Spring 1-1-2014

Essays on Firm Heterogeneity, Product Quality, and International Trade

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A thesis submitted to the

Faculty of the Graduate School of the

University of Colorado in partial fulfillment

of the requirements for the degree of

Doctor of Philosophy

Department of Economics

2014

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Essays on Firm Heterogeneity, Product Quality, and International Trade
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The final copy of this thesis has been examined by the signatories, and we find that both the content and the form meet acceptable presentation standards of scholarly work in the above mentioned discipline.

Whang, Un Jung (Ph.D., Economics)

Essays on Firm Heterogeneity, Product Quality, and International Trade

Thesis directed by Prof. James R. Markusen

Thesis consists of three different chapters: i) Who Exports Better Quality Products to Smaller or More Distant Markets? ii) Skilled-Labor Intensity Differences across Firms, Product Quality, and Wage Inequality, and iii) Structural Transformation and Comparative Advantage: Implications for Small Open Economies.

In the first chapter, I examine the role of product quality heterogeneity and firms competition in determining the spatial patterns of within-product unit values across destinations. Using product-level export data, it is shown that the average export unit value of a product shipped from the US or Korea increases in distance and decreases in destination market size. However, within-product average unit value for products sourced from China and India decreases (increase) in distance (market size). To interpret these different spatial patterns of unit values across exporting countries, model of quality heterogeneity is developed in which firms differ in their workers' skill level and more skilled workers are more productive in performing tasks that improve on product quality. The model predicts that in relatively skill-abundant countries, exporting firms specialize in high quality varieties using relatively cheap skilled labor, whereas, in relatively skill-scarce countries, firms with lower quality goods are more competitive.

The second chapter proposes a theory to explain the relative wage-rate increase for skilled labor that results from trade liberalization that relies on within-sector reallocations of production resources (skilled and unskilled labor) across firms. Motivated by some stylized facts, in a model with firm heterogeneity, including firms that differ in their skill intensity even within a narrowly defined industry, firms with relatively high skill intensity that are more likely to be exporters, and a positive association between a firm's skill intensity and its product quality, I develop a general equilibrium model where firms with a higher skill intensity endogenously choose a higher-quality product, and tend to be more profitable. In this framework,

a reduction in trade costs allows members of the workforce to reallocate to more efficient firms that produce higher-quality products, using their skilled labor more intensively, resulting in a rising skill premium. The main sources of the increasing wage inequality that followed trade openness are a positive link between a firm's skill intensity, its product quality, and quality competition.

My researches mainly include, but are not limited to, the microeconomic aspects of international trade. I also investigate economic development and growth and in particular, the effect of such trade-related mechanisms as comparative advantage on the structural transformation of economies. In the third chapter, I use data from the last half century to show that revealed comparative advantage in agriculture (manufacturing) is negatively (positively) associated with the rate of decline in labor share in agriculture. Motivated by this finding, we construct and calibrate a simple open-economy model, where there is learning-by-doing in manufacturing and industry supplied inputs to agricultural production. We focus on the effects of comparative advantage and learning-by-doing on structural transformation and calibrate our model to the US and the UK data to estimate key parameters of the model. Our quantitative experiments show that holding constant other factors a small difference in a country's comparative advantage can account for a large variation in structural transformation for small open economies, which does not require nearly as much differential productivity growth as in closed economy models.

Dedication

This thesis is dedicated to my parents.

For their endless love, support, and encouragement

Acknowledgements

First and foremost, I would like to express my sincere gratitude to my main advisor Prof. James R. Markusen for the continuous support of my Ph.D study and research, for his patience, motivation, enthusiasm, and immense knowledge. His guidance helped me in all the time of research and writing of this thesis. Without his guidance and persistent help this dissertation would not have been possible. I could not have imagined having a better advisor and mentor for my Ph.D study.

Besides, I would like to thank the rest of my thesis committee: Prof. Keith E. Maskus, Prof. Murat Iyigun, Prof. Wolfgang Keller, Prof. Jin-Hyuk Kim, Prof. Thibault Fally, and Prof. Moonhawk Kim for their encouragement, insightful comments, and hard questions. In particular, I am deeply grateful to Prof. keith Maskus and Jin-kyuk Kim who always gives me constructive comments and suggestions for letting me be more productive. My sincere thanks also goes to Dr. Soyoung Kim and Dr. Young-sik Kim for their continuous supports and advices who help me to endure at the end of Ph.D program. I also would like to thank the Department of Economics and especially Patricia Holocomb for all the assistance. I also thank all my friends in department for the passionate discussions and for all the fun we have had in the last four years.

Last but not the least, I would like to thank my parents, Hwan-Heung Hwang and Myo-Hee Cho, for their faith in me and allowing me to be as ambitious as I wanted. They are always supporting me spiritually throughout my life. I owe them everything, and I wish to say how much I love and appreciate them. Also, I thank my wife Eunsun Park. Her support, encouragement, quite patience allow me to finish this arduous journey. I am also thankful to my little sons, Justin and Aiden, who let me know what true happiness is. They always give me smile and courage for over 8 years. Finally, I would like to dedicate this work to my sisters: Sung-Hee, Yun-Suk, Jung-Suk, and Hyun-Suk, who always support me with their best wishes.

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Chapter 1

Who Exports Better Quality Products to Smaller or More Distant Markets?

1.1 Introduction

Average export unit values vary across destinations even within narrowly defined product categories. For instance, U.S. exports of men's blazers to New Zealand are 30 times more expensive than the same product exported to Korea. One explanation for these differences in average export unit values across markets is firms' self-selection behavior. As is well known in the literature, firms' self-selection into exports is often derived from the sorting of firms with heterogeneous productivity across markets. In these standard models, a product's average export unit value varies across destinations because of the differing composition of exporting firms across markets.[1] To be more specific, Melitz (2003) considers a model of firm heterogeneity with respect to productivity, where labor is assumed to be homogeneous and product quality is identical across firms. In this model, a more productive firm, with a lower marginal cost, charges a lower price and becomes more profitable. In this context, more productive firms can penetrate difficult markets relatively easily, and as a result within-product average unit values would decrease with the increasing difficulty in market penetration (e.g., smaller and/or more distant markets).

Recent empirical evidence, however, shows that larger exporting firms are more skill intensive, and they pay higher wages simply due to their employing a higher proportion of skilled labor (e.g., a higher ratio of skilled to unskilled workers).[2] Further, the spatial patterns of export unit values - the variation of average

[1] Another possible explanation involves within-firm price discrimination or within-firm selection of product quality across markets. See Harrigan et al. (2011) and Bastos and Silva (2010), which explain within-firm price variations across destinations using firm-level data. Without firm-level data at hand, one cannot directly distinguish the within-firm selection effect from the firms' self-selection effect. However, the estimation results conducted in a later section with product-level data allow one to indirectly capture the relative importance of the firms' self-selection effect rather than the within-firm channel.

[2] See Schank et al. (2007) and Irarrazabal et al. (2009) for evidence of skill-intensity differences across firms and the exporter

free-on-board (f.o.b.) unit values with respect to importer characteristics, such as distance and market size - seem inconsistent with standard theories of heterogeneous firms in that exporters charge higher prices than non-exporters do (see, e.g., Baldwin and Harrigan 2011). In this paper, I examine product-level export data from four different countries (the U.S., South Korea, China, and India) to document the spatial patterns of export unit values by using a reduced-form gravity equation.[3] The variations in the average export unit values across foreign markets are systematically related to the distance between countries and the destination market's size. The effects of market size and distance on average export unit values have opposite signs regardless of exporting country, whereas these spatial patterns vary across exporting countries. The average export unit values of products shipped from the U.S. or Korea are positively (negatively) associated with distance (market size). In contrast, these effects are the opposite for China and India.

In line with recent studies (e.g., Baldwin and Harrigan 2011; Johnson 2012) that emphasize the importance of product quality in determining firms' competitiveness, I incorporate across-firm differences in product quality in the spirit of firm heterogeneity with heterogeneous workers, where firms endogenously determine their own product quality in response to their employees' skill level. In this theoretical framework, quality differentiation and firms competition in a model with firm heterogeneity play an important role in explaining the observed spatial patterns of export unit values found in the empirical evidence. Two main features of the model are outlined as follows: First, firms in a country are heterogeneous with respect to the skill level of their workers. Higher-skilled workers are more expensive to employ, and they have no productive advantage in producing a basic unit of physical output (e.g., assembly work such as screwing nuts onto bolts). However, higher-skilled workers have a productive advantage in improving product quality compared to lower-skilled workers.[4] Second, firms in different countries face different wage schedules as a function of skill level. To be more precise, the skill elasticity of the wage rate is assumed to be lower in relatively skill-abundant countries than in relatively skill-scarce countries.

This paper aims to contribute to the literature as follows: First, existing studies (e.g., Kneller and

wage premium.

[3] I choose China and India because the size of their economies is similar to that of the U.S., but these countries are different from the U.S. in regard to income level and skilled-labor abundance. Comparing Chinese exports to Korean exports also gives useful information about within-firm selection of export prices across markets in that Korea is the closest country to China.

[4] For evidence of a positive association between firms' product quality and the skill level of their workers, see Kyoji and Keiko (2010) and Kugler and Verhoogen (2012).

Yu 2008; Baldwin and Harrigan 2011; Johnson 2012) focus on the spatial patterns of unit values using export data from a single country. Consequently, they are unable to capture the differences in the spatial patterns of unit values across exporting countries.[5] Second, this paper introduces quality heterogeneity in the standard model of trade, where product quality is endogenously chosen by individual firms, whereas Kneller and Yu (2008), Baldwin and Harrigan (2011), and Johnson (2012) incorporate product quality into a model of heterogeneous firms by assuming that quality is determined exogenously as a function of a firm's idiosyncratic marginal cost. Finally, the model can present some stylized facts that are not clearly explained in the existing theoretical models, such as within-product specialization across countries.[6] Firms producing lower-quality products in developed/skill-abundant countries are less efficient, so they are more likely to exit a market. As a result, only the firms with high enough product quality tend to be exporters. In contrast, in developing/skill-scarce countries, firms producing low-quality varieties using relatively cheap, unskilled labor are more competitive and tend to export.

The remainder of this paper is organized as follows: Section 2 contains a brief review of the relevant theories and empirical evidence on the relationship between unit values and the characteristics of exporters and importers. Section 3 describes the data, the empirical methods, the results, and robustness checks. Section 4 lays out a model of endogenous quality differentiation that potentially explains the different spatial patterns of the average f.o.b. export unit values of products across the exporting countries that are found in Section 3. The last section provides a conclusion.

1.2 Literature Review

In standard models of heterogeneous firms without quality differentiation, pioneered by Melitz (2003), a product's average f.o.b. export price should decrease with distance and increase with market size due to the self-selection of more efficient firms with lower prices into tougher markets. In contrast, an increasing number of authors emphasize the role of product quality in accounting for a link between the patterns of the average export price and the importer's characteristics such as trade cost and market size (see, e.g., Schott

[5] The spatial patterns of within-product export unit values may depend on the exporting country's characteristics, such as its level of development or skill abundance.

[6] For empirical evidence of within-product specialization across exporting countries, see Schott (2004).

2004; Baldwin and Harrigan 2011; Johnson 2012). For instance, Johnson (2012) investigates a relationship between the observed export price and the export threshold across importing countries, which informs on the correlation between the quality-adjusted and the observed price. He finds that the average export price is negatively correlated to the quality-adjusted price in the majority of U.S. manufacturing sectors. These findings are consistent with models of quality heterogeneity in which firms that supply higher-quality products at higher prices become more competitive.

Another recent paper by Baldwin and Harrigan (2011) exploits US export data and uses a simple reduced-form gravity equation to show that within-product unit value is positively associated with distance as a proxy for trade costs, while it decreases with the market size of a destination. The authors point out that leading theoretical models of firm heterogeneity fail to account for these findings and suggest a quality-augmented model, where quality rises faster than (idiosyncratic) marginal cost. Under this assumption of quality differences across firms, firms with the highest marginal cost are most profitable because they compete on a quality-adjusted price. Since Baldwin and Harrigan assume that the firm's product quality is exogenously determined by its marginal cost, they have some difficulty accounting for the exogenously given quality function. Further, Baldwin and Harrigan's model cannot support the spatial patterns of export unit values for products sourced from China. Indeed, Kneller and Yu (2008) find that the average unit values are positively associated with both distance and market size in the majority of Chinese export sectors, which is inconsistent with the model suggested by Baldwin and Harrigan (2011) as well as the standard Melitz model. To account for these findings, Kneller and Yu consider a price discrimination model with a linear demand and show that average export prices are jointly determined by the sorting of heterogeneous firms and by within-firm price discrimination.

Bastos and Silva (2010) also show that the positive effects of both distance and market size on unit values can be explained by within-firm price discrimination as well as by firms' self-selection using Portuguese firm-level data. These findings by Bastos and Silva are, however, inconsistent with the heterogeneous quality model with a linear demand proposed by Kneller and Yu (2008) in that firms differentiate their products and charge higher prices in smaller and/or more distant markets.[7] In contrast, Harrigan et al. (2011) use U.S.

[7] In the model of Melitz and Ottaviano (2008) with a linear demand, firms can more easily export their products to relatively

firm-level data and confirm that there is no empirical evidence to support within-firm price discrimination based on geographical distance.

This paper builds on recent empirical evidence on the relationship between the level of exporter development and product quality (e.g., Schott 2004; Hallak and Schott 2011) and the link between firm-specific product quality and firm's skilled-labor intensity (marginal cost) (e.g., Verhoogen 2008; Kyoji and Keiko 2010; Johnson 2012; Kugler and Verhoogen 2012) to analyze the role of within-product quality differences in a model with heterogeneous firms and to explain the different spatial patterns of the average export unit values across exporting countries.

