilon = \min_{\{\alpha, f_a, \phi\}} \sum_t \left[\alpha\tilde{\lambda}_a(t)-\bar{\alpha}(t)\right]^2 + \sum_t \left[\frac{\tilde{\bar{\varphi}}(t+1)}{\tilde{\bar{\varphi}}(t)} - \frac{\bar{\varphi}(t+1)}{\bar{\varphi}(t)}\right]^2, \tag{2.54}
$$

where $\bar{\alpha}$ is the sector intermediates production share in the data and $\tilde{x}$ denotes an endogenous variable x in the model.

The calibration procedure is the following. Given trade shares in the data, as well as the guesses for values of α, f_a, and ϕ, we can solve for the equilibrium of the model year by year. We then compute intermediates production share $\alpha\lambda_a$ and TFP growth for this given set of parameters. We search through possible values of α, f_a, and ϕ and find the ones that satisfy (2.54). The details are in appendix B.4.

2.6.2.3 Model Fit

Table 2.4 presents the calibrated parameters. One thing to note is that the specialization premium at the initial year 2000 is around 1.25.[20] The fit of the model is presented in Figure 2.5. We see that the fit on changes in intermediates production share is quite good but the fit on TFP growth is poor. The reason may be that trade shocks are not major drivers of industry TFP change.

Table 2.4: Calibrated Parameters

data moments	parameter values
intermediates share TFP growth	$\alpha = 0.76,\ f_a = 2.30,\ \phi = 0.123,\ s_a(00) = 1.25$
trade share fraction of exporters	$\tau(00)$ to $\tau(07)$: $\tau(00) = 1.36$ $f_x = 2.84$

Notes: The table presents the calibrated parameters. Intermediates production share in the data is the average industry intermediates production share weighted by sales. Trade share in the data is the observed import penetration ratio. Average sector TFP growth is weighted by industry sales.

2.6.3 Counterfactuals

Armed with a framework which is able to explain the variations in sector intermediates production share in the data, we investigate the effects of changes in variable trade costs on the trade share of intermediates and welfare.

[20]The magnitude of the specialization premium is consistent with the estimates of the effects of imported intermediates on productivity in the literature. For example, Halpern et al. (2015) estimates that using imported intermediates in production would increase a firm's revenue productivity by 22% for Hungary.

Figure 2.5: Intermediates production share and TFP growth: model VS data

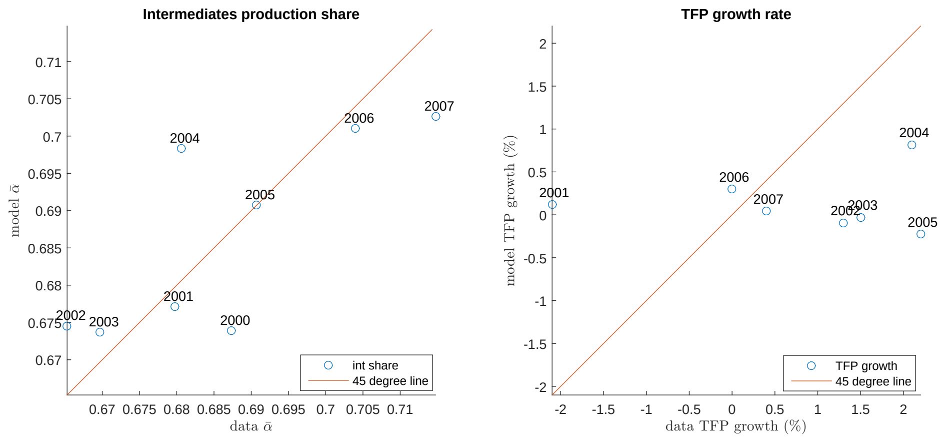
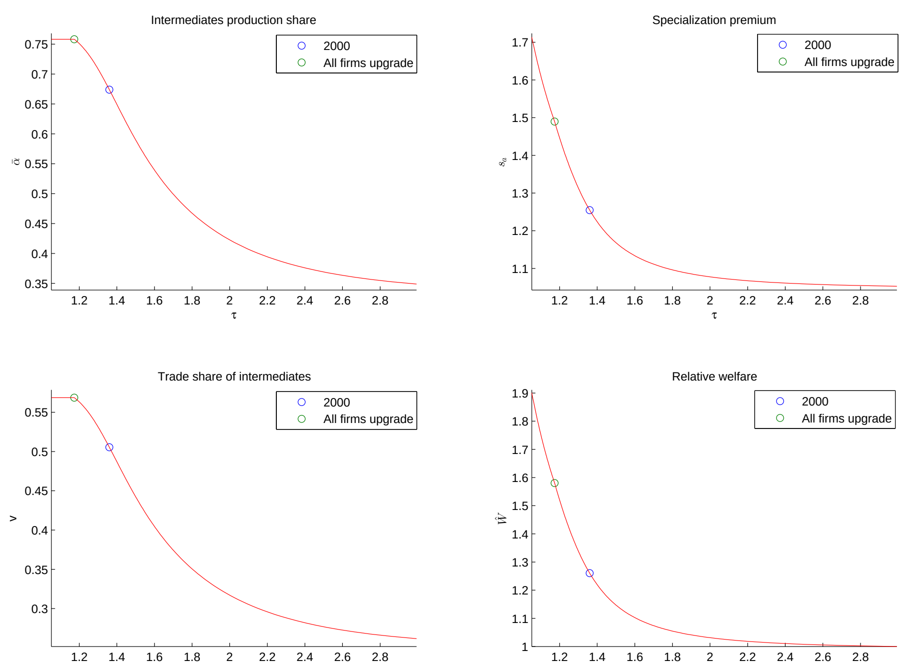


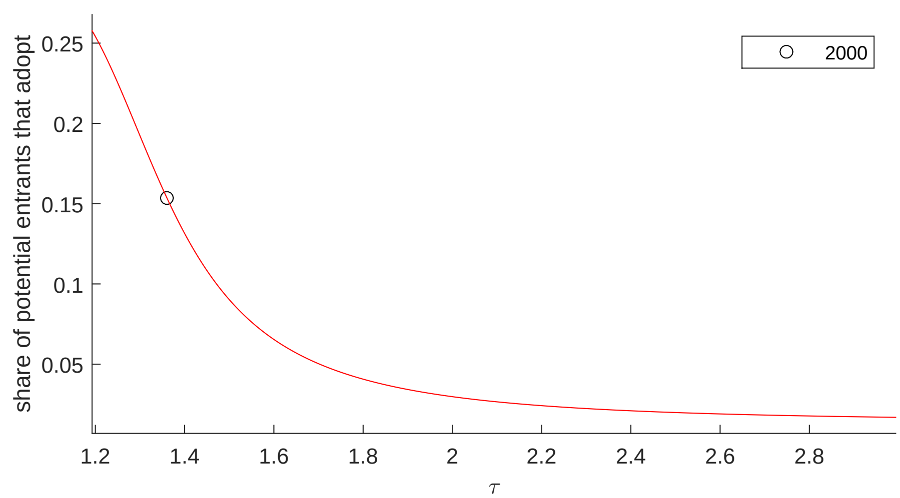
Figure 2.6: Effects of changes in variable trade cost: baseline



Notes: The bottom right figure plots the welfare relative to autarky.

Figure 2.6 presents the counterfactuals of varying variable trade costs. We see that at high levels of trade cost, the specialization premium is low so that not many firms adopt, implying low intermediates production share and small welfare gains. When trade cost is low enough (around 1.5), the specialization premium is large enough so that a larger fraction of firms begin to use intermediates, leading to sizable increase in trade share of intermediates and welfare gains.

Figure 2.7: Share of potential entrants that adopt



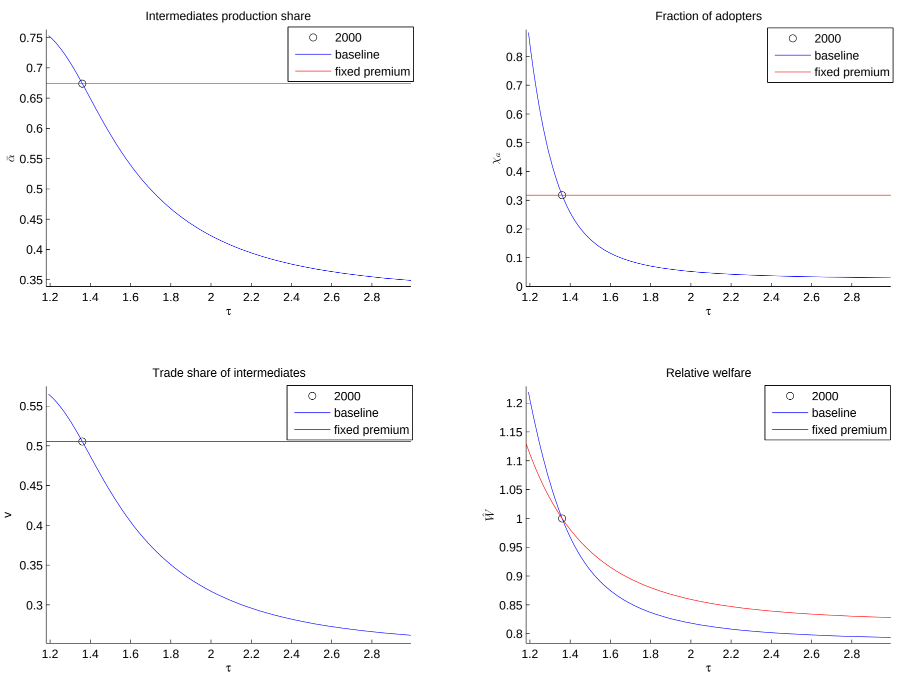
One thing to note is that not only the fraction but also the *total number* of firms that adopt increases ($\bar{\varphi}_a$ decreases). This is presented in Figure 2.7, where we show that the share of potential entrants that adopt increases as variable trade cost falls.[21] The reason is that the increase in specialization premium is large enough to induce some domestic firms to adopt. Therefore we see in Figure 2.6 that even if the level of trade cost at 2000 is low, reducing it still yields significant welfare gains.