1.3 Empirical Analysis

1.3.1 Data Description

The main data set is drawn from the UN Commodity Trade Statistics Database (COMTRADE) database for the year 2007. I mainly use export data from the U.S., South Korea, China, and India. For each country's exports, the United Nations Statistical Division reports data for all trading partners classified by the 6-digit Harmonized System (HS). These data contain total export value and quantity for each HS-6 product broken down by trading partner. The analysis also includes country information: the level of real income (GDP per worker) and market size (PPP GDP).[8] In addition, I use several proxies for bilateral trade costs from the Centre d'Etudes Prospectives et d'Informations Internationales (CEPII) gravity dataset. The geographic distances are measured between the most populated city in both exporting and importing countries.[9] The common legal system variable takes the value one if the exporting and importing countries share the same legal system, and the common language dummy is one if the same language is spoken by at least 9% of the population in both countries. Also, if the destination country is landlocked, the landlocked variable is one. I also use trade policy measures for 2006 such as World Trade Organization (WTO) membership, regional trade agreements (RTA), and common currency region.

small and less distant foreign markets. In contrast, in the Melitz model with CES preference, more difficult markets are represented by longer distance and smaller market size.

[8] The country indicator variables are taken from the World Development Indicators (WDI).

[9] For instance, distances for U.S. exports are measured in kilometers from Chicago to the most populated city in importing countries.

The variable of interest is the average unit value of exports for each HS-6 product category, which is computed by dividing total value by quantity. The unit value captures the average f.o.b. export price of all firms that export a given product to a given destination. For instance, the average unit value of product p from country i to destination country j, UV_{pij}, is the ratio EX_{pij}/Q_{pij}, where EX_{pij} is the total export value and Q_{pij} is the quantity.

Varieties within the HS-6 category are assumed to be vertically differentiated, but horizontally equivalent in order to highlight the fact that a higher unit value is associated with a higher product quality. However, this assumption may be problematic in that there are horizontally different multiple varieties within the 6-digit-level HS category. Vodka, for instance, can be referred to as a single product within the HS-6 category (HS6: 220860) because it has no sub-category in the 10-digit commodity code (i.e., HS10: 2208600000); however, an electrothermic coffee or tea maker (HS6: 851671) defined as a single HS-6 code has two 10-digit categories: Electrothermic Coffee Maker (HS10: 8516711000) and Electrothermic Tea Maker (HS10: 8516712000).

Table 1.1: Summary Statistics for US Exports

	HS 6		*HS 10*	
	All Sectors	*Manufacturing*	*All Sectors*	*Manufacturing*
Total Number of Products	5059	4189	8904	7346

Notes: The US Census Bureau reports HS 10-digit product categories sourced from the United States, which allows one to identify which products within HS-6 category have multiple sub-varieties defined by HS 10-digit level.

Table 1.1 describes summary statistics for product comparisons between HS-6 and HS-10 categories for U.S. exports in 2011. The U.S. exports approximately 8,900 different HS-10-category products, while it exports in more than 5,000 different HS-6-category products. Nearly 70% (i.e., approximately 3,500 different products) of total products listed under HS-6 are the same under both HS-6 and HS-10 categories. Because most HS-6-category products coincide with those under HS-10, the assumptions about vertical differentiation and horizontal equivalence are not a concern. For a more detailed comparison, I estimate the effects of importer characteristics on average export unit value for products that are common in both HS-6 and HS-10 categories and compare these with the estimation results obtained using all products under the

HS 6-digit category. In fact, the estimated results for these two different sample groups are almost exactly the same. They are reported later in Table 1.3.

1.3.2 Estimation and Results

For each exporting country i, the average f.o.b. unit value is regressed on the characteristics of the importing country including a measure of distance, market size, real income per worker, and several proxies for trade costs. The regression equation is of the form:

$$\begin{aligned} log(UV)_{pij} = \alpha_p + \beta_{i1} log(Y)_j + \beta_{i2} log(Y/L)_j + \beta_{i3} log(Dist)_{ij} + \beta_{i4} LandL_j + \beta_{i5} Comleg_{ij} \\ + \beta_{i6} Comlang_{ij} + \beta_{i7} RTA_{ij} + \beta_{i8} WTO_j + \beta_{i9} Comcur_{ij} + \varepsilon_{pj}, \end{aligned} \tag{1.1}$$

where $\ln(UV)_{pij}$ is the log of the average f.o.b. export unit value of a product p shipped from country i to destination j. Y and Y/L represent PPP GDP (e.g., market size) and PPP GDP per worker, respectively.[10] $Dist_{ij}$ is a measure of distance between i and j. $LandL_j$ is the dummy variables, which equals one if country j is landlocked. The dummy variable $Comleg_{ij}$ takes the value one if both countries share a common legal system. The $Comlang_{ij}$ variable indicates whether the same language is spoken by at least 9% of the population in both countries. Trade policy measures are WTO membership, a regional trade agreement (RTA), and a common currency ($Comcur$).[11]

The product fixed effect, α_p, controls for the difference in average unit value (e.g., gold versus copper). It also captures the difference in unit measurement (e.g., items versus kilograms). The most common measurements of quantities are items and kilograms, which account for 97% of total observations in U.S. export data. In the regression, I drop all other units including bushels, barrels, and squares. In what follows, I restrict the sample to trade flows by manufacturing sectors only. In addition, I remove possible outliers by discarding export flows below 20 units. Product-level average unit values are noisy indicators, especially for small enough trade volume. By dropping export flows of fewer than 20 units, the estimation results are less affected by noisy or economically unimportant observations. The remaining observations cover more than 93% of total U.S. exports.

[10] I include GDP per worker in the regression as an independent variable that controls for demand-related effects.

[11] WTO_j takes the value of one if the importing country j is a WTO member. RTA and $Comcur$ variables indicate one if both exporting and importing countries are in a regional trade agreement and common monetary area, respectively.

Table 1.2: Main Regression Results from Four Different Countries' Export Data

	Exporting Countries			
	USA	*CHN*	*KOR*	*IND*
Log real GDP	-0.021^{***}	0.020^{***}	-0.015^{**}	0.026^{***}
	(-3.37)	(3.20)	(-2.09)	(4.91)
Log real GDP per worker	0.057^{***}	0.064^{***}	0.061^{***}	0.047^{***}
	(5.69)	(6.14)	(5.34)	(4.93)
Log distance	0.136^{***}	-0.046^{**}	0.025^{***}	-0.020^{*}
	(7.86)	(-2.58)	(2.02)	(-1.67)
Landlocked	0.116^{***}	0.243^{***}	0.089^{***}	0.082^{***}
	(4.96)	(5.77)	(3.21)	(2.80)
Common Legal	-0.012	0.067^{**}	0.081^{**}	-0.072^{***}
	(-0.51)	(2.36)	(2.16)	(-2.77)
Common Language	-0.070^{***}	-0.120^{***}	-0.020	0.013
	(-3.42)	(-3.50)	(-0.94)	(0.52)
RTA	-0.079^{***}	-	-0.084^{***}	-0.046
	(-3.27)		(-3.47)	(-1.42)
WTO	-0.048	0.037	0.036^{**}	0.059^{**}
	(-1.62)	(1.22)	(2.48)	(2.32)
Common Currency	-0.088	-	-	-
	(-3.69)			
Number of observation	140141	203057	56252	104515
Number of product	3665	3835	3111	3696

Notes: The estimator is the OLS with HS-6 product fixed effects. The dependent variable is the average f.o.b. export unit value of a product. For each exporting country, the sample is restricted to the largest 100 partners and trade flows for manufactured goods only. The sample includes only items and kilogram as a quantity measurement. Robust t-statistics clustered by importing country are in parentheses. ***, **, and * refer to statistical significance at the 1%, 5%, and 10% level respectively.

First, I estimate equation (1.1) using ordinary least squares (OLS) regression with product fixed effects.[12] Table 1.2 reports the estimation results, where robust standard errors clustered by importing country are used for dealing with an arbitrary correlation of the error terms within each observation. In each exporting country, the effects of market size and distance on average export unit values have opposite signs. The intuition behind this result may lie in the fact that more efficient firms self-select themselves into smaller, more distant markets. Another distinct pattern is that the signs of the coefficients with respect to market size and distance for the U.S. and South Korea are the exact opposite of those for China and India. For both the U.S. and South Korea, distance has a positive effect on export unit values, while market size has a negative effect. The effects of distance and market size on average f.o.b. export unit values, however, are negative

[12] The regression includes both GDP and GDP per worker as regressors, so the coefficient on GDP is hard to interpret if these two variables are highly correlated. Thus, I also test it including GDP alone in the regression, and the result is significant and similar as in Table 1.2. Even if the coefficient of GDP increases slightly for all exporting countries, its sign remains the same as shown in Table 1.2. In fact, the correlation between GDP and GDP per worker is negligibly low (smaller than 0.16).

and positive, respectively for China and India. These spatial patterns of unit values for products exported from the U.S. and Korea are consistent with findings by Baldwin and Harrigan (2011). As mentioned in the previous section, however, their model cannot account for the spatial patterns of China and India's average export prices.

Another interesting finding is that the effect of distance on average unit values for Chinese exports is exactly opposite to that for Korea. Note that China is the closest country to Korea. If within-firm selection of product quality across markets with variable geographical distances exists, the effect of distance on unit values determined by within-firm selection should be the same for both countries. For example, each firm produces vertically differentiated varieties, and exports better-quality products to more distant markets. This type of within-firm selection implies that distance has a positive effect on unit values. Thus, the opposite effects of distance on average export unit values (negative for China and positive for Korea) are mainly driven by the sorting of exporting firms across markets, but not caused by within-firm selection.[13] In fact, recent work by Harrigan et al. (2011), using firm-level data from the U.S., shows that there is no empirical evidence that links within-firm price variation across markets and distance.

In addition to the effects of market size and distance, I find that average export unit values of a product are positively associated with the importers' real income per worker, which is statistically significant regardless of exporting country. This suggests that the demand-side effect seems to play an important role in shaping the variation in unit values across markets. The positive association between the importers' GDP per worker and the average unit values can be explained by both within-firm selection of product quality across markets and firms' self-selection into exporting.[14] In fact, Bastos and Silva (2010) exploit Portuguese firm-level data to show that the positive effect of income per worker on unit values is mainly due to within-firm selection of export prices across markets, while the sorting mechanism has a relatively small effect on the variation of unit values.

[13] Bastos and Silva (2010) use Portuguese firm-level data to show that the positive correlation between distance and the average export unit values is driven by not only within-firm selection, but also by the differing composition of firms across exporting markets. Based on this within-firm variation of export prices across markets, the absolute value of the coefficient on distance estimated from Chinese exports is smaller than the true effect, while the positive effect of distance obtained from Korean exports is overestimated.

[14] See Bernard et al. (2006) where the authors point out the importance of the within-firm channel in determining the effect of real income per worker on trade flows.

Table 1.3 presents two estimation results obtained by using full and restricted samples that demonstrate issues regarding the existence of multiple sub-varieties within the 6-digit-level HS category. To do so, I first estimate equation (1.1) using the full sample classified by the 6-digit Harmonized System for U.S. export data. I then use a restricted sample of HS-6 products that are common across both HS-6 and HS-10 categories. As shown in Table 3, estimates for these two samples are very similar. This finding supports the assumption that the HS 6-digit level of product disaggregation is high enough to identify at least the effects of market size and distance on the average export unit value.

Table 1.3: HS-6 versus Restricted Sample in HS-6 for US Exports in 2007

	HS 6	*Restricted Sample in HS 6*
Log real GDP	-0.0239^{***}	-0.0232^{***}
	(0.0052)	(0.0056)
Log real GDP per worker	0.0516^{***}	0.0573^{***}
	(0.0103)	(0.0111)
Log distance	0.1461^{***}	0.1460^{***}
	(0.0170)	(0.0163)
Number of observation	208704	118224
Number of product	4641	3124

Notes: The estimator is the OLS with HS-6 product fixed effects for U.S. export data in 2007. The dependent variable is the average f.o.b. export unit value of a product. Full sample includes all product categories in HS 6 and all importing countries (150 countries). For the sake of brevity, only the coefficients on real GDP, GDP per worker, and distance are presented. Robust standard error clustered by importing country are in parentheses. ***, **, and * refer to statistical significance at the 1%, 5%, and 10% level, respectively.

Next, I examine the role of exporting country's level of development (e.g., real GDP per worker) in shaping a relationship between unit values, market size, and distance. To do that, I regress the average unit values on distance, market size, income per worker, and the interactions between those regressors and exporters' GDP per worker. Since the spatial patterns of unit values may depend on a country's level of economic development, this estimation with interaction terms would provide useful information on a link between the spatial patterns of unit values and the exporters' levels of development. The regression equation is

$$\begin{aligned} log(UV)_{pij} = \alpha_{pi} + \beta_1 log(Y)_j + \beta_1^{'} log(Y/L)_i * log(Y)_j + \beta_2 log(Y/L)_j + \beta_2^{'} log(Y/L)_i * log(Y/L)_j \\ + \beta_3 log(Dist)_{ij} + \beta_3^{'} log(Y/L)_i * log(Dist)_{ij} + \beta_5 Comleg_{ij} \\ + \beta_7 RTA_{ij} + \beta_8 WTO_j + \beta_9 Comcur_{ij} + \varepsilon_{pij}, \end{aligned} \tag{1.2}$$

where the country-product fixed effects, α_{pi}, controls for heterogeneity across exporting countries and products.

Table 1.4 presents the results of a country-product fixed effect estimation as well as a product fixed effect estimation. The estimates in column (1) with product fixed effects reveal that the positive effect of market size on within-product average unit values decreases with the exporting country's level of GDP per worker. As a result, countries like the U.S. and Korea, where real incomes per worker are relatively high, have a negative association between the average export unit value and market size. In contrast, column (1) indicates that the effect of distance on within-product unit values varies across exporting countries' income levels. Indeed, the effect of distance on average unit values is negative for low-income countries such as China and India, while it is positive for relatively high-income countries like the U.S. and Korea.

Table 1.4: Estimation Results with Interaction Terms

	(1) *Log(Unit Value)*	(2) *Log(Unit Value)*
Log(Y_j)	0.290^{***}	0.175^{***}
	(6.66)	(5.55)
Log(Y_j)*Log(Exporter GDP per worker)	-0.026^{***}	-0.017^{***}
	(-5.96)	(-5.43)
Log $(Y/L)_j$	-0.009	0.083^{*}
	(-0.16)	(1.80)
Log$(Y/L)_j$*Log(Exporter GDP per worker)	0.007	-0.002
	(1.20)	(-0.62)
Log (Dist)	-1.258^{***}	-0.496^{***}
	(-8.58)	(-5.82)
Log(Dist)*Log(Exporter GDP per worker)	0.123^{***}	0.052^{***}
	(8.82)	(6.16)
Product fixed effects	Yes	
Country-product fixed effects		Yes
Number of observation	502027	502027
Number of product	4037	4037

Notes: The estimator (1) is the OLS with HS-6 product fixed effects. The estimator (2) is the OLS with country-product fixed effects. For the sake of brevity, this table only reports the coefficients of PPP GDP, GDP per worker, distance, and the interaction terms obtained from the regression equation (2). Robust t-statistics clustered by importing country are in parentheses. ***, **, and * refer to statistical significance at the 1%, 5%, and 10% level, respectively.

Column (2) in Table 1.4 reports the results obtained under the OLS estimation with country-product fixed effects. The effects of market size and distance on within-country-product unit values vary across exporters' GDP per worker, and the role of exporters' income levels in shaping the spatial patterns is the same as shown in column (1) using a product-fixed effect estimation. The findings from these pooled regressions are qualitatively the same as in the previous results derived by using equation (1). The pooled regression with interaction terms, however, clearly shows the important link between the unit values' spatial patterns and the exporting countries' levels of development.[15]

In contrast, the estimates in columns (1) and (2) provide no statistical evidence of a relationship between exporting countries' levels of development and the effect of importer's GDP per worker on unit values. In column (2), the weakly positive effect of importer's GDP per worker on within-country-product unit values does not depend on the exporters' levels of development.

Figure 1.1: Relationships between Spatial Patterns of Unit Value and Exporter's GDP per worker

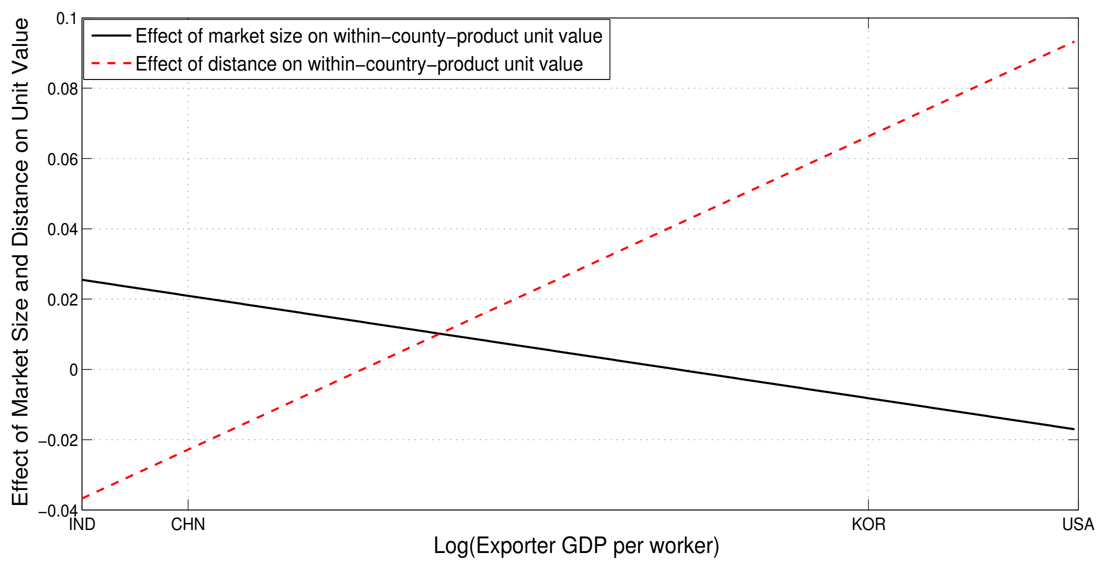

Figure 1.1 graphically illustrates the estimation results with country-product fixed effects. The dashed line captures the negative effect of distance on within-country-product unit values for relatively low-income countries like China and India. The effect of distance on the average unit value increases with the income levels of the exporting countries so that it becomes positive for high-income countries, such as the U.S. and Korea. The solid line captures the effect of market size on within-country-product unit values. The positive effect of market size on unit values decreases with exporters' income levels and it becomes negative

[15] As a robustness check, I extend the empirical analysis by adding six more exporting countries (Brazil, France, Germany, Japan, Mexico, and the UK) and compare it with the previous results shown in Table 1.4. The basic results of this estimation including the ten largest exporting countries, which is shown in Appendex A.1, are consistent with the estimation results presented in Table 1.4.

for relatively rich countries. Therefore, the average unit values of products sourced from poor countries increases with a destination market's size; whereas, the market size has a negative effect on unit values of products that are exported from relatively rich countries. That is, the larger the destination market size, the larger (smaller) is the average export unit value of products sent from relatively poor (rich) countries.

1.3.3 Robustness

To see if the main results are robust to the restricted sample, I first re-estimate equation (1.1) above within each HS 2-digit product category using only Chinese and U.S. export data. Table 1.5 presents the estimation results. For each sector of U.S. exports, the relationships between export unit values, market size, and distance are essentially the same as those in the previous results. For U.S. exports, distance has a positive effect on unit value, while the average export unit value decreases with market size. In the majority of Chinese export sectors, within-product average unit values decrease and increase with distance and market size respectively. Hence, the different spatial patterns of the average unit values between the U.S. and China are also found at the sector level.

Table 1.5: Regression Results within HS 2-digit Sector Level

	US			*CHN*		
HS 2-digit	*GDP*	*Distance*	*# of Prod.*	*GDP*	*Distance*	*# of Prod.*
Chemical/Allied Industries	-0.031^{**}	0.113^{***}	714	0.014	0.035^{**}	708
Plastic/Rubbers	-0.045^{***}	0.076^{**}	205	0.021^{**}	-0.036^{*}	210
Skin/Leather/Furs	-0.033^{**}	0.061^{***}	55	0.037^{**}	-0.086^{*}	58
Wood/Wood Products	-0.033^{***}	0.066^{***}	182	0.028^{***}	0.016	206
Textiles	-0.017	0.113^{***}	775	0.030^{***}	-0.040^{**}	729
Footwear/Headgear	-0.003	0.109^{**}	24	0.076	-0.094^{**}	27
Stone/Class	-0.028^{***}	0.055^{***}	122	0.046^{***}	0.029	158
Metals	-0.032^{***}	0.085^{***}	551	0.033^{***}	-0.004	552
Machinery/Electrical	0.001	0.054^{***}	663	-0.005	-0.129^{***}	742
Transportation	0.020^{**}	0.034^{*}	104	0.021^{**}	-0.056^{*}	110
Miscellaneous	-0.011^{**}	0.071^{***}	270	0.009	-0.144^{***}	335

Notes: The estimator is the OLS with HS-6 product fixed effects clustering by importing country for both U.S. and Chinese export data. For the sake of brevity, this table only reports the coefficients of PPP GDP and distance obtained from the regression using equation (1). ***, **, and * refer to significance at the 1%, 5%, and 10% level, respectively.

Since a product's unit value reflects its quality, the variation in unit values across markets may depend on firms' incentives for quality upgrading, which varies across different product groups. For instance, firms may have a greater incentive to upgrade their product quality for durable consumption goods because consumers care more about the product quality of durable goods than that of non-durables. Such product groups, however, cannot be captured at the HS 2-digit level. Thus, I use Broad Economic Categories such as capital, intermediate, and consumption goods, to classify products into end-use categories and to examine the spatial patterns of unit values within product categories.

Table 1.6 displays the results of these estimations within different end-use product groups. The first two columns for U.S. exports indicate that the average f.o.b. export unit value of a product decreases with market size, while it is positively associated with distance in most product categories except for Food/Beverage/Fuel. It should be noted that the effects of both distance and market size on unit values are higher for durable consumption goods rather than non-durable products.

Table 1.6: Regression Results within Different Product Groups Classified by End-Use Categories

	US				*CHN*			
	GDP	*Dist.*	*Obs.*	*Prod.*	*GDP*	*Dist.*	*Obs.*	*Prod.*
(1) Capital goods	$-.023^{***}$	$.053^{***}$	30970	552	$-.030^{*}$	$-.173^{***}$	38229	559
(2) Consumption goods	$-.035^{***}$	$.052^{**}$	33927	991	$.031^{***}$	$-.043^{*}$	51737	987
i) Excluding food/beverages	$-.038^{***}$	$.068^{**}$	23878	580	$.030^{***}$	$-.061^{***}$	44253	619
ii) Durable goods	$-.058^{***}$	$.112^{***}$	5070	100	$-.047$	$-.106^{**}$	7180	112
(3) Intermediate goods	$-.046^{***}$	$.105^{***}$	100751	2725	.004	.001	128962	2794
i) Food/Beverage/Fuel	$-.018$	$.067^{***}$	3670	152	$-.004$	.084	2032	139
ii) Industrial supplies	$-.047^{***}$	$.107^{***}$	97081	2573	.004	$-.000$	126930	2655

Notes: The estimator is the OLS with HS 6 product fixed effects clustering by import country for both U.S. and Chinese export data. This table only displays the coefficients of real GDP and distance obtained from the regression using equation (1). ***, **, and * refer to statistical significance at the 1%, 5%, and 10% level, respectively.

For Chinese exports, on the other hand, the negative association between unit values and distance found in the previous main regression is also shown in both capital and consumption goods, but this effect is absent in intermediate goods. The negative effect of distance on the average unit value is much larger for durable consumption goods than for non-durable goods. For intermediate goods, neither distance nor market size show significant effects on unit values. Since product quality differences are more likely to occur in capital and consumption goods rather than in intermediate goods, it seems plausible that there is no significant evidence for a relationship between market size, distance, and unit values for intermediate goods. However, the opposite spatial patterns of unit values between the U.S. and China are remarkable for capital and consumption goods.

Finally, I re-estimate equation (1.1) using only the list of differentiated products classified by Rauch, which explains 77% of total observations and 55% of total products for U.S. exports. Since the spatial pattern of export unit values is mainly driven by firms' self-selection mechanism, homogeneous products are inappropriate in a model of quality heterogeneity.[16] Therefore, an estimation using only differentiated products would be informative on the spatial patterns of unit values, especially for products that can be vertically differentiated in respect to quality attributes.

Table 1.7: Estimation Results for only Differentiated Products Classified by Rauch

	Exporting Countries			
	USA	*CHN*	*KOR*	*IND*
Log real GDP	-0.032^{***}	0.023^{***}	-0.014	0.032^{***}
	(-4.37)	(3.32)	(-1.62)	(5.18)
Log real GDP per worker	0.025^{**}	0.061^{***}	0.065^{***}	0.042^{***}
	(2.24)	(5.60)	(5.08)	(4.38)
Log Distance	0.077^{***}	-0.070^{***}	0.029^{**}	-0.043^{***}
	(4.66)	(-3.60)	(2.11)	(-3.17)
Landlocked	0.090^{***}	0.218^{***}	0.086^{***}	0.064^{**}
	(4.89)	(4.91)	(3.31)	(2.36)
Common Legal System	0.021	0.076^{**}	0.065^{*}	-0.047^{*}
	(0.83)	(2.28)	(1.67)	(-1.79)
Common Language	-0.111^{***}	-0.109^{***}	-0.019	-0.005
	(-4.92)	(-2.69)	(-0.84)	(-0.19)
RTA	-0.099^{***}	-	-0.092^{***}	-0.075^{**}
	(-3.69)		(-4.15)	(-2.32)
WTO	-0.076^{**}	0.044	0.041^{**}	0.066^{**}
	(-2.33)	(1.23)	(2.74)	(2.36)
Common Currency	-0.165^{***}	-	-	-
	(-6.54)			
Number of observation	97239	131242	35157	65670
Number of product	2673	2120	1602	2030

Notes: Dependent variable is the average f.o.b. export unit value of products. Each exporter's sample is restricted to the largest 100 partners and trade flows for manufacturing products only. Robust t-statistics clustered by importing country are in parentheses. ***, **, and * refer to statistical significance at the 1%, 5%, and 10 % level respectively.

Table 1.7 reports the estimation results from the OLS regression with product fixed effects for which only differentiated products are included in the sample. For all exporting countries, the signs of coefficients of real GDP and distance are exactly the same as those shown in Table 1.2. However, the magnitude of

[16] Examples of homogeneous products at the HS 6-digit level are unwrought gold powder and refined copper.

coefficients in absolute value with respect to GDP and distance increases slightly for all exporting countries except for the USA. In contrast, in the estimation that uses only products that are classified as homogeneous (not reported here), the effects of both market size and distance on the average unit values are not statistically significant except for the USA. The negative and positive associations between unit values, market size, and distance for U.S. exports holds in both homogeneous and differentiated goods.

1.4 Model of Quality Heterogeneity

The empirical evidence presented in the previous section is inconsistent with a standard model of heterogeneous firms (e.g., Melitz 2003) in the sense that the model fails to account for the spatial patterns of export unit values for U.S. and Korean export data. In this section, I develop a simple trade model where quality differentiation across firms plays a key role in accounting for why the spatial patterns of the average export unit values vary with exporting countries. Based on a Melitz-style model, I incorporate product quality into a model of firm heterogeneity with constant elasticity of substitution preference and country-specific fixed entry costs. In this framework, consumers prefer higher-quality products and firms produce goods that vary with respect to quality. In the following discussion, I focus on a one-sector version of the model.