In Figure 2.8, we compare our framework with the fixed specialization pre-

[21] The number of potential entrants M is fixed, so an increase in the share of potential entrants that adopt implies a rise in the total number of adopters.

mium model for the same reductions in variable trade costs. We parameterize the fixed specialization premium model according to proposition 2.5.1 so that the two frameworks have the same welfare at 2000. Clearly, the fixed specialization premium

Figure 2.8: Effects of changes in variable trade cost: comparison



Notes: The bottom right figure plots the welfare relative to 2000 for each model.

model has constant intermediates production share and trade share of intermediates, so it can't explain the increases in these shares as in our framework. Moreover, it cannot explain the declines in the labor income share. Our framework also generates larger welfare gains (losses) when trade cost is reduced (increased).

How much additional gains are generated by endogenous specialization premium? We can compare the welfare gains from the two models, and the difference is generated by the new channel in our framework. As the two models are parameterized to have the same level of variable trade cost at 2000, we conduct a simple exercise by increasing the variable cost to infinity (autarky). We find that the gains from trade relative to autarky are 26% in our framework and 21% in the fixed specialization premium model.[22] Therefore, an additional 5 percentage points of welfare gains come from endogenous specialization, or around 20% of the total welfare gains in our framework.

2.7 Extensions

In this section, we investigate how the implications of our framework change under alternative specification of fixed cost and free entry.

2.7.1 Fixed Costs

We assume that all fixed costs are paid in terms of labor. What happens if they are paid using both labor and intermediates? Consider a setting where there is a homogeneous good produced by perfectly competitive firms with price $p_f = w^{1-\alpha\lambda_a} P^{\alpha\lambda_a}$, and all fixed costs are paid in terms of this homogeneous good. All implications of our framework stay unchanged except first, welfare gains from trade are larger as the real cost of homogeneous good falls after a reduction in trade cost. This effect is the same as in standard models where fixed costs are paid in terms of both labor and intermediates, as discussed in Arkolakis et al. (2012). Second, the labor income share in total national income is constant. Observe that

[22] In Figure 2.8 the welfare gains are relative to year 2000 but not autarky, so the numbers are smaller in the figure.

the labor market clearing condition becomes:

$$
\begin{aligned}
wL &= \frac{\sigma-1}{\sigma}(1-\alpha\lambda_a)Y + (1-\alpha\lambda_a)\frac{k-\sigma+1}{\sigma k}Y \\
&= \left(\frac{\sigma-1}{\sigma} + \frac{k-\sigma+1}{\sigma k}\right)(1-\alpha\lambda_a)Y,
\end{aligned} \tag{2.55}
$$

where total wage payment for fixed costs is only $1-\alpha\lambda_a$ of total fixed costs payment. Aggregate profits are adjusted according to

$$
\Pi = \frac{1}{\sigma}Y - F = \left(\frac{1}{\sigma} - \frac{k-\sigma+1}{\sigma k}\right)(1-\alpha\lambda_a)Y. \tag{2.56}
$$

Therefore, labor income share in total national income is constant at

$$
\lambda_w^f = \frac{wL}{wL+\Pi} = \left(\frac{\sigma-1}{\sigma} + \frac{k-\sigma+1}{\sigma k}\right). \tag{2.57}
$$

Observe that the share parameter in the fixed cost, $\alpha\lambda_a$, is decreasing in trade cost. If instead the share is fixed at some constant as in standard trade models, the result that labor income share is decreasing in trade cost still holds.

2.7.2 Free Entry

We show that under free entry, welfare gains from trade are larger than the case under fixed number of potential entrants. The intuition is that a larger specialization premium induces more potential entrants after a reduction in trade cost. In the following, we first derive the general equilibrium conditions under free entry and then show both theoretically and quantitatively the free entry version of the model generates larger welfare gains.

2.7.2.1 General Equilibrium

Assume that each firm pays an entry fee of f_e units of labor, and draw its productivity from an ex ante pareto distribution $G(\varphi)$. After that the firm decides whether to produce, adopt, and export. The free entry condition states that ex ante, expected profit will equal the entry fee

$$[1 - G(\bar{\varphi}_n)]\,\bar{\pi} = f_e. \tag{2.58}$$

where $\bar{\pi}$ is average profit of all operating firms

$$\bar{\pi} = \int_{\bar{\varphi}_n}^{\bar{\varphi}_a} \pi_n(\varphi)\frac{dG(\varphi)}{1 - G(\bar{\varphi}_n)} + \int_{\bar{\varphi}_a}^{\infty} \pi_a(\varphi)\frac{dG(\varphi)}{1 - G(\bar{\varphi}_n)} + \int_{\bar{\varphi}_x}^{\infty} \pi_x(\varphi)\frac{dG(\varphi)}{1 - G(\bar{\varphi}_n)}. \tag{2.59}$$

Profits can be written in terms of productivity cutoffs

$$\pi_v(\varphi) = \begin{cases} [\pi_n(\bar{\varphi}_n) + f_n]\left(\frac{\varphi}{\bar{\varphi}_n}\right)^{\sigma-1} - f_n & v = n, \\ [\pi_a(\bar{\varphi}_a) + f_n + f_a]\left(\frac{\varphi}{\bar{\varphi}_a}\right)^{\sigma-1} - f_n - f_a & v = a, \\ [\pi_x(\bar{\varphi}_x) + f_x]\left(\frac{\varphi}{\bar{\varphi}_x}\right)^{\sigma-1} - f_x & v = x, \end{cases} \tag{2.60}$$

Substituting expressions (2.59) and (2.60) into the free entry condition (2.58), we obtain

$$\begin{aligned} &f_n \int_{\bar{\varphi}_n}^{\infty} \left[\left(\frac{\varphi}{\bar{\varphi}_n}\right)^{\sigma-1} - 1\right] dG(\varphi) + f_a \int_{\bar{\varphi}_a}^{\infty} \left[\left(\frac{\varphi}{\bar{\varphi}_a}\right)^{\sigma-1} - 1\right] dG(\varphi) \\ &+ f_x \int_{\bar{\varphi}_x}^{\infty} \left[\left(\frac{\varphi}{\bar{\varphi}_x}\right)^{\sigma-1} - 1\right] dG(\varphi) = f_e. \end{aligned} \tag{2.61}$$

Utilizing the pareto distribution, the above expression can be further simplified to

$$\frac{(\sigma-1)(\varphi_{\min})^k}{k-\sigma+1}\left[f_n\left(\bar{\varphi}_n\right)^{-k} + f_a\left(\bar{\varphi}_a\right)^{-k} + f_x\left(\bar{\varphi}_x\right)^{-k}\right] = f_e. \tag{2.62}$$

Substituting total sales $Y = \frac{\sigma k}{k-\sigma+1} (\varphi_{\min})^k M \left[f_n (\bar{\varphi}_n)^{-k} + f_a (\bar{\varphi}_a)^{-k} + f_x (\bar{\varphi}_x)^{-k} \right]$ into the above expression yields

$$M = \frac{(\sigma - 1)}{\sigma k} \frac{Y}{f_e}. \tag{2.63}$$

For the labor market, first observe that the variable profit is the sum of fixed cost payments plus the profit

$$\frac{Y}{\sigma} = F + \Pi = F + M f_e, \tag{2.64}$$

where the last step utilizes the free entry condition. Labor market clearing implies that total labor supply equals the sum of labor used in production, fixed cost payments, and entry cost payments:

$$L = \frac{\sigma - 1}{\sigma}(1 - \alpha\lambda_a)Y + \frac{Y}{\sigma}. \tag{2.65}$$

Substituting (2.65) into (2.63) we get the number of potential entrants

$$M = \frac{(\sigma - 1)}{\sigma k} \frac{L}{f_e} (\lambda_l)^{-1}. \tag{2.66}$$

As the labor share λ_l is constant in the fixed specialization premium model, M is also fixed under free entry. Therefore, all implications under fixed M carry over to free entry under fixed specialization premium.

With endogenous specialization premium the labor share is increasing in trade cost, implying that the number of potential entrants is decreasing in trade costs. This is the key difference from the fixed M model. Because an increase in M leads to an increase in the specialization premium from proposition 2.5.7, welfare gains are likely to be larger.

2.7.2.2 Welfare

We first define the parameter restrictions on the free entry model to have the same initial aggregate outcome as restricted entry.

Proposition 2.7.1. *Our framework under free entry has the same values of parameters as restricted entry except for the labor supply:*

$$L_{FE} = L\left[\frac{\sigma-1}{\sigma}(1-\alpha\lambda_a(0))+\frac{1}{\sigma}\right]\bigg/\left[\frac{\sigma-1}{\sigma}(1-\alpha\lambda_a(0))+\frac{k-\sigma+1}{k\sigma}\right]. \quad (2.67)$$

And the value of entry cost is given by expression (2.63)

$$f_e = \frac{(\sigma-1)}{\sigma k}\frac{Y(0)}{M}. \quad (2.68)$$

Under the above parameterization the two frameworks have the same initial aggregate outcome.