1.4.1 Consumption

From the demand side, a representative consumer in each country i cares about product quality as well as price. The consumer's utility function takes the Dixit-Stiglitz CES preference over the consumption of differentiated varieties,

$$U_i = \left(\int_{\omega \in \Omega_i} [q_i(\omega) x_i(\omega)]^{\sigma - 1/\sigma} d\omega \right)^{\sigma/\sigma - 1}, \tag{1.3}$$

where ω denotes an individual variety in the potential set Ω_i of varieties that are available in country i. $\sigma > 1$ is the elasticity of substitution between varieties. $q(\omega)$ and $x(\omega)$ denote quality and quantity of variety ω, respectively. Preferences are assumed to be identical across countries. The corresponding demand function for variety ω in country i is

$$\begin{aligned} x_i(p_i(\omega), q_i(\omega)) &= q_i(\omega)^{\sigma-1} p_i(\omega)^{-\sigma} \tilde{P}_i^{\sigma-1} E_i, \\ \tilde{x}_i(\tilde{p}_i(\omega)) &= [\tilde{p}_i(\omega)]^{-\sigma} \tilde{P}_i^{\sigma-1} E_i, \end{aligned} \tag{1.4}$$

where $\tilde{x}_i(\omega) = q_i(\omega)x_i(\omega)$ and $\tilde{p}_i(\omega) = p_i(\omega)/q_i(\omega)$ are the quantity measured in units of utility and the quality-adjusted price of variety ω respectively. $\tilde{P}_i = \left(\int [\tilde{p}_i(\omega)]^{1-\sigma} d\omega\right)^{\frac{1}{1-\sigma}}$ is the aggregate quality-adjusted price index of consumption and E_i is the total expenditure in country i.

1.4.2 Production

Each variety of the differentiated good is produced by a monopolistically competitive firm. Labor is the only factor of production related to variable costs, with each worker supplying one unit of labor.[17] I do not close the labor market, so the model here will be a partial equilibrium model. This allows me to specify a simple cost function where workers are differentiated by skill level and higher-skilled labor commands a higher wage. Unlike the standard model of firm heterogeneity in Melitz (2003), I assume that firms do not differ in their productivity.[18] Instead of the Hicks-neutral productivity differences, after paying a fixed entry cost, each firm draws a "*technology suitability or management ability*" that makes use of workers' specific skill level.

The amount of labor that firms must hire to produce one unit of output depends on product quality as well as workers' skill level. The units of labor required to produce a unit of output consist of two components: the amount of labor associated with simple tasks that are not involved in product quality (e.g., assembly work such as screwing nuts onto bolts) and additional units of labor related to product quality (e.g., quality-related work such as technology-combined design). I assume that productivity related to assembly work does not vary across workers' skill levels, so all firms have the same productivity for these simple tasks. In other words, more highly skilled workers have no productive advantage in assembling the physical output.

[17] Production involves both fixed and variable costs. The fixed costs take the form of capital assets with the rental rate on capital being normalized to one, while the variable costs require only the labor.

[18] See Irarrazabal et al. (2009) where the authors confirm that over 67% of the exporter productivity premium reflects differences in skill-intensiveness rather than intrinsic firm efficiency using Norwegian firm-level data that matches employer and employee. That is, firm heterogeneity is mainly sourced by workers' skill level across firms.

Since more highly skilled workers are assumed to be more expensive to hire, marginal cost associated with these simple tasks increases with workers' skill level.

In addition, I assume that producing better-quality goods requires additional units of labor, and higher-skilled workers are more productive in performing tasks that improve on product quality. This is a reasonable assumption in the sense that manufacturing higher-quality products often requires more complex technology and such a technology can be more easily handled by higher-skilled workers. As a result, firms that draw a "*technology suitability*" for a higher-skilled labor force incur a higher marginal cost of simple assembly work but a lower marginal cost of tasks associated with product quality.

A firm must bear an overhead cost to produce output. For the sake of tractability, I assume that the fixed cost takes the form of capital assets with the rental rate on capital being implicitly treated as one. For simplicity, I make the following parametric assumption regarding the form of the cost function: the total cost of firms that draw a skill level $\theta \in [\underline{\theta}, \overline{\theta}]$ in country i is

$$TC_i(\theta, q) = f_i + w_i(\theta)\left[1 + \frac{q^{\phi}}{\theta}\right] x_i(\theta, q), \tag{1.5}$$

where f_i denotes the fixed overhead cost of production in country i measured in units of capital.[19] $x_i(\theta, q)$ is the quantity produced by firms with skill level θ and quality level q. $w(\theta)$ is the wage rate of workers with skill level θ. ϕ denotes the elasticity of marginal cost with respect to quality, which is common across firms as well as countries.

A firm's marginal cost function that is positively associated with product quality, $w_i(\theta)\left[1 + \frac{q^{\phi}}{\theta}\right]$, can be justified as follows.[20] If there is no quality dimension in the model (i.e., $q = 0$), then the model is of the standard form, where it is reasonable to assume that high-skilled workers have no productivity advantage in assembling output without adding product quality (e.g., screwing nuts onto bolts). As long as a more highly skilled labor force gets paid a higher wage (i.e., $w(\theta)$ increases with θ), this translates into a higher marginal cost so that firms using more highly skilled workers are less efficient. More highly skilled workers, however, have a comparative advantage in making quality goods (i.e., $q > 0$); that is, highly skilled workers

[19] Note that the cost function is homogeneous of degree one in input prices.

[20] See Xiang (2005), Verhoogen (2008), and Kugler and Verhoogen (2008) for evidence of a positive association between product quality and input costs (and hence marginal costs).

are relatively more productive in performing tasks that are related to product quality.[21]

Another key assumption is that countries differ by wage schedule as a function of skill level; that is, $w_i(\theta)$ depends on county i. I assume that i) the wage function is exogenously given based on a country's skilled-labor abundance, ii) the wage rate increases with workers' skill level, and iii) the rate of growth in the wage rate is higher in relatively skill-scarce countries than in skill-abundant countries.[22]

Firms' profit maximization is a two-stage process: All firms first choose their product quality q simultaneously after drawing on their workers' skill level, θ. Second, firms simultaneously choose their prices and output levels given the quality of their products. With monopolistic competition and a continuum of varieties, no one firm can influence the aggregate price and quality level so that firms take the aggregate quality-adjusted price index, $\tilde{P}$, as given.[23] The optimal price and quality chosen by firms with θ can be solved by working backwards from the second stage. In the second stage, a firm chooses the price and quantity given its quality q by solving

$$\begin{aligned} \max_{\{p,\, x\}} \quad & p_i(\theta,q)x_i(\theta,q) - f_i - w_i(\theta)\left[1+\frac{q^{\phi}}{\theta}\right]x_i(\theta,q) \\ \text{s.t.} \quad & x_i(\theta,q) = q^{\sigma-1}\left[p_i(\theta,q)\right]^{-\sigma}\tilde{P}_i^{\sigma-1}E_i, \end{aligned} \tag{1.6}$$

taking $\tilde{P}_i$ and E_i as given. The optimal price charged by firms with θ and q is a constant mark-up over their marginal cost: $p_i(\theta,q) = \left(\frac{\sigma}{\sigma-1}\right) w_i(\theta)\left[1+\frac{q^{\phi}}{\theta}\right]$.

Knowing this price rule corresponding to given product quality q, firms in the first stage choose their optimal qualities in response to their own workers' skill level θ. The firm with skill level θ in country i

[21] Taking the derivative of the second term of marginal costs, $w(\theta)\frac{q^{\phi}}{\theta}$, with respect to the skill level θ gives that marginal costs decrease with θ under the assumption of $w_i'(\theta)\frac{\theta}{w_i(\theta)} < 1$. Hereafter, I assume that $w_i'(\theta)\frac{\theta}{w_i(\theta)} < 1$ holds, that is, higher-skilled workers are relatively more productive when doing the quality-related tasks compared to lower-skilled workers.

[22] That is, the skill elasticity of the wage rate differs across countries and it is steeper in skill-scare countries than in relatively skill-abundant countries.

[23] Note that $\tilde{P} = \left(\int_{\omega}[\tilde{p}(\omega)]^{1-\sigma}d\omega\right)^{1/1-\sigma}$, where $\tilde{p}$ is the quality-adjusted price defined by p/q. Although $\tilde{P}_i$ is endogenous to the industry, firms take it as an exogenous variable since firm's size is negligible relative to the industry as a whole under the assumption of monopolistic competition.

chooses the optimal product quality to solve

$$\max_{\{q\}} \quad p_i(\theta,q)x_i(\theta,q) - f_i - w_i(\theta)\left[1+\frac{q^{\phi}}{\theta}\right]x_i(\theta,q)$$
$$\text{s.t.} \quad x_i(\theta,q) = q^{\sigma-1}\left[p_i(\theta,q)\right]^{-\sigma}\tilde{P}_i^{\sigma-1}E_i \tag{1.7}$$
$$\text{and} \quad p_i(\theta,q) = \left(\frac{\sigma}{\sigma-1}\right)w_i(\theta)\left[1+\frac{q^{\phi}}{\theta}\right].$$

Taking $\tilde{P}_i$ and E_i as given, solving the maximization problem above gives the optimal choice of quality for firms with their workers' skill level θ,

$$q^*(\theta) = \left(\frac{1}{\phi-1}\right)^{\frac{1}{\phi}}\theta^{\frac{1}{\phi}}. \tag{1.8}$$

where $\phi > 1$, which is the sufficient second-order condition for the solution to be a maximum. It is not obvious whether the marginal cost of quality is convex in some abstract measure of quality. However, the fact that the quality elasticity of marginal cost is greater than one, $\phi > 1$, seems plausible in that higher-skilled labor involves relatively high-quality products.[24] In fact, Kyoji and Keiko (2010) use Japanese factory-level data to show that a product's unit value (product quality) is positively associated with a firm's skilled-labor intensity.

Substituting the optimal quality into the marginal cost function yields: $MC(\theta) = \left(\frac{\phi}{\phi-1}\right)w_i(\theta)$. Since $\frac{\phi}{\phi-1} > 1$, all firms in country i pay more than $w_i(\theta)$ to produce one unit of output. That is, all firms have an incentive to improve their products' quality: $q^*(\theta) > 0$ for all $\theta \in [\underline{\theta}, \overline{\theta}]$.

1.4.3 Firms Selection into Exporting

To enter the export market, firms must bear a fixed cost as well as an iceberg-type variable cost. Each firm chooses which foreign markets to enter and its export price. Firms in a country i selling to destination d pay a fixed entry cost f_{id} and must ship $\tau_{id} > 1$ units of the variety for one unit to arrive in destination d. Using the optimal quality schedule in equation (1.8), a firm with θ in a country i sets its f.o.b. export price for destination d, which is given by

[24] See Cremer and Thisse (1994), Khandelwal (2010), and Schmitt (2002), where the authors assume the quadratic form of marginal cost (MC) with respect to quality: $MC(w,q) = w + q^2$, where w and q are a firm-specific and a quality-specific component, respectively.

$$\frac{p_{id}(\theta,q^*)}{\tau_{id}} = \frac{\sigma}{\sigma-1}MC(\theta,q^*) = \frac{\sigma\phi}{(\sigma-1)(\phi-1)}w_i(\theta). \tag{1.9}$$

Since $\frac{\sigma\phi}{(\sigma-1)(\phi-1)} > 0$, firms with a higher θ export a higher-quality product at a higher price. It should be noted that the within-firm f.o.b. export price of a product does not vary across markets due to the absence of an iceberg trade cost term τ_{id} on the right-hand side of equation (1.9). Since each firm charges the exact same f.o.b. export price across destinations, there is no price discrimination across markets in this theoretical framework. In this context, the variation of average f.o.b. export unit values across destinations can be driven by the sorting of heterogeneous firms across export markets. In other words, the number of firms that are efficient enough to sell their products to foreign markets varies across destinations. For example, only a few large profitable firms tend to export their varieties to relatively difficult markets (e.g., smaller and/or more distant markets).

Based on the optimal price, quantity, and quality schedule constructed in the previous section, the revenue of firms with θ in country i exporting to country d is

$$R_{id}(\theta) = p_{id}x_{id} = \left(\frac{p_{id}(\theta)}{q^*(\theta)}\right)^{1-\sigma}\tilde{P_d}^{\sigma-1}E_d = \lambda E_d\left(\frac{\tilde{P_d}}{\tau_{id}}\right)^{\sigma-1}[w_i(\theta)]^{(1-\sigma)}\,\theta^{\frac{(\sigma-1)}{\phi}}, \tag{1.10}$$

where λ is a positive constant. Notice that firm revenue is a function of product quality as well as price because firms compete on quality-adjusted price, p/q. Whether firms' revenue increases with their workers' skill level θ depends on a country-specific wage schedule, $w_i(\theta)$. Since $\sigma > 1$ and $\phi > 1$, the firm-specific value θ has two opposite effects on firms' revenue: (i) a higher θ leads to a higher revenue via the last term $\theta^{\frac{(\sigma-1)}{\phi}}$ in equation (1.10). (ii) the increase in θ reduces revenue because firms with higher θ face a higher wage rate, which is captured by $[w_i(\theta)]^{(1-\sigma)}$, where we have a negative exponent. It follows from equation (1.10) that

$$\frac{dR_i(\theta)}{d\theta}\begin{cases} >0 & when\;\; w_i'(\theta)\frac{\theta}{w_i(\theta)} < \frac{1}{\phi} \\ <0 & when\;\; w_i'(\theta)\frac{\theta}{w_i(\theta)} > \frac{1}{\phi}, \end{cases} \tag{1.11}$$

where $w_i'(\theta)$ denotes the derivative of wage with respect to θ. Note that the term $w_i'(\theta)\frac{\theta}{w_i(\theta)}$ refers to the skill elasticity of the wage rate for country i. When the wage increases relatively slowly as skill level rises, this is $w_i'(\theta)\frac{\theta}{w_i(\theta)} < \frac{1}{\phi}$, firms with the highest θ are the most efficient. In contrast, in countries with $w_i'(\theta)\frac{\theta}{w_i(\theta)} > \frac{1}{\phi}$, an increase in θ reduces revenue. Since the wage rate increases relatively quickly with skill level, the benefits of producing higher-quality goods using more highly skilled workers are offset by the relatively higher wages for skilled labor. In other words, firms in these countries benefit from manufacturing lower-quality products using relatively cheap, less-skilled labor.

A firm from country i selling to country d must incur a country-specific fixed cost f_{id}. Firms opt to export if they earn positive profits, that is, $\frac{1}{\sigma}R_{id} \geq f_{id}$. The zero-profit condition and the revenue equation (1.10) yield a cut-off level of θ, at which a firm is indifferent between exporting and not exporting:

$$[w_i(\theta_{id}^*)]^{-\phi}\theta_{id}^* = \gamma\left(\frac{\tau_{id}}{\tilde{P}_d}\right)^{\phi}\left(\frac{f_{id}}{E_d}\right)^{\frac{\phi}{\sigma-1}}, \tag{1.12}$$

where $\gamma > 0$ is constant. Note that the effects of the variable trade cost τ_{id} (e.g., distance between trading partners) and E_d (e.g., a destination market's size) on the threshold skill level θ_{id}^* depend on a country-specific wage schedule $w_i(\theta)$.

When $w_i'(\theta)\frac{\theta}{w_i(\theta)} < \frac{1}{\phi}$ holds, the quality-adjusted export price decreases with θ, so that only the firms with $\theta \in [\theta_{id}^*,\ \overline{\theta}]$ are able to export.[25] In this case, the skill level cut-off, θ_{id}^*, increases with variable trade cost (τ_{id}) and decreases with market size (E_d). As a consequence, the average f.o.b. export unit value of products shipped from these countries with $w_i'(\theta)\frac{\theta}{w_i(\theta)} < \frac{1}{\phi}$ is positively associated with distance, while it decreases with a destination market's size.

In contrast, for exporting country i with $w_i'(\theta)\frac{\theta}{w_i(\theta)} > \frac{1}{\phi}$, only the firms with $\theta \in [\underline{\theta},\ \theta_{id}^*]$ are profitable enough to export their varieties to country d and the skill level cut-off decreases with distance and increases with market size. Since firms with higher θ charge higher prices, the average f.o.b. export unit values decrease with increasing distance to a destination market, while it is positively related to market size.

Suppose that firms in country i export their varieties to countries A and B, and country A is more distant and/or smaller than country B. Thus, for firms in country i, exporting to country A is more difficult than exporting to country B. Figure 1.2 and 1.3 graphically illustrate the spatial patterns of unit values across exporting countries: the market difficulty has a positive effect on the average f.o.b. export unit values in the case that $w_i'(\theta)\frac{\theta}{w_i(\theta)} < \frac{1}{\phi}$; whereas within-product unit values decrease with distance and increase with market size when $w_i'(\theta)\frac{\theta}{w_i(\theta)} > \frac{1}{\phi}$. In Figure 1.2, the average unit values of products sold in country

[25] The f.o.b. based quality-adjusted price can be expressed by $\frac{p_{id}^*(\theta)}{\tau_{id}q^*(\theta)} = \eta w(\theta)\theta^{-1/\phi}$, where η is a positive constant. Thus, firms' quality-adjusted price decreases with θ when the following condition holds: $w_i'(\theta)\frac{\theta}{w_i(\theta)} < \frac{1}{\phi}$.

A are higher than that in market B because firms' export prices monotonically increase with θ and fewer firms with relatively high θ export to more difficult market A. In contrast, the negative association between market difficulty and average export prices is illustrated in Figure 1.3. These different spatial patterns of the average export unit values across exporting countries are driven by firms' self-selection into exports under the assumption of a country-specific wage schedule.

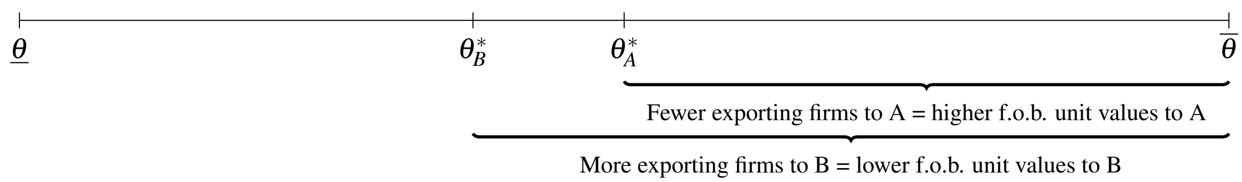

Figure 1.2: $w_i'(\theta)\frac{\theta}{w_i(\theta)} < \frac{1}{\phi} \iff \theta_A^* > \theta_B^*$

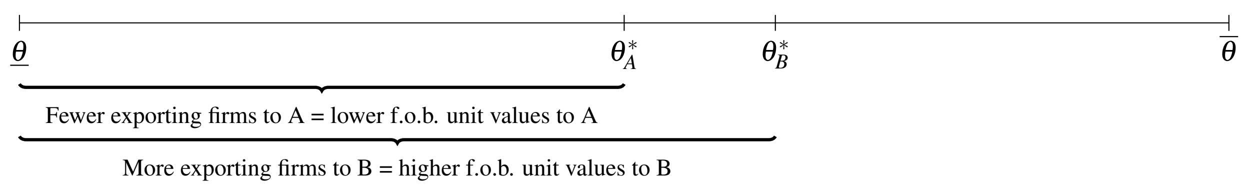

Figure 1.3: $w_i'(\theta)\frac{\theta}{w_i(\theta)} > \frac{1}{\phi} \iff \theta_A^* < \theta_B^*$

Table 1.8 below summaries the theoretical analysis in which the spatial patterns of unit values depend on a country-specific wage schedule as a function of skill level $w_i(\theta)$. Assuming $w_i'(\theta)\frac{\theta}{w_i(\theta)} < \frac{1}{\phi}$, the model predicts that firms employing higher-skilled labor are more profitable and, as a result, they can provide their varieties to relatively difficult markets. This prediction seems to be consistent with the empirical findings from U.S. and Korean exports. In contrast, when $w_i'(\theta)\frac{\theta}{w_i(\theta)} > \frac{1}{\phi}$, the model suggests that firms with lower-skilled labor are more competitive and can more easily penetrate difficult markets. This prediction seems to fit the empirical findings using export data from China and India. Skilled workers in China or India are relatively less efficient at producing high-quality varieties compared to those in relatively skilled-labor abundant counties. As a result, in relatively skill-scarce countries, firms that produce lower-quality products using relatively cheap unskilled labor tend to be more competitive.

In sum, the different spatial patterns of the average f.o.b. export unit values across exporting countries are captured by the wage schedule for skilled labor, which differs across countries. The difference in wage schedules for skilled labor is a key factor in the theoretical model used to explain the empirical results obtained from the data. The results of the data analysis seem to be supported by the theory that assumes that the slope of the wage schedules in skill-scarce countries such as China and India is steeper than one in both the U.S. and Korea, which are relatively skill-abundant countries. This assumption can be partially supported by some statistical data, which shows that the wage ratio of skilled- to unskilled-labor is much lower in developed than developing countries.[26] It should be noted, however, that potential differences in the wage schedules between those two groups of countries cannot be inferred from the empirical findings obtained from the data analysis.

Table 1.8: Summary of Different Spatial Patterns of the Average f.o.b. Export Unit Value

$w_i'(\theta)\frac{\theta}{w_i(\theta)} < \frac{1}{\phi}$	$w_i'(\theta)\frac{\theta}{w_i(\theta)} > \frac{1}{\phi}$
Quality-adjusted price decreases with skill level	Quality-adjusted price increases with skill level
Average unit value increases with distance	Average unit value decreases with distance
Average unit value decreases with market size	Average unit value increases with market size
Specialize relatively high-quality products	Specialize relatively low-quality product
Relatively skill-abundant countries (US and Korea)	Relatively skill-scarce countries (China and India)

1.5 Conclusions

The main purpose of this study is to emphasize the role of product quality differences in the model of firm heterogeneity to explain the variation of export unit values across destination markets. I estimated the effects of distance and destination market size on the average f.o.b. export unit values using HS-6 product level data for different exporting countries and found that the average f.o.b. export unit values of a product shipped from the U.S. or Korea increase with distance and decrease with market size. Within-product average unit values for products sourced from China and India decrease with distance and increase with market size. A model is developed to reconcile these two different spatial patterns, where a country-specific

[26] Based on the Global Trade Analysis Project (GTAP) data set in 1995, the average ratio of skilled- to unskilled-labor wage is 1.8 for developed countries, while it is about 3.5 for developing countries (see, e.g., Markusen 2002).

wage schedule over skill level has an important role in determining the spatial patterns of unit values across exporting countries. The model predicts that in relatively skill-abundant countries, firms using higher-skilled labor are more competitive and are able to export their varieties at higher prices to more difficult markets. In contrast, firms in relatively skill-scarce countries prefer being lower cost in order to produce lower-quality products using lower-skilled workers, and the average f.o.b. export unit values decrease with the increasing difficulty in market penetration.

Chapter 2

Skilled-Labor Intensity Differences across Firms, Product Quality, and Wage Inequality

2.1 Introduction

A large number of literatures have shown that wage inequality both within and between skill groups grows as a result of trade liberalization (see, e.g., Feenstra and Hanson 1995; Zhu and Trefler 2005; Yeaple 2005; Burstein and Vogel 2010; Helpman et al. 2010: Davis and Harrigan 2011).[1] Recent theoretical works on trade openness and the exporter wage premium (that is, the wage differential between exporters and non-exporters) in the field of international trade have focused on a model of firm heterogeneity with labor market friction, while labor is assumed to be homogeneous (see, e.g., Egger and Kreickemeier 2009; Helpman and Itskhoki 2009; Helpman et al. 2010; Davis and Harrigan 2011). In spite of homogeneous workers, labor market imperfections allow ex-ante identical workers to be paid different wages across firms. As a result, within-group wage inequality occurs when trade liberalization, under the assumption of firm heterogeneity, affect firms differently. In this class of models, the exporter wage premium is mainly driven by the within-group wage differential between exporters and non-exporters.

Recent studies exploit the matched employer-employee data to show that the skill intensity varies across firms even within a narrowly defined industry. It also shows that firms with a higher level of skill intensity (i.e., a higher ratio of skilled to unskilled labor that produces a unit of output) are more likely to export, so that the exporter wage premium occurs simply due to their employing a higher proportion

[1] Feenstra and Hanson (1995) and Zhu and Trefler (2005) propose multinational outsourcing as a possible reason for the rising wage inequality, while Yeaple (2005) and Burstein and Vogel (2010) emphasize skills-biased technical change in a model with firm heterogeneity to explain a positive link between trade openness and between-group wage inequality. Davis and Harrigan (2011) and Helpman et al. (2010) explain the within-group wage inequality by introducing a search and matching friction in a labor market with ex-ante identical workers.

of skilled labor (see, e.g., Schank et al. 2007; Irarrazabal et al. 2009).[2] In this context, the different composition of production resources across firms must be taken into account in order to accurately analyze the link between wage inequality and trade integration.

In addition, recent empirical research has shown that a product's quality increases with a firm's skilled-labor intensity (see, e.g., Kyoji and Keiko 2010; Kugler and Verhoogen 2012).[3] That is, firms that use their skilled workers relatively intensively produce higher-quality goods. These well-established, stylized facts on firm heterogeneity seem to imply that firms with a higher skill intensity specialize in a higher-quality product and tend to be more competitive/profitable. Consequently, they are more likely to become exporters in the presence of such trade costs as fixed export costs and variable trade costs.[4] Since firms represented in a model with firm heterogeneity are unevenly affected by globalization, as trade costs fall production resources in a perfectly competitive labor market can be reallocated towards more efficient firms. In this context, the effect of trade liberalization on wage inequality cannot be fully described without considering both across-firm differences in skill intensity and firms' competitiveness in product quality.

In this paper, I develop a model of firm heterogeneity to address how trade liberalization affects the within-sector relative wage of skilled workers (i.e., the skill premium), under the assumption of a perfectly competitive labor market. Instead of intrinsic productivity differences across firms, Melitz (2003), I assume that firms only differ in the skill intensity of their production technology (that is, the differences in the ratio of skilled to unskilled labor used to produce one unit of output).[5] Additionally, I assume that skilled workers are more productive in performing tasks that improve product quality. In this framework, each firm

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[2] See also Bernard et al. (2007), Crozet and Trionfetti (2011), and Harrigan and Reshef (2011) for evidence of firm heterogeneity with respect to factor intensity. Irarrazabal et al. (2009) show that the exporter wage premium is mainly caused by differences in workforce composition across firms. Similarly, Schank et al. (2007) use linked employer-employed data from Germany to confirm that the wage differential between exporters and non-exporters becomes small enough when employees' observable and unobservable characteristics are controlled for.

[3] See Kyoji and Keiko (2010) for the empirical evidence of a significant and positive association between the unit value of a product (as measured by quality) and a firms' white-collar worker intensity using the factory level of the Japanese manufacturing sector.

[4] See Schott (2004), Bastos and Silva (2010), Baldwin and Harrigan (2011), Harrigan et al. (2011), and Johnson 2012 for a positive association between a firm's product quality and its competitiveness.