We see that the labor supply under free entry is larger. This is because some of the labor force is used to pay for the entry fee. Now we show that under free entry welfare gains from trade are larger given the same reduction in trade cost:

Proposition 2.7.2. *Given the same reductions in trade costs, endogenous specialization with free entry implies larger welfare gains from trade than restricted entry under the same initial equilibria:*

$$\frac{d\ln W_{FE}}{d\ln\tau} < \frac{d\ln W}{d\ln\tau}, \quad \frac{d\ln W_{FE}}{d\ln f_x} < \frac{d\ln W}{d\ln f_x}. \quad (2.69)$$

Proof. It is equivalent to show that $\frac{d\ln P_{FE}}{d\ln\tau} > \frac{d\ln P}{d\ln\tau}$. The price equation under free entry can be written as

$$P_{FE} = \left(\Lambda_{FE}\left[\lambda_l^{FE}(s_a,\tau)\right]^{-\frac{k}{\sigma-1}} X\right)^{-\frac{1}{k}},$$

where $\lambda_l^{FE}(s_a,\tau) = \frac{\sigma-1}{\sigma}\left(\frac{(f_n)^{1-\frac{k}{\sigma-1}} - \left[(s_a)^{\sigma-1}-1\right]^{\frac{k}{\sigma-1}-1}(f_a)^{1-\frac{k}{\sigma-1}}}{(f_n)^{1-\frac{k}{\sigma-1}} + [(s_a)^{\sigma-1}-1]^{\frac{k}{\sigma-1}}(f_a)^{1-\frac{k}{\sigma-1}} + \tau^{-k}(s_a)^k(f_x)^{1-\frac{k}{\sigma-1}}}\right)\alpha$ $+\frac{\sigma-1}{\sigma}(1-\alpha)+\frac{1}{\sigma}$, and $\Lambda_{FE} = (\tilde{\sigma})^{\frac{k}{\sigma-1}-1}(L_{FE})^{\frac{k}{\sigma-1}}\left(\frac{\sigma}{\sigma-1}\right)^{1-\sigma}\frac{\sigma-1}{\sigma(k-\sigma+1)f_e}(\varphi_{\min})^k$ is a constant. For comparison, the price equation under restricted entry is

$$P = \left(\Lambda_2\left[\lambda_l(s_a,\tau)\right]^{1-\frac{k}{\sigma-1}} X\right)^{-\frac{1}{k}},$$

We next show that the amplification from changes in labor share is larger under free entry. From the proof of proposition 2.5.1, effects of changes in trade costs on the price index can be written as

$$\frac{d\ln P}{d\ln\tau} = \left.\frac{\partial \ln P}{\partial \ln \tau}\right|_{s_a} \Big/ \left(1+\alpha\frac{\partial \ln P}{\partial \ln s_a}\right).$$

The direct effect in the numerater can be further decomposed into the effects on productivity thresholds and labor share:

$$\left.\frac{\partial \ln P}{\partial \ln \tau}\right|_{s_a} = -\frac{1}{k}\frac{\partial \ln X}{\partial \ln \tau} + \left[\frac{k-\sigma+1}{k(\sigma-1)}\right]\frac{\partial \ln \lambda_l}{\partial \ln \tau},$$
$$\left.\frac{\partial \ln P_{FE}}{\partial \ln \tau}\right|_{s_a} = -\frac{1}{k}\frac{\partial \ln X}{\partial \ln \tau} + \left(\frac{1}{\sigma-1}\right)\frac{\partial \ln \lambda_l^{FE}}{\partial \ln \tau}.$$

The indirect effect from endogenous specialization premium in the denominator can also be decomposed into the effects on productivity thresholds and labor share:

$$\frac{\partial \ln P}{\partial \ln s_a} = -\frac{1}{k}\frac{\partial \ln X}{\partial \ln s_a} + \left[\frac{k-\sigma+1}{k(\sigma-1)}\right]\frac{\partial \ln \lambda_l}{\partial \ln s_a},$$
$$\frac{\partial \ln P_{FE}}{\partial \ln s_a} = -\frac{1}{k}\frac{\partial \ln X}{\partial \ln s_a} + \left(\frac{1}{\sigma-1}\right)\frac{\partial \ln \lambda_l^{FE}}{\partial \ln s_a}.$$

Therefore, it is sufficient to show that $\frac{\partial \ln \lambda_l^{FE}}{\partial \ln \tau} > \left(\frac{k-\sigma+1}{k}\right)\frac{\partial \ln \lambda_l}{\partial \ln \tau}$ and $\frac{\partial \ln \lambda_l^{FE}}{\partial \ln s_a} < \left(\frac{k-\sigma+1}{k}\right)\frac{\partial \ln \lambda_l}{\partial \ln s_a}$.

Define $C = \frac{\sigma-1}{\sigma}\left(\frac{(f_n)^{1-\frac{k}{\sigma-1}} - \left[(s_a)^{\sigma-1}-1\right]^{\frac{k}{\sigma-1}-1}(f_a)^{1-\frac{k}{\sigma-1}}}{(f_n)^{1-\frac{k}{\sigma-1}} + [(s_a)^{\sigma-1}-1]^{\frac{k}{\sigma-1}}(f_a)^{1-\frac{k}{\sigma-1}} + \tau^{-k}(s_a)^k(f_x)^{1-\frac{k}{\sigma-1}}}\right)\alpha + \frac{\sigma-1}{\sigma}(1-$

α) so that $\lambda_l = C + \frac{k-\sigma+1}{k\sigma}$ and $\lambda_l^{FE} = C + \frac{1}{\sigma}$. Therefore,

$$\begin{aligned}
\frac{\partial \ln \lambda_l^{FE}}{\partial \ln \tau} &= \frac{C}{C + 1/\sigma} \frac{\partial \ln C}{\partial \ln \tau} \\
&= \left(\frac{k-\sigma+1}{k}\right) \frac{C}{\frac{k-\sigma+1}{k} C + \frac{k-\sigma+1}{k\sigma}} \frac{\partial \ln C}{\partial \ln \tau} \\
&> \left(\frac{k-\sigma+1}{k}\right) \frac{C}{C + \frac{k-\sigma+1}{k\sigma}} \frac{\partial \ln C}{\partial \ln \tau} \\
&= \left(\frac{k-\sigma+1}{k}\right) \frac{\partial \ln \lambda_l}{\partial \ln \tau},
\end{aligned}$$

where the inequality follows from $\frac{\partial \ln C}{\partial \ln \tau} > 0$. Similarly with $\frac{\partial \ln C}{\partial \ln s_a} < 0$, we have $\frac{\partial \ln \lambda_l^{FE}}{\partial \ln s_a} < \left(\frac{k-\sigma+1}{k}\right) \frac{\partial \ln \lambda_l}{\partial \ln s_a}$. □

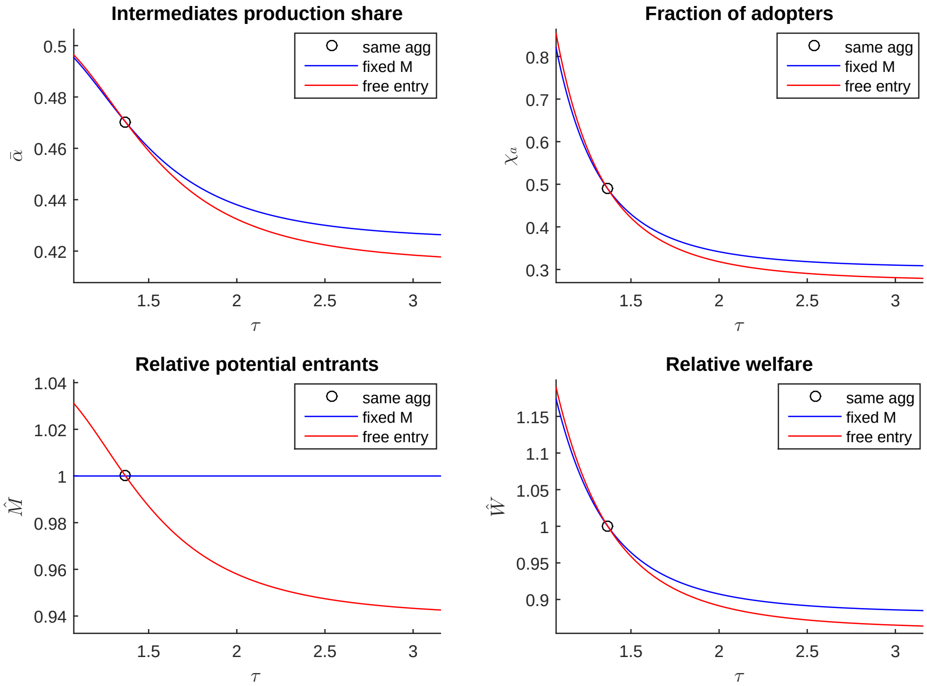
Intuitively, free entry generates larger amplification on the labor share so that the welfare gains from trade are larger.