[5] Irarrazabal et al. (2009) investigate the importance of firm's workforce composition relative to intrinsic firm productivity as sources of the exporter's productivity premium, and show that over 67% of the exporter productivity premium reflects differences in workforce composition rather than intrinsic firm productivity. In fact, the main results in my model are not affected by including Hicks-neutral productivity differences across firms in the sense that a more productive firm chooses a technology that uses higher skill intensive labor to produce a higher-quality product. For the sake of tractability, I focus on a model without heterogeneous productivity across firms.

endogenously chooses its optimal product quality, given its own production technology. To be more specific, firms with a higher skill intensity choose to provide a better-quality product and become more profitable, in what is known as "quality competition".[6]

The key driving force behind the increase in wage inequality that results from trade cost reductions is the reallocation of production resources towards more profitable firms, which use skilled labor relatively intensively in order to produce higher-quality products. A decrease in trade costs allows existing exporters to increase their production of high quality goods so as to make additional sales in foreign markets. This increased production is accompanied by an increase in the relative demand for skilled labor because these firms are relatively more skill intensive than average. Besides, the relatively unskilled-labor-intensive non-exporters that produce lower-quality products are forced to exit the market due to the increase in import competition. As a result, the inter-firm reallocation of the workforce towards more skilled-labor-intensive manufacturing leads to the increase in the relative demand for skilled workers. The two mechanisms, described above, imply that trade liberalization increases the within-sector wage inequality between the two skill groups. In contrast to the first two effects, which raise the skill premium, the relative skill intensity of firms hat become new exporters, as a result of the reduced trade barriers, is ambiguous. For example, when the relative skill intensity of these new exporters is higher than average, the skill premium increases; otherwise, the skill premium will decline. But the last effect is not big enough to overturn the first two effects, so that the skill premium unambiguously increases as trade costs (both fixed and variable) fall.

The main results of this study are summarized as follows: The reduction in trade costs (fixed and/or variable trade costs) increases the within-sector wage inequality between skilled and unskilled workers. This pattern occurs regardless of the resource endowment differences between the trading countries.[7] The effect of the lower trade costs on the skill premium is larger when a country trades with relatively skill-abundant countries than when it trades with relatively skill-scarce countries. Furthermore, when two asymmetric countries trade with each other, the skill premium in a relatively skill-scare country is much higher and

[6] As noted in Baldwin and Ito (2011), I use the term "quality competition" when firms' competitiveness depends on the quality-adjusted price (i.e., price/quality), where firms with a lower quality-adjusted price are more efficient.

[7] This pattern contradicts the Stolper-Samuelson effect in the Heckscher-Ohlin model assuming a homogeneous quality of product. Therefore, the pattern of wage inequality following trade liberalization seems to depend on sector or disaggregated product-level. In this context, analyzing the effect of trade liberalization on wage inequality should be considered at least at the sector-level, but not at the aggregate level.

increases faster as trade costs fall than in that of a relatively skill-abundant counterpart. Lastly, when the barriers to trade are high enough, two-way trade between similar economies, in terms of factor endowments, is more prevalent than trade between asymmetric countries. This is consistent with the well-known stylized fact that the large volume of world trade is associated with trade among similar economies.

This paper is related to the literature that analyzes the effect of trade openness on within-sector wage inequality between skill groups (Burstein and Vogel 2010; Harrigan and Reshef 2011; Vannoorenberghe 2011; Sampson 2012, among others). The models presented in these studies consider across-firm differences in productivity with heterogeneous workers or with skill-biased heterogeneous firms, but they exclude the quality dimension. The standard model of firm heterogeneity without considering quality differentiation, including that of Melitz (2003), however, conflicts with recent empirical findings from both product- and firm-level data (see, for example, Verhoogen 2008; Bastos and Silva 2010; Baldwin and Harrigan 2011; Kugler and Verhoogen 2012). In these studies, the authors found a positive correlation between the quality of a firm's product (that is, the unit value of a product) and its profitability. Since the differences in product quality in a model with firm heterogeneity is an important source of firms' competitiveness, at least in some sectors, quality heterogeneity, in a market with vertically differentiated products, must be taken into consideration when establishing a relationship between the skill premium and trade liberalization. In this context, this paper also contributes to the literature on firms' competitiveness and product quality where quality heterogeneity plays a critical role in shaping firms' efficiency (see, for example, Schott 2004; Bastos and Silva 2010; Baldwin and Harrigan 2011; Harrigan et al. 2011; Johnson 2012).

The literature closest to my model is that of Harrigan and Reshef (2011). These studies present models where production technology, in terms of skill intensity, varies across firms. Harrigan and Reshef employ a skill-biased technology where they assume that intrinsic firm productivity is positively correlated with skill intensity. In their model, a reduction in trade costs ensures that only more productive firms with higher skill intensity tend to be exporters. Thus, the relative demand for skilled labor increases, resulting in the increase in wage inequality. This paper is similar to Harrigan and Reshef's, with the exception that, in my model, the relatively high-skill-intensive firms become more efficient by endogenously choosing higher-quality products. In fact, Harrigan and Reshef (2011) briefly gives an alternative interpretation of the model, adapting the “quality competition” framework. But they assume that product quality is exogenously given in the form of demand, and that it is positively correlated with skill intensity, whereas in my model, the levels of product quality are determined endogenously by individual firms given their own skill intensity, so that it plausibly explains why firms with a higher skilled-labor intensity optimally choose to produce a higher-quality good. Therefore, the increase in wage inequality following trade liberalization can be explained by a positive link between a firm’s skilled-labor intensity and its product quality, and “quality competition”, where, assuming that skilled workers have comparative advantage in producing quality goods, a product’s quality levels are endogenously determined by individual firms.

The main purpose of this paper is to emphasize the importance of “quality competition”, at least in some (vertically) differentiated products markets, in accounting for the positive relationship between the within-sector skill premium and trade liberalization. Verhoogen (2008) explains the increase in within-plant wage inequality in Mexico as a result of the peso’s devaluation (resulting in expanding trade) by introducing a quality-upgrading mechanism in a partial equilibrium framework. To be more specific, Verhoogen argues that the more productive exporting firms tend to upgrade their product quality in the face of increased trade with rich northern countries. He also notes that upgrading product quality requires each worker be better trained and more productive, and thus higher-quality. Hence, this quality upgrading mechanism leads to an increase in the within-plant wage inequality, and thereby a rise in the within-sector skill premium. In contrast, in my model, the within-firm skill intensity is not affected by exporting activity. Rather, the within-sector skill premium increases because of the reallocation of production resources towards the higher-skill-intensive firms, and not because of within-plant skill upgrading. In fact, recent empirical findings support this argument: there is no effect of trade liberalization on firm-level skill upgrading (see, for example, Bernard and Jensen 1994; Trefler 2004; Vannoorenberghe 2011; Harrigan and Reshef 2011).

The remainder of the paper is organized as follows: Section 2 consists of two parts: First, a model of endogenous quality is described. This model’s endogenous quality exists in conjunction with across-firm differences in skill intensity in a closed economy, where a higher skill intensive firm chooses a higher product quality, and becomes more competitive, and only firms that produce high enough quality goods find it worthwhile to remain in the market. Second, I extend the model to an open economy, in which I analyze the effect of trade integration on wage inequality, where trade liberalization can be represented by a reduction in trade costs (fixed export and/or variable trade costs).[8] In Section 2, a numerical exercise is also conducted for each autarky and open economy. Finally, Section 3 presents some concluding remarks.

2.2 The Theoretical Model

In this section, I develop a general equilibrium model of international trade, which builds on Melitz (2003), Bernard et al. (2007) and Harrigan and Reshef (2011), where a positive association between a firm's skill intensity and its product quality, and quality competition play an important role in explaining the increase in the within-sector wage inequality between two skill groups as a result of an increasing openness to trade. In the following discussion, I focus on a one-sector version of the model in a vertically differentiated products market.

2.2.1 The Basic Set-up

2.2.1.1 Consumption

From the demand side, a representative consumer in a country cares about a product's quality as well as its price. The consumer's utility function takes the Dixit-Stiglitz CES preference over the consumption of the differentiated varieties. The utility of each consumer is given by

$$U = \left(\int_{\omega \in \Omega} [q(\omega)x(\omega)]^{\frac{\sigma-1}{\sigma}} d\omega \right)^{\frac{\sigma}{\sigma-1}}, \tag{2.1}$$

where ω denotes an individual variety in the potential set Ω of varieties that are available in the economy. $\sigma > 1$ is the elasticity of substitution between varieties. $q(\omega)$ and $x(\omega)$ denote quality and quantity of variety ω respectively.

Preferences are assumed to be identical across countries. Given the revenue E, a representative consumer chooses the consumption of each variety to maximize his utility. The corresponding demand function

[8] I consider the costly trade model not only between identical countries, but also between different countries in terms of their resources endowment.

for variety ω is

$$x(p(\omega),q(\omega)) = q(\omega)^{\sigma-1}p(\omega)^{-\sigma}\tilde{P}^{\sigma-1}E,$$
$$\tilde{x}(\tilde{p}(\omega)) = [\tilde{p}(\omega)]^{-\sigma}\tilde{P}^{\sigma-1}E, \tag{2.2}$$

where $\tilde{x}(\omega) = q(\omega)x(\omega)$ and $\tilde{p}(\omega) = p(\omega)/q(\omega)$ are the quantity measured in units of utility and the quality-adjusted price of variety ω respectively. $\tilde{P} = \left(\int_{\omega\in\Omega}[\tilde{p}_i(\omega)]^{1-\sigma}d\omega\right)^{1/1-\sigma}$ is the aggregate quality-adjusted price index of consumption and E is total expenditure in this economy.

2.2.1.2 Production

Each variety of the differentiated good is produced by a monopolistically competitive firm that uses both skilled and unskilled labor. Unlike the standard model of heterogeneous firms along the lines of Melitz (2003), I assume that there are no intrinsic productivity differences across firms. Instead of having Hicks-neutral productivity differences, firms only differ in their skill-intensive technology. That is, firms discover their own skill intensity after paying a sunk entry cost.[9]

Production involves both fixed and variable costs. A fixed production cost is assumed to be the same across firms in the same country, while the variable costs differ according to the firm-specific skill intensity and product quality. I assume that the function of the variable costs takes the Cobb-Douglas form and the marginal costs consist of two components: simple costs to assemble a physical output, and the additional costs that are related to product quality (quality-related work such as a technology-combined design). The total cost of firms that draw on skill intensity θ from a common distribution $G(\theta)$, where $\theta \in [0,1]$, is

$$TC(\theta,q) = f\overline{w} + s^{\theta}w^{1-\theta}\,[1+\Psi(\theta,q)]\,x(\theta,q), \tag{2.3}$$

where $f\overline{w}$ denotes the fixed production cost in terms of units of labor, which is the same across firms in the same economy, but might be different across countries.[10] s and w denote the wage rate of skilled and

[9] Within-sector productivity differences across firms can be substantially explained by differences in skill intensity (that is, the different proportions of skilled worker across firms). In a recent paper that uses firm-level data that matches employer and employee for Norwegian Manufacturing sector, the authors confirm the fact that over 67% of the exporter productivity premium reflects differences in skill intensiveness rather than in intrinsic firm efficiency (Irarrazabal et al. 2009). See also Crozet and Trionfetti (2011) for empirical evidence that factor intensities differ across firms even within the same industry.

[10] As in Harrigan and Reshef (2011), I assume that $\overline{w}$ depends on the economy's overall factor abundance and $\overline{w} = \left(\frac{H}{H+L}\right)s + \left(\frac{L}{H+L}\right)w$, where H and L are the economy's inelastic aggregate supplies of skilled and unskilled labor respectively. The cost function, therefore, is homogeneous of degree one in input prices.

unskilled labor respectively. $x(\theta, q)$ denotes the quantity of a variety with quality level q that is produced by a firm with skill level θ.

Regarding a simple assembly task, I assume that skilled workers have no productive advantage, so that the marginal cost related to this work increases with a firm's skill intensity, assuming the wage ratio of skilled to unskilled worker is greater than one; that is, $s^{\theta} w^{1-\theta}$ increases with θ. In addition, I assume that producing better-quality products requires higher costs and skilled workers show greater productivity in performing tasks that improve product quality (i.e., $\Psi_q(\theta, q) > 0$ and $\Psi_{\theta}(\theta, q) < 0$). This is a reasonable assumption in that producing a higher-quality product often requires a more complex technology and such a technology is difficult to follow unless the labor force is skilled enough.[11] As a result, a firm with a higher skill intensity faces a higher marginal cost of simple assembly work, but a lower marginal cost of quality-associated work.

For the sake of tractability, I make the following parametric assumption regarding the functional form of $\Psi(\theta, q)$: the total cost of firms with skill intensity θ is

$$TC(\theta, q) = f\overline{w} + s^{\theta} w^{1-\theta} \left[1 + \frac{q^{\phi}}{\theta^{\alpha}}\right] x(\theta, q), \tag{2.4}$$

where the parameter ϕ is the elasticity of the marginal cost with respect to quality, which is common across firms as well as countries. The parameter α measures the degree of skilled workers' efficiency on the quality-related tasks.

A firm's marginal-cost function, $s^{\theta} w^{1-\theta} \left[1 + \frac{q^{\phi}}{\theta^{\alpha}}\right]$, can be justified as follows: If there is no quality dimension in the model ($q = 0$), then the model is of the standard form, where it is reasonable to assume that skilled workers have no productivity advantage in assembling output without adding product quality (such as screwing nuts onto bolts). As long as skilled workers command a higher wage (for example where $s > w$), this translates to a higher marginal cost, so that firms with a higher skill intensity are less efficient. In contrast, skilled workers have a comparative advantage in making quality goods (i.e., $q > 0$); that is, skilled workers are relatively more productive in performing tasks that are related to product quality.[12]

[11] See Abowd et al. (1996), Kyoji and Keiko (2010) and Kugler and Verhoogen (2012) for a positive relationship between a firm's skill intensity and its product quality.

[12] Taking the derivative of the second term of marginal costs, $(s^{\theta} w^{1-\theta}) \frac{q^{\phi}}{\theta^{\alpha}}$ with respect to skill intensity θ gives marginal cost

Firms in a monopolistic competition set a constant mark-up over their marginal costs. A firm with skill intensity θ chooses its optimal product quality endogenously to solve[13]

$$\begin{aligned} \max_{\{q\}} \quad & p(\theta,q)x(\theta,q) - f\overline{w} - s^{\theta}w^{1-\theta}\left[1+\frac{q^{\phi}}{\theta^{\alpha}}\right]x(\theta,q) \\ \text{s.t.} \quad & x(\theta,q) = q^{\sigma-1}p(\theta,q)^{-\sigma}\tilde{P}^{\sigma-1}E \\ \text{and} \quad & p(\theta,q) = \left(\frac{\sigma}{\sigma-1}\right)s^{\theta}w^{1-\theta}\left[1+\frac{q^{\phi}}{\theta^{\alpha}}\right]. \end{aligned} \tag{2.5}$$

Taking $\tilde{P}$ and E as given, solving the maximization problem above gives the optimal choice of quality for firms with their skill intensity θ,[14]

$$q^{*}(\theta) = \left(\frac{1}{\phi-1}\right)^{\frac{1}{\phi}}\theta^{\frac{\alpha}{\phi}}, \tag{2.6}$$

where $\phi > 1$ by the second-order condition for a maximum.[15] The positive association between a firm's skill intensity and its product quality is consistent with recent empirical findings. Indeed, using factory-level Japanese manufacturing data, Kyoji and Keiko (2010) show that the unit value of a product (that is, a product's quality) is positively correlated with a firm's white-collar intensity.

Substituting the optimal quality schedule, $q^{*}(\theta)$, into the marginal-cost function yields

$$MC(\theta) = \left(\frac{\phi}{\phi-1}\right)s^{\theta}w^{1-\theta}. \tag{2.7}$$

Since $\frac{\phi}{\phi-1} > 1$, all firms in a country pay more than $s^{\theta}w^{1-\theta}$ to produce one unit of output. That is, all firms have an incentive for adding quality, $q^{*}(\theta) > 0$ for all $\theta \in [0,1]$. Notice that the price of a variety that is produced by firms with θ is $p(\theta) = \left(\frac{\sigma}{\sigma-1}\right)MC(\theta)$. Since $\sigma > 1$, firms with a higher skill intensity set a

---

decreases with skill intensity θ, assuming that α is high enough. For more details regarding this assumption on α, see the following section.

[13] One can think of this profit maximization as a two-stage process: All firms first choose their product quality q simultaneously after discovering their own skill intensity, θ. Second, firms simultaneously choose their prices and output levels given their product qualities. With monopolistic competition and a continuum of varieties, no one firm can influence the aggregate price and quality level so that firms take the aggregate quality-adjusted price index, $\tilde{P}$, as given. The optimal price and quality chosen by firms with skill intensity θ can be solved by working backwards from the second stage. In the second stage, a firm chooses the price and quantity, given its quality q, so that the optimal price charged by firms with skill intensity θ and quality q is a constant mark-up over their marginal cost: $p(\theta,q) = \left(\frac{\sigma}{\sigma-1}\right)s^{\theta}w^{1-\theta}\left[1+\frac{q^{\phi}}{\theta^{\alpha}}\right]$. Knowing this price rule given each product quality, firms in the first stage choose their optimal quality in response to their own skill intensity, which is shown in equation (2.5).

[14] Note that $\tilde{P} = \left(\int_{\omega\in\Omega}[\tilde{p}(\omega)]^{1-\sigma}d\omega\right)^{1/1-\sigma}$. Although $\tilde{P}$ is endogenous to the industry, firms take it as an exogenous variable since a firm's size is negligible relative to the industry, as a whole, under the assumption of monopolistic competition.

[15] See Cremer and Thisse (1994), Khandelwal (2010), and Schmitt (2002), where the authors assume the quadratic form of marginal cost (MC) with respect to quality, $MC(\varphi,q) = \varphi + q^{2}$ where φ and q are a firm-specific and a quality-specific component, respectively.

higher price because they manufacture the relatively better-quality product. The bottom line is that firms with a higher skill intensity θ produce a higher quality variety and charge a higher price, which is consistent with a number of empirical findings.

2.2.2 The Closed Economy

In this section, I analyze the autarky equilibrium, where the wage ratio of skilled to unskilled worker (the skill premium) and the skill intensity threshold, below which firms exit the market, are endogenously determined. In the following section, I consider the costly trade equilibrium that exists in an open economy, and then investigate the effect of trade liberalization on wage inequality.

2.2.2.1 Firm Competition, Entry, Exit, and Free Entry Condition

Using the pricing rule, and the optimal quantity and quality schedule constructed in the previous section, the revenue of firms with skill intensity θ is

$$R(\theta) = \left(\frac{p(\theta)}{q(\theta)}\right)^{1-\sigma} \tilde{P}^{\sigma-1}E = \lambda w^{1-\sigma}\left(\frac{s}{w}\right)^{\theta(1-\sigma)} \theta^{\frac{\alpha(\sigma-1)}{\phi}} \tilde{P}^{\sigma-1}E, \tag{2.8}$$

where $\lambda = \left[\left(\frac{\sigma}{\sigma-1}\right)\left(\frac{\phi}{\phi-1}\right)\left(\frac{1}{\phi-1}\right)^{-1/\phi}\right]^{1-\sigma} > 0$ is constant. Note that the firm's revenue is a function of product quality as well as price because firms compete on the quality-adjusted price, p/q, rather than on price p.

The firm-specific skill intensity θ has two opposite effects on the firm's revenue: (i) a higher θ leads to a higher revenue via the last term in equation (2.8), $\theta^{\frac{\alpha(\sigma-1)}{\phi}}$, and (ii) the increase in θ reduces the firm's revenue, because firms with a higher θ face a higher cost, which is captured by $\left(\frac{s}{w}\right)^{\theta(1-\sigma)}$, where we have a negative exponent due to $\sigma > 1$. These opposite effects occur because firms with a higher skill intensity increase their revenue by selling a relatively high-quality product at a higher price. At the same time, these firms pay a higher wage, thereby reducing their revenue.

When $\alpha > \phi ln(\frac{s}{w})$ the firm's revenue increases with skill intensity θ.[16] Recent empirical studies of international trade support the view that firm's skill intensity increases revenue through their production

[16] Taking the derivative of the firm's revenue function with respect to θ gives $\frac{\partial R(\theta)}{\partial \theta} > 0$ if $\alpha > \phi ln(\frac{s}{w})\theta$ for $\theta \in [0,1]$, so when $\alpha > \phi ln(\frac{s}{w})$ the firm's revenue increases with skill intensity θ for all $\theta \in [0,1]$.

of higher-quality products: (i) a more skill intensive firm is more likely to be an exporter (e.g., Schank et al. 2007; Bas 2012), (ii) exporters pay higher wages because the labor force employed by exporting firms are relatively biased toward skilled labor (see, e.g., Irarrazabal et al. 2009), and (iii) a positive association between firm's skill intensity and product quality, and more successful firms set higher prices, which implies "quality competition" (e.g., Verhoogen 2008; Kyoji and Keiko 2010; Bastos and Silva 2010; Baldwin and Harrigan 2011; Kugler and Verhoogen 2012). Hence, as suggested in a number of empirical findings, I assume that $\alpha > \phi ln(\frac{s}{w})$ holds, so that a firm's revenue increases with firm-specific skilled-labor intensity θ and its resulting product quality. That is, firms with a higher θ produce a better quality variety and become more profitable. This inequality condition plays a key role in determining the rising wage inequality attributed to a reduction in trade costs because this assumption leads to a positive link between a firm's skill intensity and its revenue, via its product quality.

Let θ^* denote a zero-profit skill intensity cut-off (i.e., skill intensity cut-off for surviving), so firms drawing a skill intensity below θ^* exit the market, while firms with a skill intensity above θ^* engage in production. There is an unbounded potential entrants and, in equilibrium, the expected value of entry is equal to the sunk entry cost $f_e\overline{w}$. Thus, the free entry condition is[17]

$$\overline{\pi} = \frac{\delta}{1-G(\theta^*)} f_e\overline{w}, \tag{2.9}$$

where $\overline{\pi}$ is the average firm's profitability from successful entry. $1-G(\theta^*)$ and δ are the *ex ante* probability of successful entry and the exogenous probability of a firm's failure respectively. The weighted-average skill intensity of successful firms is determined by the *ex post* probability distribution of θ and the zero-profit threshold θ^*, which is as follows:

$$\tilde{\theta}(\theta^*) = \left[\frac{1}{1-G(\theta^*)}\int_{\theta^*}^{1} \theta^{\sigma-1} g(\theta) d\theta\right]^{1/(\sigma-1)}. \tag{2.10}$$

Using firm's profit function, $\pi(\theta) = \frac{R(\theta)}{\sigma} - f\overline{w}$, the average firm profitability can be obtained by the weighted average skill intensity of successful entrants which is denoted by $\tilde{\theta}(\theta^*)$:

$$\overline{\pi} = \frac{R(\tilde{\theta}(\theta^*))}{\sigma} - f\overline{w}. \tag{2.11}$$

[17] See Melitz (2003), Bernard et al. (2007), and Harrigan and Reshef (2011) for the free entry condition in detail. In fact, the free entry condition implies that the expected value of entry, $\frac{1-G(\theta^*)}{\delta}\overline{\pi}$, equals the sunk fixed entry cost, $f_e\overline{w}$, that is, in effect, equivalent to equation (2.9).

Using the zero-profit condition, $\frac{R(\theta^*)}{\sigma} = f\overline{w}$, the average firm profitability can be written as $\overline{\pi} = f\overline{w}\left[\frac{R(\tilde{\theta}(\theta^*))}{R(\theta^*)} - 1\right]$. Based on the revenue function given by the equation (2.8), the average firm profitability is

$$\overline{\pi} = f\overline{w}\left\{\left(\frac{s}{w}\right)^{(\tilde{\theta}(\theta)-\theta^*)(1-\sigma)}\left(\frac{\tilde{\theta}(\theta^*)}{\theta^*}\right)^{\frac{\alpha(\sigma-1)}{\phi}} - 1\right\}. \tag{2.12}$$

From equations (2.9) and (2.12), we have

$$\left(\frac{s}{w}\right)^{(\tilde{\theta}(\theta^*)-\theta^*)(1-\sigma)}\left(\frac{\tilde{\theta}(\theta^*)}{\theta^*}\right)^{\frac{\alpha(\sigma-1)}{\phi}} - 1 = \frac{\delta}{1-G(\theta^*)}\frac{f_e}{f}, \tag{2.13}$$

where the weighted-average skill intensity for surviving firms, $\tilde{\theta}(\theta^*)$, is given by equation (2.10). The condition in equation (2.13) simply implies that the expected value of entry equals the sunk fixed entry cost. These two equations (2.10) and (2.13) show a negative association between the relative wage of skilled workers s/w and the surviving cut-off θ^* in equilibrium, which is described in more detail later in this section.

2.2.2.2 Labor Market Equilibrium

I assume that the labor market is perfectly competitive, and is following Harrigan and Reshef (2011). Notice that the firm's marginal cost in response to its optimal quality, q^*, is $MC(\theta, q^*(\theta)) = \left(\frac{\phi}{\phi-1}\right)s^{\theta}w^{1-\theta}$. The labor demand for each type of worker (skilled and unskilled) to produce one unit of output can be obtained by applying Shepard's Lemma. Hence, the skilled and unskilled labor demand per unit of output are

$$\begin{aligned} d_h\left(\theta, \frac{s}{w}\right) &= \left(\frac{\phi}{\phi-1}\right)\theta\left(\frac{s}{w}\right)^{\theta-1}, \\ d_l\left(\theta, \frac{s}{w}\right) &= \left(\frac{\phi}{\phi-1}\right)(1-\theta)\left(\frac{s}{w}\right)^{\theta}, \end{aligned} \tag{2.14}$$

where d_h and d_l represent the unit labor demand for skilled and unskilled workers respectively. Hereafter, I use subscript h to indicate skilled workers and l to indicate unskilled workers. To produce one unit of good, a more skill-intensive firm (firms with a higher θ) uses a relatively high proportion of skilled labor. This relationship can be easily captured by $\frac{d_h}{d_l}(\theta, \frac{s}{w}) = \left(\frac{\theta}{1-\theta}\right)\left(\frac{w}{s}\right)$, and where the relative share of skilled to unskilled workers needed to manufacture one unit of variety increases with θ. Also note that the ratio of skilled to unskilled workers to produce a unit of output is inversely related to the relative wage of skilled workers (s/w).

Based on the quantity demanded, optimal quality, and pricing, the total output of firms with θ is

$$x(\theta) = \gamma w^{-\sigma} \left(\frac{s}{w}\right)^{-\theta\sigma} \theta^{\frac{\alpha(\sigma-1)}{\phi}} \tilde{P}^{\sigma-1} E, \tag{2.15}$$

where $\gamma = \left(\frac{\sigma}{\sigma-1}\right)^{-\sigma} \left(\frac{\phi}{\phi-1}\right)^{-\sigma} \left(\frac{1}{\phi-1}\right)^{(\sigma-1)/\phi}$ is a positive constant. Therefore, the total skilled and unskilled labor demand of firms with θ are

$$\begin{aligned} D_h(\theta, \frac{s}{w}) &= d_h\left(\theta, \frac{s}{w}\right) x(\theta) = \eta w^{-\sigma} \left(\frac{s}{w}\right)^{\theta(1-\sigma)-1} \theta^{\frac{\alpha(\sigma-1)}{\phi}} \theta \tilde{P}^{\sigma-1} E, \\ D_l(\theta, \frac{s}{w}) &= d_l\left(\theta, \frac{s}{w}\right) x(\theta) = \eta w^{-\sigma} \left(\frac{s}{w}\right)^{\theta(1-\sigma)} \theta^{\frac{\alpha(\sigma-1)}{\phi}} (1-\theta) \tilde{P}^{\sigma-1} E, \end{aligned} \tag{2.16}$$

where $\eta = \left(\frac{\sigma}{\sigma-1}\right)^{-\sigma} \left(\frac{\phi}{\phi-1}\right)^{1-\sigma} \left(\frac{1}{\phi-1}\right)^{(\sigma-1)/\phi} > 0$ is constant.