2.7.2.3 Quantitative Comparison

What is the quantitative importance of this additional amplification on the labor share? We address this question by comparing the welfare gains from trade from changes in iceberg costs. The natural way is to use the same parameters as in table 2.4. However, the condition for a unique equilibrium is violated under free entry for this set of parameters. Therefore, we use a smaller value of $\alpha = 0.5$ and adjust $\phi = 0.285$ to have the same specialization premium at 2000 for the baseline calibration.

The two frameworks have the same aggregate outcomes at 2000 level domestic expenditure share, and the values of f_e and L_{FE} are given by proposition 2.7.1. Figure 2.9 shows the effects of reduction in variable trade cost for the fixed and free

Figure 2.9: Effects of changes in iceberg cost: fixed VS free entry



entry frameworks. We see that free entry amplifies the changes in intermediates production share, fraction of adopters, and welfare gains.

2.8 Conclusion

In this paper, we develop a tractable trade model in which firms choose whether to upgrade the technology to use intermediate inputs. The specialization premium is decreasing in trade costs because imported intermediates lower the price of the intermediates bundle, which induces more firms to upgrade and use intermediates. Our framework implies an increase in trade share of intermediates and intermediates production share after trade liberalization. Moreover, there are additional gains from trade due to endogenous changes in specialization premium.

In the quantitative exercise, we show that our simple two symmetric country setting is able to match the changes in intermediates production share in the U.S. manufacturing sector. We also show that the additional welfare gains from endogenous specialization premium contributes to 20% of the total welfare gains relative to autarky.

Looking ahead, our framework is flexible enough and can be applied to solve other interesting problems. For example, the model can be used to understand the global decline in labor share across countries. Another interesting application is to investigate the effects of trade policy uncertainty on the decisions of firms to use intermediates.

Appendix A: International Trade, Structural Change and the Skill Premium

A.1 Calibration Details

This section gives more detail on how I calibrate sectoral production efficiency T_n^k.

1. I have to make one normalization in each sector to identify T_n^k. I choose to normalize $P_{\text{ROW}}^k(2007) = 1$ for $k \in \Omega$. Using (1.20), $T_n^k(2007)$ is identified.

2. Given $T_n^k(2007)$, I back out T_{US}^k in other periods by matching the average sectoral productivity growth in the data.

    - Average sectoral productivity in the model has to be corrected for international trade. Following Finicelli et al. (2013),

    $$\bar{T}_n^k = \Gamma \left(\frac{\theta^k + 1 - \sigma}{\theta^k} \right) \left(T_n^k \right)^{\frac{1}{\theta^k}} \left(\pi_{nn}^k \right)^{-\frac{1}{\theta^k}}$$

    so that everything else equal, a more open country (smaller π_{nn}^k) has higher average productivity because it produces less goods with low productivity.

- The average yearly productivity growth in agriculture, manufacturing and services in the U.S. are 3.8%, 2.4% and 1.3% respectively from Herrendorf et al. (2013).
- T^k_{US} in other periods are found from $\bar{T}^A_{\text{US}}(t) = \bar{T}^A_{\text{US}}(2007) \times 1.038^{-(2007-t)}$, $\bar{T}^M_{\text{US}}(t) = \bar{T}^M_{\text{US}}(2007) \times 1.024^{-(2007-t)}$, $\bar{T}^S_{\text{US}}(t) = \bar{T}^S_{\text{US}}(2007) \times 1.013^{-(2007-t)}$ by assuming same growth rate in sectoral productivity.

3. Back out $P^k_{\text{US}}(t)$ in other periods from (1.17), and then retrieve $T^k_n(t)$ in other periods for $n \neq$ U.S. from (1.20).

A.2 Data

All classifications of industries and countries follow the GTAP codes.

Classification of Industries:

- Agriculture: Paddy rice; Wheat; Cereal grains nec; Vegetables, fruit, nuts; Oil seeds; Sugar cane, sugar beet; Plant-based fibers; Crops nec; Cattle, sheep, goats, horses; Animal products nec; Raw milk; Wool, silk-worm cocoons; Forestry; Fishing; Meat: cattle,sheep,goats,horse; Meat products nec; Vegetable oils and fats; Dairy products; Processed rice; Sugar; Food products nec; Beverages and tobacco products
- Manufacturing: Coal; Oil; Gas; Minerals nec; Textiles; Wearing apparel; Leather products; Wood products; Paper products, publishing; Petroleum, coal products; Chemical,rubber,plastic prods; Mineral products nec; Ferrous

metals; Metals nec; Metal products; Motor vehicles and parts; Transport equipment nec; Electronic equipment; Machinery and equipment nec; Manufactures nec

- Services: Electricity; Gas manufacture, distribution; Water; Construction; Trade; Transport nec; Sea transport; Air transport; Communication; Financial services nec; Insurance; Business services nec; Recreation and other services; PubAdmin/Defence/Health/Education; Dwellings

Classification of Regions:

- OECD: Australia (AUS) Austria (AUT) Belgium (BEL) Canada (CAN) Germany (DEU) Denmark (DNK) Spain (ESP) Finland (FIN) France (FRA) UK (GBR) Greece (GRC) Ireland (IRL) Italy (ITA) Japan (JPN) Korea (KOR) Luxembourg (LUX) Netherlands (NLD) Portugal (PRT) Sweden (SWE) U.S. (USA)

- Non-OECD: China (CHN) Indonesia (IDN) India (IND) Philippines (PHL) Thailand (THA) Argentina (ARG) Brazil (BRA) Chile (CHL) Mexico (MEX) Peru (PER) Uruguay (URY) Venezuela (VEN) Czech Republic (CZE) Hungary (HUN) Poland (POL) Slovakia (SVK) Slovenia (SVN)

Skill Premium:

The skill premium in each country is computed from the following sources:

- OECD and Eastern European countries: from EU KLEMS. Following Parro (2013), I use data on the share of total hours worked by high skilled and medium skilled workers over 15 years old and the share in total labor compensation to high skilled and medium skilled workers over 15 years old.

- Latin American countries: from SEDLAC (CEDLAS and The World Bank). Skill premium is computed as the wage ratio of the high skilled to the medium skilled.

- East Asian countries: Azam (2010) for India, Ge and Yang (2014) for China, Di Gropello and Sakellariou (2010) for Indonesia, Philippines and Thailand. Skill premium is computed as the wage ratio of college graduates to high school graduates.

As EU KLEMS only contain relevant data to compute the skill premium in as late as year 2005, the skill premium of the OECD and Eastern European countries in the end year corresponds to year 2005.

A.3 Simple Model

In this section I derive the equations to illustrate the channels that affect the skill premium. I assume that there are two countries, $N = 2$; that there are two sectors, $k = a, b$, and sector b is the skill intensive ($\beta_n^b > \beta_n^a$) and income elastic ($b_b > 0 > b_a$) sector; that value added share is the same across sectors and countries, $v_n^k = v$.

Following Burstein and Vogel (2016), define factor content of trade of factor l

in country n, $FCT_n(l)$ as :

$$FCT_n(l) = \sum_{k=\{a,b\}} l_n^k \omega_n^k, \quad l = U, S$$

where l_n^k is the amount of factor l used in the production of sector k goods. The weight ω_n^k is the sectoral net exports share in production, $\omega_n^k = \frac{X_{-nn}^k - X_{n-n}^k}{X_{-nn}^k + X_{nn}^k}$. $FCT_n(l) > 0$ if country n is a net exporter of factor l; and vice versa if country n is a net importer of factor l.

From the labor market clearing conditions (1.10), equilibrium skill premium in this simple model can be expressed as:

$$\frac{w_n^s}{w_n^u} = \frac{U_n - FCT_n(U)}{S_n - FCT_n(S)} \frac{\sum_{k=\{a,b\}} \beta_n^k \left[v s_n^k + (1-v) e_n^k \right]}{\sum_{k=\{a,b\}} (1-\beta_n^k) \left[v s_n^k + (1-v) e_n^k \right]},$$

where $e_n^k = \sum_{l=a,b} e_n^{lk} y_n^l$ is the average intermediates expenditure share on sector k. $\frac{U_n - FCT_n(U)}{S_n - FCT_n(S)}$ captures the effect of factor contents of trade on the skill premium, while $\frac{\sum_{k=\{a,b\}} \beta_n^k \left[v s_n^k + (1-v) e_n^k \right]}{\sum_{k=\{a,b\}} \left(1-\beta_n^k\right) \left[v s_n^k + (1-v) e_n^k \right]}$ captures the effect of domestic expenditure shares. If expenditure shares are constant, such as in a standard HO model, only changes in the factor contents of trade affect the skill premium.

Expenditure shares are not constant due to changing household and intermediates expenditure shares. Utilizing the identity $s_n^a + s_n^b = 1$ and $e_n^a + e_n^b = 1$, the expenditure share part can be written as:

$$\frac{\sum_{k=\{a,b\}} \beta_n^k \left[v s_n^k + (1-v) e_n^k \right]}{\sum_{k=\{a,b\}} (1-\beta_n^k) \left[v s_n^k + (1-v) e_n^k \right]} = \frac{\beta_n^a + \left(\beta_n^b - \beta_n^a\right) \left[v s_n^b + (1-v) e_n^b \right]}{1 - \beta_n^a + \left(\beta_n^a - \beta_n^b\right) \left[v s_n^b + (1-v) e_n^b \right]}.$$

It implies that the changes in the numerator and the denominator due to structural changes (Δs_n^b and Δe_n^b) are opposite in sign. Therefore, I only investigate the changes in the numerator in the following.

I decompose the changes in numerator into changes in household and intermediates expenditure shares:

$$\Delta Num_n = vNum_n\left(\Delta s_n^b\right) + (1-v)Num_n\left(\Delta e_n^b\right).$$

On the household side:

$$Num_n\left(\Delta s_n^b\right) = \left(\beta_n^b - \beta_n^a\right)\Delta s_n^b,$$

as consumers demand relatively more skill intensive goods ($\Delta s_n^b > 0$), $Num_n\left(\Delta s_n^b\right) > 0$ so that the skill premium tends to increase.

For the intermediates expenditure share, substitute in $e_n^b = e_n^{ab}y_n^a + e_n^{bb}y_n^b$ and utilizing the identities $e_n^{aa} + e_n^{ab} = 1$, $e_n^{ba} + e_n^{bb} = 1$ and $y_n^a + y_n^b = 1$, we have

$$Num_n(\Delta e_n^k) = \left(\beta_n^b - \beta_n^a\right)\Delta e_n^b$$
$$= \left(\beta_n^b - \beta_n^a\right)\left[\underbrace{\left(e_n^{aa} + e_n^{bb} - 1\right)\Delta y_n^b}_{\text{between-sector}} + \underbrace{\left(y_n^b\Delta e_n^{bb} - y_n^a\Delta e_n^{aa}\right)}_{\text{within-sector}} + \underbrace{\left(\Delta e_n^{aa} + \Delta e_n^{bb}\right)\Delta y_n^b}_{\text{interaction}}\right].$$

If production in each sector uses its own inputs intensively ($e_n^{aa}, e_n^{bb} > \frac{1}{2}$), the between-sector component is positive, so that reallocation to skill intensive sectors ($\Delta y_n^b > 0$) further raises the skill premium. If firms uses more skill intensive intermediates overtime within each sector ($\Delta e_n^{aa} < 0$ and $\Delta e_n^{bb} > 0$), the within-sector component is positive. The sign of the interaction term is ambiguous, but the magnitude is likely to be small.

A.4 Structural Change

I measure the effects of different shocks on structural change by production reallocation index (PRI), which is defined as

$$PRI_i = 1 - \frac{|\Delta\tilde{y}_i^A - \Delta y_i^A| + |\Delta\tilde{y}_i^M - \Delta y_i^M| + |\Delta\tilde{y}_i^S - \Delta y_i^S|}{|\Delta y_i^A| + |\Delta y_i^M| + |\Delta y_i^S|},$$

where $\Delta y_i^k = y_i^k(07) - y_i^k(97)$ is the observed change in production share, and $\Delta\tilde{y}_i^k = y_i^k(c) - y_i^k(97)$ is the counterfactual change. PRI has the following properties:

1. $PRI \leq 1$; $PRI = 1$ if the counterfactual predicts the exact changes in production shares.

2. $PRI = 0$ if the counterfactual predicts no changes in production shares.

3. It is possible to have $PRI < 0$, if the counterfactual predicts much larger changes in production shares or changes in the opposite direction.

When PRI takes positive value it can be interpreted as the fraction of observed changes in production shares that is explained by the forces operative in the counterfactual scenario.

Table A.1 presents the implied PRI when each type of shocks is applied individually to the initial equilibrium. The main observation is that the change in sectoral production efficiency is the major driver of structural change, while shocks to endowment and SBTC play virtually no roles. Looking at each country, reductions in trade costs are more important in OECD countries, while sectoral productivity progress is more important in non-OECD countries.

Table A.1: Decomposition of PRI across countries

	Endowment	Trade costs	Sectoral tech	SBTC	Residuals
All	0.00	0.05	0.31	0.00	0.14
AUS	-0.03	-0.22	0.19	0.06	0.26
AUT	-0.01	0.56	-0.54	0.21	0.56
BEL	0.02	0.32	0.03	-0.05	-0.47
CAN	0.04	0.01	0.88	-0.19	0.16
DEU	0.06	0.45	-0.71	-0.01	0.87
DNK	0.00	-0.35	0.41	-0.07	-0.09
ESP	-0.06	0.27	-0.01	0.09	-0.79
FIN	-0.01	-0.44	-0.05	-0.02	-0.14
FRA	0.07	0.44	0.48	-0.12	-0.65
GBR	0.02	0.24	0.31	0.02	0.39
GRC	0.01	0.18	0.39	-0.01	0.26
IRL	0.12	-0.48	0.53	0.11	0.46
ITA	-0.11	-0.59	0.97	0.10	0.81
JPN	-0.22	0.08	-0.53	0.00	-1.28
KOR	0.03	-0.04	0.71	0.00	-0.09
LUX	-0.01	0.40	-0.28	0.01	0.31
NLD	0.02	0.29	-0.29	-0.08	0.49
PRT	-0.06	0.05	0.84	0.10	0.18
SWE	0.03	0.28	-1.06	0.04	-1.53
USA	-0.03	0.49	0.12	-0.01	-1.04
ARG	0.00	-0.08	0.14	0.00	0.69
BRA	-0.02	-0.16	0.27	0.01	0.68
CHL	0.02	-0.21	0.54	0.05	-0.17
CHN	0.02	0.39	0.73	-0.01	-0.69
CZE	0.00	0.04	0.42	-0.12	-0.09
HUN	0.04	0.44	0.34	0.02	-0.10
IDN	-0.01	-0.11	0.58	0.09	-0.44
IND	0.00	-0.16	0.24	-0.03	0.75
MEX	0.01	-0.07	0.40	-0.01	0.66
PER	0.00	0.36	0.01	0.04	0.49
PHL	-0.05	0.33	0.65	-0.04	0.32
POL	0.01	0.28	0.55	-0.01	0.14
SVK	0.00	-0.50	0.47	0.00	-0.17
SVN	-0.01	-0.19	0.22	0.13	0.15
THA	0.01	0.22	0.83	-0.01	-0.23
URY	0.04	-0.32	-0.38	-0.22	-0.28
VEN	0.18	-0.01	-0.82	-0.05	-0.57

A.5 Comparing the Results to Cravino and Sotelo (2016)

As mentioned in the literature review, Cravino and Sotelo (2016) also calculate the effects of trade on the skill premium in the presence of structural change. I compare my results to them by conducting the same counterfactual exercise in their work. The counterfactual exercise compares the baseline model to a scenario where all countries are in autarky. By assuming that the same set of fundamental shocks are operative in both the baseline and autarky model, including shocks to endowment, skill intensity, sectoral production efficiency, and residuals, the exercise computes the effects of trade on the skill premium by obtaining the differential effects of skill premium implied by the two models under the same set of fundamental shocks.[1] The advantage of this approach is that the effects of trade on the skill premium can be computed with only information on the changes in sectoral trade shares and revenue shares. The disadvantage of the approach is that we do know whether it is technical change or reductions in the trade costs that are driving the changes in trade and revenue shares.

Column two of Table A.2 presents the effects of trade on the skill premium under the autarky experiment in my framework. The main observation is that trade has no effect on the skill premium under the autarky experiment. The reason is that the same fundamental shocks under the closed and open economy will operate quite differently. In addition, trade induces structural change due to complementarity across sectors in Cravino and Sotelo (2016). In my framework, it is mainly due to

[1] Shocks to trade costs and deficits are set to infinity and zero respectively in the autarky model.

nonhomothetic preferences, while the force of complementarity between sectors is small due to the small magnitudes of price elasticities in Table 1.4.

Table A.2: Effects of trade on the skill premium: comparison

	Baseline	CS exercise	CS results
All	8.31	0.29	
All (CS)	8.27	0.37	2.50
AUS	5.62	0.37	0.80
AUT	4.91	-0.09	5.40
BEL	8.27	3.00	2.30
CAN	2.82	-0.36	2.30
DEU	4.06	-1.20	
DNK	8.45	1.75	5.30
ESP	10.89	1.36	5.50
FIN	7.45	1.94	1.60
FRA	7.02	1.32	2.50
GBR	6.92	0.96	5.30
GRC	23.44	9.97	14.90
IRL	13.10	5.53	2.20
ITA	7.29	0.68	2.30
JPN	1.16	0.30	-0.10
KOR	4.95	-0.65	-1.00
LUX	17.03	-3.76	
NLD	9.27	-2.17	2.40
PRT	9.12	4.69	12.60
SWE	7.32	2.70	
USA	2.01	0.89	3.70
ARG	4.25	-3.53	
BRA	3.13	-2.12	-1.90
CHL	6.80	-5.11	
CHN	20.28	0.15	-2.70
CZE	7.71	-3.48	-1.20
HUN	13.46	-5.91	10.00
IDN	11.49	0.52	
IND	8.31	2.34	8.70
MEX	9.38	-1.76	4.40
PER	10.57	-2.33	
PHL	29.11	-6.58	
POL	19.39	-4.27	14.40
SVK	9.01	0.29	4.00
SVN	13.63	0.76	
THA	18.29	-5.80	
URY	12.23	-3.03	
VEN	3.46	0.36	

Notes: The first column presents the effects of trade in the baseline counterfactual. The second column presents the results of the autarky experiment using my framework. The last row presents the results from Cravino and Sotelo (2016). The second row computes the median value for a set of countries in Cravino and Sotelo (2016).

A.6 Controling the Effects of Home Technical Change on Trade

One potential drawback of the baseline analysis is that the trade shocks do not incorporate the effects of home technical change on trade flows. It tends to *over-estimate* the effects of trade on the skill premium, as the actual changes in comparative advantage due to changes in relative sectoral production efficiency across countries are exaggerated. As sectoral productivity growth is highest in agriculture and lowest in services from Table 1.7, only considering foreign technical change as trade shocks tends to make home country relatively more productive in manufacturing and services, so that the home country is more likely to be a net exporter in skill intensive sectors.

However, home technical change affects the domestic economy regardless of trade. To overcome this difficulty, I transform the first order effects of shocks on home production efficiency into an equivalent shock on the bilateral trade cost, such that these two shocks have the same first order effects on the trade flows at home. The trade cost equivalent home technology shock has two components, an equivalent shock on the export cost $\tilde{d}^k_{-nn}$, and an equivalent shock on the import cost $\tilde{d}^k_{n-n}$ in home country n. The idea here is to capture the effects of home technical change on exports with an equivalent decrease in the costs of exporting, and the effects on imports with an equivalent increase in the costs of importing.[2]

To find the export cost equivalent $\tilde{d}^k_{-nn}$, I start from (1.7) with country $i = n$.

[2] For example, a rise in home production efficiency makes it more difficult for foreign firms to export to the home country, as if there is an increase in the import cost at home.

The first order effect of changes in home sectoral production efficiency $\hat{T}_n^k$ on its own exports is:

$$d\ln\pi_{-nn}^k = d\ln T_n^k - d\ln\Phi_{-n}^k,$$

where the second term is the direct effect of home technical change on foreign sectoral prices. Use the fact that $\Phi_{-n}^k = T_n^k\left(c_n^k d_{-nn}^k\right)^{-\theta^k} + \sum_{l\neq n} T_l^k\left(c_l^k d_{-nl}^k\right)^{-\theta^k}$, the first order effect of $\hat{T}_n^k$ on its exports is:

$$d\ln\pi_{-nn}^k = \left(1-\pi_{-nn}^k\right)d\ln T_n^k. \tag{A.1}$$

Similarly, the first order effect of export cost shock $\hat{d}_{-nn}^k$ on home's exports is:

$$d\ln\pi_{-nn}^k = -\theta^k\left(1-\pi_{-nn}^k\right)d\ln d_{-nn}^k, \tag{A.2}$$

which again includes the direct effect on foreign sectoral prices. Compare (A.1) and (A.2), the export cost equivalent home technology shock is:

$$\tilde{d}_{-nn}^k = \left(\hat{T}_n^k\right)^{-\frac{1}{\theta^k}}, \quad -n\neq n. \tag{A.3}$$

Similar procedure applies to the import cost equivalent $\tilde{d}_{n-n}^k$. From (1.7) with country n as the importer, the first order effect of changes in home sectoral production efficiency $\hat{T}_n^k$ on its own imports is:

$$d\ln\pi_{n-n}^k(\hat{T}_n^k) = -\pi_{nn}^k d\ln T_n^k. \tag{A.4}$$

The only difference from the export case is that home technical change affects imports only through home prices.

For the first order effect of import cost shocks, I have to consider all home country's trading partners together, as all import costs affect home price. From

(1.7), the first order effect of import cost shocks of all trading partners of home $\{\hat{d}^k_{n-n}\}_{-n}$ is:

$$d\ln \pi^k_{n-n} = \underbrace{-\theta^k \left(1-\pi^k_{n-n}\right) d\ln d^k_{n-n}}_{\text{direct effect of } \hat{d}^k_{n-n}} + \underbrace{\theta^k \sum_{l\neq n,-n} \pi^k_{nl} d\ln d^k_{nl}}_{\text{other import costs}}, \quad -n \neq n. \tag{A.5}$$

The effects of $\{\hat{d}^k_{n-n}\}_{-n}$ on imports from country $-n$ consist of two components. The first component is the direct effect from changes in import costs from country $-n$. The second component captures the effect of changes in import costs with other foreign countries on home price. Compare (A.4) and (A.5), the import cost equivalent home technology shock is:

$$\tilde{d}^k_{n-n} = \left(\hat{T}^k_n\right)^{\frac{1}{\theta^k}}, \quad -n \neq n. \tag{A.6}$$

Expressions (A.3) and (A.6) imply that the trade cost equivalent home technology shock is:

$$\{\tilde{d}^k_{-nn}, \tilde{d}^k_{n-n}\} \equiv \hat{T}^k_n, \quad -n \neq n. \tag{A.7}$$

Armed with the trade cost equivalent home technology shocks, I regroup the shocks into trade and technology:

1. Trade shocks:
    - trade cost shocks: $\{\hat{\kappa}^k_{mi}, \hat{\tau}^k_{mi}, \Delta D_n\}$,
    - technology-related trade shocks: $\{\hat{T}^k_{-n}, \tilde{d}^k_{-nn}, \tilde{d}^k_{n-n}\}$;
2. Technology shocks:
    - skill biased technical change: $\Delta\beta^k_n$,

- neutral technical change: $\left\{\hat{T}_n^k, \left(\tilde{d}_{-nn}^k\right)^{-1}, \left(\tilde{d}_{n-n}^k\right)^{-1}\right\}$.

The only difference from the baseline grouping is that part of the changes in home production efficiency is now attributed to trade.[3] The labor supply and model residual shocks remain the same.

I apply the above shocks to the same baseline model, and the results are presented in Table A.3. Compared with the baseline groups of shocks, now the effects of trade decline from 8.4% to 4.3%, while the effects of technical change increase from 1.6% to 5.9%. The difference is due to the smaller effects of technology-related trade shocks. The exercise shows the importance of controling for the effects of home technical change on trade flows.

Table A.3: Changes in the skill premium under alternative shocks (%): baseline

	All trade shocks	All tech shocks	Trade costs	Foreign tech tech-related	NTC	SBTC
			Baseline			
All	8.38	1.56	-0.45	8.03	-3.67	5.34
OECD	7.31	2.29	0.20	6.31	-2.98	5.91
Non-OECD	10.57	1.74	-2.67	13.02	-4.79	4.07
			Home tech adjusted			
All	4.31	5.86	-0.45	3.92	-0.22	5.34
OECD	4.31	6.46	0.20	3.44	-0.22	5.91
Non-OECD	5.40	3.57	-2.67	5.61	-0.43	4.07

I also do the same exercise on the no structural change model. Table A.4 illus-

[3] One caveat of the new grouping is that now trade and technology shocks are not orthogonal to each other, as $\tilde{d}_{-nn}^k$ and $\left(\tilde{d}_{-nn}^k\right)^{-1}$ are correlated. Therefore I may double count the general equilibrium effects coming from the trade cost equivalent shocks.

Table A.4: Changes in the skill premium under alternative shocks (%): no structural change model

	All trade shocks	All tech shocks	Trade costs	Foreign tech tech-related	NTC	SBTC
			Baseline			
All	4.33	2.26	-0.22	4.46	-3.11	5.41
OECD	4.00	3.27	0.06	3.46	-2.78	6.00
Non-OECD	4.52	0.24	-0.87	5.32	-3.92	4.06
			Home tech adjusted			
All	0.68	4.49	-0.22	0.53	-0.74	5.41
OECD	1.06	5.49	0.06	0.78	-0.64	6.00
Non-OECD	0.42	1.96	-0.87	0.38	-1.44	4.06

trates the results. Though the changes in the skill premium induced by trade and technical change are quite different under these two grouping schemes, the contribution from structural change is similar. In particular, structural change increases the skill premium by 4.2% in OECD countries, and 6.7% in non-OECD countries, compared to 2.3% in OECD 7.7% in non-OECD when the effects of home technical change on trade flows are not taken into account.

In sum, controling the effects of home technical change on trade flows implies smaller effects of trade on the skill premium, but the effects remain positive and economically significant.

Appendix B: Intermediates Specialization and Welfare Gains from Trade

B.1 Data

B.1.1 Cross Country Evidence

We combine 24 GTAP manufacturing industries into 9 industries as below:

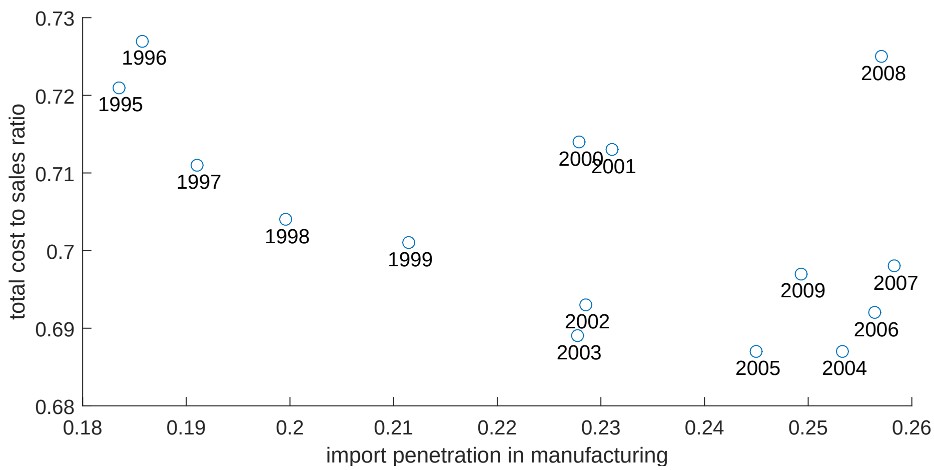
Table B.1: GTAP industry classification

	GTAP industry codes	Description
Food	cmt omt vol mil sgr	meat, vegetable oil and fats, diary, sugar
	pcr ofd b_t	processed rice, beverages and tobacco
Textile	tex wap lea	textiles, apparel, leather
Wood	lum ppp	wood, paper, publishing
Chemical	p_c crp nmm	petroleum, coal products, chemical
		rubber, plastic, mineral products
Metal	i_s nfm fmp	Ferrous metals, metal products
Motor	mvh otn	motor vehicles and parts, transport
Electronic	ele	equipment, electronic equipment
Machine	ome	machinery and equipment
Rest manu	omf	other manufacturing

B.1.2 US Manufacturing

In NBER CES database, we compute the observed industry production cost as $E_{nk} = matcost + payroll + invest$, and plot the ratio of this observed expenditure to sales in Figure B.1. We see that this ratio looks fairly constant post 2000, except

Figure B.1: Observed expenditure in production relative to sales: 1995-2009



Notes: Import penetration is computed as ratio of total manufacturing import values to total manufacturing absorption.

in the recessionary years. (In recessions, markup tends to be lower than normal, which may be the reason why the cost ratio is larger in recessions.)

B.2 Two Stage Production

The two stage production extension is to show that our framework can be interpreted as firms replace less productive part of the production process with intermediate inputs, therefore specialization within a firm.

The production has two stages. In the first stage, firms use only labor to produce two types of intermediates with the following technology

$$\begin{aligned} x_1 &= z_1 l_1 \\ x_2 &= z_2 l_2, \end{aligned} \tag{B.1}$$

where z_i is production efficiency and l_i is labor used in type i intermediates. Without loss of generality we assume production of type 1 intermediates is relatively more efficient, $z_1 > z_2$. In the second stage, firms produce final good by aggregating these two types of intermediates:

$$y(\varphi) = \varphi x_1^{1-\alpha} x_2^{\alpha} \tag{B.2}$$

Notice that firms are homogeneous in the production of first stage intermediates, but heterogeneous in productivity at aggregating intermediates as captured by φ.

Instead of producing both types of intermediates by itself, firms have the option to pay a fixed cost of f_a units of labor to replace *only one* type of intermediates with the market intermediates bundle, which is a CES aggregate of stage two goods in the economy at price P. So we can write the unit cost of the firm as

$$c_v(\varphi) = \begin{cases} \frac{w}{\varphi z_1^{1-\alpha} z_2^{\alpha}} & v = 0, \text{ no adoption,} \\ \frac{1}{\varphi \phi^{1-\alpha} z_2^{\alpha}} w^{\alpha} P^{1-\alpha} & v = 1, \text{ pay } f_a \text{ and replace } x_1, \\ \frac{1}{\varphi \phi^{\alpha} z_1^{1-\alpha}} w^{1-\alpha} P^{\alpha} & v = 2, \text{ pay } f_a \text{ and replace } x_2, \end{cases}$$

where ϕ is the productivity effect of using the market intermediates bundle. Notice that for firms to be willing to replace either type of intermediates, we require $c_0(\varphi) > c_1(\varphi)$ and $c_0(\varphi) > c_2(\varphi)$.

We now derive the conditions under which firms always choose to replace type 2 intermediates under adoption. This requires $\frac{c_1(\varphi)}{c_2(\varphi)} \geq 1$. If $\alpha \geq 0.5$ as the case in our quantification, we have

$$\frac{c_1(\varphi)}{c_2(\varphi)} = \frac{w^{2\alpha-1}P^{1-2\alpha}z_1^{1-\alpha}}{\phi^{1-2\alpha}z_2^{\alpha}} = \frac{z_1^{1-\alpha}z_2^{2\alpha-1}}{z_2^{\alpha}}\left[\frac{c_0(\varphi)}{c_2(\varphi)}\right]^{\frac{2\alpha-1}{\alpha}} \geq \left(\frac{z_1}{z_2}\right)^{1-\alpha} > 1,$$

where the last step utilizes the assumption that production of type 1 intermediates is more efficient. If instead $\alpha < 0.5$, a sufficient condition for $\frac{c_1(\varphi)}{c_2(\varphi)} \geq 1$ is that

$$z_1 > \left(\phi\frac{w}{P}\right)^{\frac{1-2\alpha}{1-\alpha}} z_2^{\frac{\alpha}{1-\alpha}},$$

which is derived by observing $\frac{c_1(\varphi)}{c_2(\varphi)} = \frac{w^{2\alpha-1}P^{1-2\alpha}z_1^{1-\alpha}}{\phi^{1-2\alpha}z_2^{\alpha}} > 1$ and $1-2\alpha > 0$.

Therefore, under sufficiently large z_1, the unit cost becomes

$$c(\varphi) = \begin{cases} \frac{w}{\varphi z_1^{1-\alpha}z_2^{\alpha}} & \text{no adoption,} \\ \frac{1}{\varphi\phi^{\alpha}z_1^{1-\alpha}}w^{1-\alpha}P^{\alpha} & \text{pay } f_a \text{ and adopt.} \end{cases} \tag{B.3}$$

Normalizing $z_1^{1-\alpha}z_2^{\alpha} = 1$ and setting $\phi = \phi^{\alpha}z_1^{1-\alpha}$ give the unit cost in our framework. Therefore, our model can be interpreted as firms become more specialized in activities that are more productive within the firm (production of type 1 intermediates here).

B.3 Equilibrium with Pareto

From demand for the firm $q(\varphi) = XP^{\sigma-1}p(\varphi)^{-\sigma}$, firm sales can be expressed as

$$y(\varphi) = p(\varphi)q(\varphi) = X\left[\frac{p(\varphi)}{P}\right]^{1-\sigma}. \tag{B.4}$$

Using optimal pricing (2.8), relative firm sales is

$$\frac{y(\varphi_1)}{y(\varphi_2)} = \left[\frac{p(\varphi_1)}{p(\varphi_2)}\right]^{1-\sigma} = \left[\frac{c(\varphi_1)}{c(\varphi_2)}\right]^{1-\sigma} = \left(\frac{\varphi_1}{\varphi_2}\right)^{\sigma-1}. \tag{B.5}$$

In addition, from CES demand, $y_v(\varphi) = \sigma\left[\pi_v(\varphi) + wf_v\right]$, $v = n, a, x$. Therefore,

$$y_v(\varphi) = \sigma\left[\pi_v(\bar{\varphi}_v) + wf_v\right]\left(\frac{\varphi}{\bar{\varphi}_v}\right)^{\sigma-1}. \tag{B.6}$$

Aggregate sales of non-adopters, adopters' domestic sales and adopters' export sales are respectively

$$\begin{aligned} Y_n &= \sigma M\left[\pi_n(\bar{\varphi}_n) + wf_n\right]\int_{\bar{\varphi}_n}^{\bar{\varphi}_a}\left(\frac{\varphi}{\bar{\varphi}_n}\right)^{\sigma-1} dG(\varphi) \\ &= \frac{\sigma k}{k-\sigma+1}\left(\varphi_{\min}\right)^k Mwf_n\left[\left(\bar{\varphi}_n\right)^{-k} - \left(\frac{\bar{\varphi}_a}{\bar{\varphi}_n}\right)^{\sigma-1}\left(\bar{\varphi}_a\right)^{-k}\right], \end{aligned} \tag{B.7}$$

$$\begin{aligned} Y_a &= \sigma M\left[\pi_a(\bar{\varphi}_a) + w(f_n+f_a)\right]\int_{\bar{\varphi}_a}^{\infty}\left(\frac{\varphi}{\bar{\varphi}_a}\right)^{\sigma-1} dG(\varphi) \\ &= \sigma M\left[\pi_n(\bar{\varphi}_a) + w(f_n+f_a)\right]\int_{\bar{\varphi}_a}^{\infty}\left(\frac{\varphi}{\bar{\varphi}_a}\right)^{\sigma-1} dG(\varphi) \\ &= \sigma M\left[\left(\pi_n(\bar{\varphi}_n) + wf_n\right)\left(\frac{\bar{\varphi}_a}{\bar{\varphi}_n}\right)^{\sigma-1} + wf_a\right]\int_{\bar{\varphi}_a}^{\infty}\left(\frac{\varphi}{\bar{\varphi}_a}\right)^{\sigma-1} dG(\varphi) \\ &= \frac{\sigma k}{k-\sigma+1}\left(\varphi_{\min}\right)^k Mw\left[f_n\left(\frac{\bar{\varphi}_a}{\bar{\varphi}_n}\right)^{\sigma-1}\left(\bar{\varphi}_a\right)^{-k} + f_a\left(\bar{\varphi}_a\right)^{-k}\right], \end{aligned} \tag{B.8}$$

$$\begin{aligned} Y_x &= \sigma M\left[\pi_x(\bar{\varphi}_x) + wf_x\right]\int_{\bar{\varphi}_x}^{\infty}\left(\frac{\varphi}{\bar{\varphi}_x}\right)^{\sigma-1} dG(\varphi) \\ &= \frac{\sigma k}{k-\sigma+1}\left(\varphi_{\min}\right)^k Mwf_x\left(\bar{\varphi}_x\right)^{-k}, \end{aligned} \tag{B.9}$$

where we utilize the fact that $\int_{\bar{\varphi}_v}^{\infty}\varphi^{\sigma-1}dG(\varphi) = \frac{k}{k-\sigma+1}\left(\varphi_{\min}\right)^k\left(\bar{\varphi}_v\right)^{\sigma-1-k}$ and the conditions for productivity thresholds (2.15), (2.10), (2.17). Therefore, the total sales Y is

$$Y = Y_n + Y_a + Y_x = \frac{\sigma k}{k-\sigma+1}\left(\varphi_{\min}\right)^k Mw\left[f_n\left(\bar{\varphi}_n\right)^{-k} + f_a\left(\bar{\varphi}_a\right)^{-k} + f_x\left(\bar{\varphi}_x\right)^{-k}\right], \tag{B.10}$$

and sales share of adopters is

$$\lambda_a = \frac{Y_a + Y_x}{Y} = \frac{\frac{(s_a)^{\sigma-1}}{(s_a)^{\sigma-1}-1}f_a\left(\bar{\varphi}_a\right)^{-k} + f_x\left(\bar{\varphi}_x\right)^{-k}}{f_n\left(\bar{\varphi}_n\right)^{-k} + f_a\left(\bar{\varphi}_a\right)^{-k} + f_x\left(\bar{\varphi}_x\right)^{-k}}. \tag{B.11}$$

We can also show that total fixed cost payments F are a constant fraction of total sales. By definition,

$$\begin{aligned} F &= wM\left[\int_{\bar{\varphi}_n}^{\bar{\varphi}_a} f_n dG(\varphi) + \int_{\bar{\varphi}_a}^{\infty}(f_n + f_a)dG(\varphi) + \int_{\bar{\varphi}_x}^{\infty} f_x dG(\varphi)\right] \\ &= wM\left(\varphi_{\min}\right)^k\left[f_n\left(\bar{\varphi}_n\right)^{-k} + f_a\left(\bar{\varphi}_a\right)^{-k} + f_x\left(\bar{\varphi}_x\right)^{-k}\right], \end{aligned} \tag{B.12}$$

which implies $\frac{F}{Y} = \frac{k-\sigma+1}{\sigma k}$. Therefore, we can simplify the labor market clearing condition (2.22) to

$$wL = \frac{\sigma-1}{\sigma}(1-\alpha\lambda_a)Y + \frac{k-\sigma+1}{\sigma k}Y. \tag{B.13}$$

We also get the labor share

$$\lambda_l = \frac{wL}{Y} = \frac{\sigma-1}{\sigma}(1-\alpha\lambda_a) + \frac{k-\sigma+1}{\sigma k}. \tag{B.14}$$

B.3.1 Trade Flows

Utilizing the pareto distribution and the productivity thresholds on exporters (2.18), the trade volumes between the two countries can be written as

$$\begin{aligned} \ln Y_x &= \ln\left[M\int_{\bar{\varphi}_x}^{\infty} p_x(\varphi)q_x(\varphi)dG(\varphi)\right] \\ &= \ln\left[\frac{\sigma k}{k-\sigma+1}\left(\varphi_{\min}\right)^k Mwf_x\right] - k\ln\bar{\varphi}_x \\ &= \ln(\Lambda_1 ML) - k\ln\tau - \left(\frac{k}{\sigma-1} - 1\right)\ln f_x + k(1-\alpha)\ln P - \frac{k}{\sigma-1}\ln\lambda_l, \end{aligned} \tag{B.15}$$

where $\Lambda_1 = \frac{k}{k-\sigma+1}\sigma^{1-\frac{k}{\sigma-1}}\left(\frac{\sigma}{\sigma-1}\right)^{-k}\left(\varphi_{\min}\right)^k$ is a constant. Comparing with the gravity equation in Chaney (2008), the two trade costs terms τ and f_x have the same elasticity, the price term is the multilateral resistance. The only difference is the last term involving the labor share, which plays a key role in generating more trade flows in response to reductions in trade costs.

B.3.2 Equilibrium

By definition, the price index P is

$$
\begin{aligned}
P^{1-\sigma} &= M\left[\int_{\bar{\varphi}_n}^{\bar{\varphi}_a}[p_n(\varphi)]^{1-\sigma}\,dG(\varphi)+\int_{\bar{\varphi}_a}^{\infty}[p_a(\varphi)]^{1-\sigma}\,dG(\varphi)+\int_{\bar{\varphi}_x}^{\infty}[p_x(\varphi)]^{1-\sigma}\,dG(\varphi)\right]\\
&=\left(\frac{\sigma}{\sigma-1}\right)^{1-\sigma}M\\
&\times\left[\int_{\bar{\varphi}_n}^{\bar{\varphi}_a}\varphi^{\sigma-1}dG(\varphi)+(s_a)^{\sigma-1}\int_{\bar{\varphi}_a}^{\infty}\varphi^{\sigma-1}dG(\varphi)+\left(\frac{s_a}{\tau}\right)^{\sigma-1}\int_{\bar{\varphi}_x}^{\infty}\varphi^{\sigma-1}dG(\varphi)\right]\\
&=\Lambda_1\left\{(\bar{\varphi}_n)^{\sigma-1-k}+\left[(s_a)^{\sigma-1}-1\right](\bar{\varphi}_a)^{\sigma-1-k}+\tau^{1-\sigma}(s_a)^{\sigma-1}(\bar{\varphi}_x)^{\sigma-1-k}\right\},
\end{aligned}
\tag{B.16}
$$

where $\Lambda_1=\left(\frac{\sigma}{\sigma-1}\right)^{1-\sigma}\frac{k}{k-\sigma+1}M\left(\varphi_{\min}\right)^k$. We then substitute in the expressions for productivity thresholds (2.16), (2.11), (2.18), sales share of adopters (B.11), and labor share (B.14), and arrive at equilibrium price (2.26).

B.4 Calibration Procedure

The model perfectly matches the import penetration $1-\lambda_x$ in each year. The calibration procedure works as the following:

1. Guess the values of α, f_a, and ϕ.

2. We choose 2000 as our base year, and use data on the fraction of exporters from Bernard et al. (2007) ($\chi_x(00) = 0.18$) to pin down the time-invariant fixed cost of exporting f_x as well as solving for the equilibrium. This can be done with the following steps:

   (a) Guess the value of entry cutoff $\bar{\varphi}_n(00)$ and sales share of adopters $\lambda_a(00)$;

(b) Find total sales $Y(00)$ according to expression (B.13):

$$Y = L \bigg/ \left[\frac{\sigma - 1}{\sigma}(1 - \alpha\lambda_a) + \frac{k - \sigma + 1}{\sigma k} \right]; \tag{B.17}$$

(c) Find $Y_n = Y(1 - \lambda_a)$ and $Y_a = Y\lambda_x - Y_n$;

(d) Re-arrange expression (B.7) and solve for the adopter cutoff, $\bar{\varphi}_a$ given the entry cutoff $\bar{\varphi}_n(00)$;

(e) Compute the specialization premium and price index using productivity thresholds (2.11) and (2.16):

$$\begin{aligned} s_a(00) &= \left[\left(\frac{f_a}{f_n} \right) \bigg/ \left(\frac{\bar{\varphi}_a}{\bar{\varphi}_n} \right)^{\sigma - 1} + 1 \right]^{\frac{1}{\sigma - 1}}, \\ P(00) &= \left(\frac{f_n}{\tilde{\sigma} Y} \right)^{\frac{1}{\sigma - 1}} (\bar{\varphi}_n)^{-1}; \end{aligned} \tag{B.18}$$

(f) Find the implied $\phi(00)$ according to $s_a(00)$: $\phi(00) = s_a(00)P(00)^{\alpha}$

(g) Check if the following two conditions hold:

$$\begin{aligned} Y_n + Y_a &= \frac{\sigma k}{k - \sigma + 1} (\varphi_{\min})^k M \left[f_n (\bar{\varphi}_n)^{-k} + f_a (\bar{\varphi}_a)^{-k} \right], \\ \phi(00) &= \phi, \end{aligned} \tag{B.19}$$

if not, start again from step (a).

(h) After the conditions in step (g) is satisfied, compute f_x and $\tau(00)$ as

$$\begin{aligned} f_x &= \frac{Y(00)(1 - \lambda_x(00))}{\frac{\sigma k}{k - \sigma + 1} (\varphi_{\min})^k M \chi_x(00) (\bar{\varphi}_n)^{-k}}, \\ \tau(00) &= [\chi_x(00)]^{-\frac{1}{k}} s_a(00) \left(\frac{f_n}{f_x} \right)^{\frac{1}{\sigma - 1}}, \end{aligned} \tag{B.20}$$

where the expressions above utilize the export cutoff (2.18) and the definition of fraction of exporters $\chi_x = \left(\frac{\bar{\varphi}_x}{\bar{\varphi}_n} \right)^{-k}$.

3. For other years ($t \neq 2000$), using the value of f_x from step 2 and domestic trade share $\lambda_x(t)$, we solve for the equilibrium in year t and find $\tau(t)$ with the following steps:

   - Follow steps (a) to (g) but with year t;
   - The variable trade cost $\tau(t)$ can be retrieved from productivity thresholds (2.16) and (2.18):

$$\tau(t) = \frac{\bar{\varphi}_x}{\bar{\varphi}_n} s_a(t) \left(\frac{f_n}{f_x}\right)^{\frac{1}{\sigma-1}}. \tag{B.21}$$

4. Compute the model-implied intermediates production share $\alpha\lambda_a$ and sector TFP growth $\frac{\bar{\phi}(t+1)}{\bar{\phi}(t)}$.

5. Find the values of α, f_a, and ϕ the satisfy (2.54) using numerical derivatives.

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