Let M denote the equilibrium mass of firms in this economy, and hence M product varieties. The aggregate labor demand in the variable costs can be obtained by integrating the total labor demand of firms with the same skill intensity over $\theta \in [\theta^*, 1]$. This gives the aggregate labor demand for skilled and unskilled labor in the variable costs, which are as follows:

$$\begin{aligned} TD_h(\theta^*, \frac{s}{w}) &= \int_{\theta^*}^{1} D_h(\theta, \frac{s}{w}) M \frac{g(\theta)}{1-G(\theta^*)} d\theta, \\ TD_l(\theta^*, \frac{s}{w}) &= \int_{\theta^*}^{1} D_l(\theta, \frac{s}{w}) M \frac{g(\theta)}{1-G(\theta^*)} d\theta, \end{aligned} \tag{2.17}$$

where $D_h(\theta, \frac{s}{w})$ and $D_l(\theta, \frac{s}{w})$ are given by equation (2.16). $\frac{g(\theta)}{1-G(\theta^*)}$ is the *ex post* probability density function of surviving firms' skill intensity, so $M\frac{g(\theta)}{1-G(\theta^*)}$ refers to the mass of successful firms with the same θ.

Next, I consider the aggregate labor demand for skilled and unskilled labor as part of the fixed costs (fixed entry and production costs). Let M_e denote the equilibrium mass of new entrants in each period, thus the mass of successful entrants for production, $[1-G(\theta^*)]M_e$, must be equal to the mass of firms, δM, who exit the market following the exogenous bad shock: $[1-G(\theta^*)]M_e = \delta M$. Therefore, the mass of new entrants can be expressed as the fraction of successful production firms, which is $M_e = \frac{\delta}{[1-G(\theta^*)]}M$. Note that the aggregate fixed costs consist of both the sunk fixed entry costs and the fixed production costs: $\left(f + \frac{\delta}{1-G(\theta^*)} f_e\right) M\overline{w}$. The aggregate demand for skilled and unskilled labor involved in these fixed costs are[18]

$$
\begin{aligned}
FD_h &= \left(\frac{H}{H+L}\right) M \left(f + \frac{\delta}{1-G(\theta^*)} f_e\right), \\
FD_l &= \left(\frac{L}{H+L}\right) M \left(f + \frac{\delta}{1-G(\theta^*)} f_e\right).
\end{aligned} \tag{2.18}
$$

where FD_h and FD_l represent the aggregate demand for skilled and unskilled labor, corresponding to the fixed costs, respectively.

These two equations in (2.18) show the ratio of the total skilled to unskilled labor demand in the fixed costs is equal to the relative skilled labor abundance, that is, $FD_h/FD_l = H/L$. This ratio of labor demand in the fixed costs signifies that the ratio of skilled to unskilled labor demand in the variable costs also equals the relative skilled labor abundance H/L. Therefore, equations (2.16) and (2.17) give the relative labor market clearing condition which is as follows:

$$
\begin{aligned}
\frac{TD_h(\theta^*, \frac{s}{w})}{TD_l(\theta^*, \frac{s}{w})} &= \frac{\int_{\theta^*}^{1} D_h(\theta, \frac{s}{w}) g(\theta) d\theta}{\int_{\theta^*}^{1} D_l(\theta, \frac{s}{w}) g(\theta) d\theta} \\
&= \frac{\left(\frac{w}{s}\right) \int_{\theta^*}^{1} \left(\frac{s}{w}\right)^{\theta(1-\sigma)} \theta^{\frac{\alpha(\sigma-1)}{\phi}} \theta g(\theta) d\theta}{\int_{\theta^*}^{1} \left(\frac{s}{w}\right)^{\theta(1-\sigma)} \theta^{\frac{\alpha(\sigma-1)}{\phi}} (1-\theta) g(\theta) d\theta} = \frac{H}{L}.
\end{aligned} \tag{2.19}
$$

2.2.2.3 Autarky Equilibrium

In this section, I discuss the equilibrium conditions for autarky. In equilibrium, the threshold of skill intensity θ^* and the skill premium s/w are determined jointly by equations (2.10), (2.13), and (2.19). All other aggregate variables are determined endogenously as a function of the parameters, θ^*, and s/w, where the wage for unskilled labor is normalized to one, $w = 1$, as a numeraire. I close this section to derive the aggregate equilibrium variables: the total revenue/expenditure E, the mass of successful firms M, and the industry price index $\tilde{P}$.

Following Melitz (2003), the aggregate revenue E, in equilibrium, must be equal to the total payment to both skilled and unskilled labor. That is, $E = wL + sH$. The mass of producing firms is determined by the fact that the total revenue must equal, in equilibrium, the average firm's revenue multiplied

[18] As in Harrigan and Reshef (2011), I assume that $\overline{w}$ depends on the economy's overall factor abundance, that is, $\overline{w} = \left(\frac{H}{H+L}\right) s + \left(\frac{L}{H+L}\right) w$, where H and L are the economy's inelastic aggregate supplies of skilled and unskilled labor respectively. The aggregate labor demand for each type of worker in the fixed costs, equation (18), can be obtained by taking the derivative of the total fixed costs, $\left(f + \frac{\delta}{1-G(\theta^*)} f_e\right) M\overline{w}$, with respect to each s and w.

by the mass of firms. Thus the mass of successful firms is: $M = \frac{E}{\overline{r}}$. Using the free entry condition (equations (2.9) and (2.11)), the average revenue can be expressed as the following equation: $R(\tilde{\theta}(\theta^*)) = \overline{r} = \sigma\left[f + \frac{\delta}{1-G(\theta^*)} f_e\right]\overline{w}$. Since $\overline{w} = \left(\frac{H}{H+L}\right) s + \left(\frac{L}{H+L}\right) w$ the mass of successful firms is expressed by

$$M = \frac{H+L}{\sigma\left[f + \frac{\delta}{1-G(\theta^*)} f_e\right]}. \tag{2.20}$$

Note that the mass of surviving firms is inversely associated with both fixed entry (f_e) and production costs (f). That is, the larger the fixed costs, the fewer the firms producing in equilibrium.

Finally, the industry price index can be derived from integrating each firm's quality-adjusted price, multiplied by the equilibrium mass of firms over $\theta \in [\theta^*, 1]$. Hence, the weighted average price index of the firms in equilibrium is

$$\begin{aligned}\tilde{P} = \left[\int_{\theta^*}^{1} \left(\frac{p(\theta)}{q(\theta)}\right)^{1-\sigma} M \frac{g(\theta)}{1-G(\theta^*)} d\theta\right]^{\frac{1}{1-\sigma}} &= M^{\frac{1}{1-\sigma}} \left[\int_{\theta^*}^{1} \left(\frac{p(\theta)}{q(\theta)}\right)^{1-\sigma} \frac{g(\theta)}{1-G(\theta^*)} d\theta\right]^{\frac{1}{1-\sigma}} \\ &= M^{\frac{1}{1-\sigma}} \frac{p(\tilde{\theta})}{q(\tilde{\theta})} = \mu M^{\frac{1}{1-\sigma}} w \left(\frac{s}{w}\right)^{\tilde{\theta}} \tilde{\theta}^{-\frac{\alpha}{\phi}},\end{aligned} \tag{2.21}$$

where $\mu = \left(\frac{\sigma}{\sigma-1}\right)\left(\frac{\phi}{\phi-1}\right)\left(\frac{1}{\phi-1}\right)^{-1/\phi}$ is a positive constant. $\tilde{\theta}$ is a function of θ^*, which is given in equation (2.10).

Proposition 2.2.1. *There exists a unique autarky equilibrium in which the zero-profit skill intensity cut-off, θ^*, and the relative wage of skilled labor, $\frac{s}{w}$, are determined.*

Proof. See Appendix A.1. ■

2.2.2.4 Numerical Exercise in Autarky

Here, I numerically solve the model, and provide a visual interpretation of the autarky equilibria described in the previous section. To do so, I assume a normal distribution for *ex ante* firm skill intensity, $G(\theta)$, where the mean is 0.5.[19] As presented in Bernard et al. (2007) and Harrigan and Reshef (2011), I use the following parameters: (1) $\sigma = 3.8$ for the elasticity of substitution, (2) $\delta = 0.025$ as a probability of

[19] I set the standard deviation at 0.15 so that skill intensity, θ is normally distributed over [0.1]. As an alternative distribution of skill intensity, I also use a uniform distribution over $[0,1]$ and the results are similar to normal distribution. In the following discussion, I focus on a normal distribution of skill intensity, which is consistent with the empirical evidence.

exit due to a bad shock, (3) $f_e = 20$ for a sunk entry cost, and (4) $f = 1$ or 2 for a fixed production cost. For ϕ and α, I set $\phi = 1.1 > 1$ and $\alpha = 1.5 > 0$ so that $\alpha > \phi ln\left(\frac{s}{w}\right)$ holds in equilibrium, which ensures that firm's revenue increases with θ.[20]

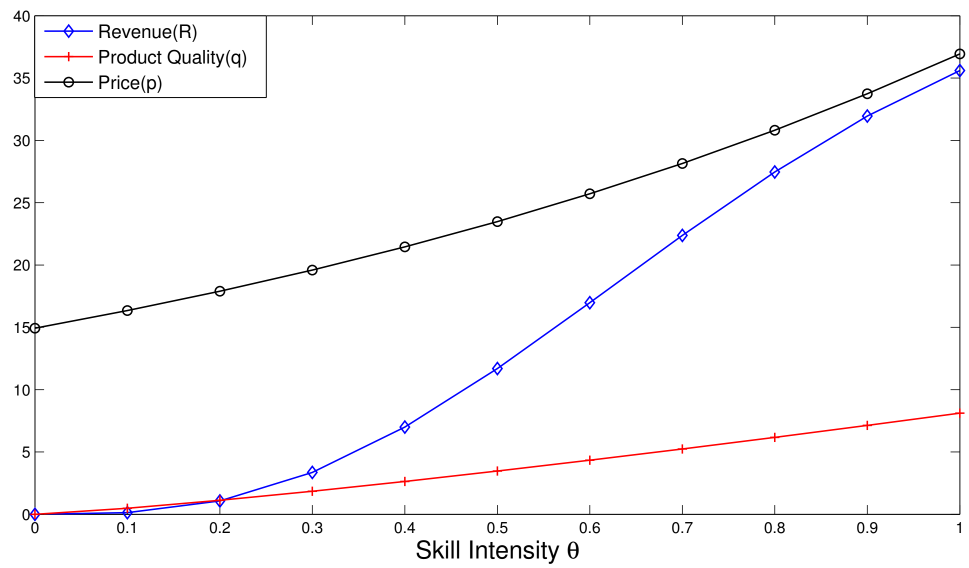


Figure 2.1: The Equilibrium Revenue, Quality, and Price in Autarky

Figure 2.1 plots the firm's revenue, product quality, and price against firm-specific skill intensity θ, for which the endowment for skilled labor, H, and unskilled labor, L, are assumed to be 1500 and 2000, respectively. As previously noted, firms with a higher θ choose a higher product quality and price. They are also the firms that end up with a higher revenue and profit. Since a firm's efficiency is inversely related to the quality-adjusted price, even firms whose products are sold at a higher price become more competitive, which is in conflict with the price-based competition in models that adhere to the spirit of Melitz (2003).

Table 2.1 presents the equilibrium skill premium s/w and the zero-profit skill intensity cut-off θ^*, which depend on both the fixed production costs f and the relative endowment of skilled labor H/L. First, all else being equal, both the skill premium and the skill intensity cut-off are positively associated with the fixed costs of production. That is, the higher the fixed costs of production, the higher are both s/w and θ^* in

[20] In the later section for an open economy, I use different sets of values for ϕ and α (e.g., $\phi = 1.5$ and $\alpha = 2$) to ensure that different values of ϕ and α do not affect the overall patterns of the skill premium and the zero-profit skill intensity cut-off as long as the condition, $\alpha > \phi \ln\left(\frac{s}{w}\right)$, holds. Indeed, *ceteris paribus*, the different sets of ϕ and α only give different scales of the skill premium and skill intensity cut-off, but they give the same patterns for these variables of interest.

Table 2.1: The Equilibrium Zero-profit Skill Intensity Cut-off (θ^*) and Skill Premium (s/w)

	$(H/L) = 0.5$		$(H/L) = 0.75$		$(H/L) = 1$	
	$f = 1$	$f = 2$	$f = 1$	$f = 2$	$f = 1$	$f = 2$
Skill Premium ($\frac{s}{w}$)	2.98	3.23	2.17	2.37	1.73	1.90
Cut-off skill intensity (θ^*)	0.42	0.47	0.45	0.50	0.46	0.52

equilibrium. These relationships are also illustrated graphically in Figure 2.2, where the relative endowment of skilled labor is fixed as $H/L = 0.75$. The intuition behind these results are natural: i) The relatively less efficient firms are forced to exit the market. This is because as the fixed production costs rise, so does θ^* and; ii) Rising θ^* leads to reallocation of production resources towards the relatively more skill intensive, competitive firms, so that the skill premium, s/w, increase in response to the increase in the relative demand for skilled labor. Since the relative endowment of skilled labor, H/L, is fixed, the increase in the skill premium stems from the increase in the zero-profit cut-off.

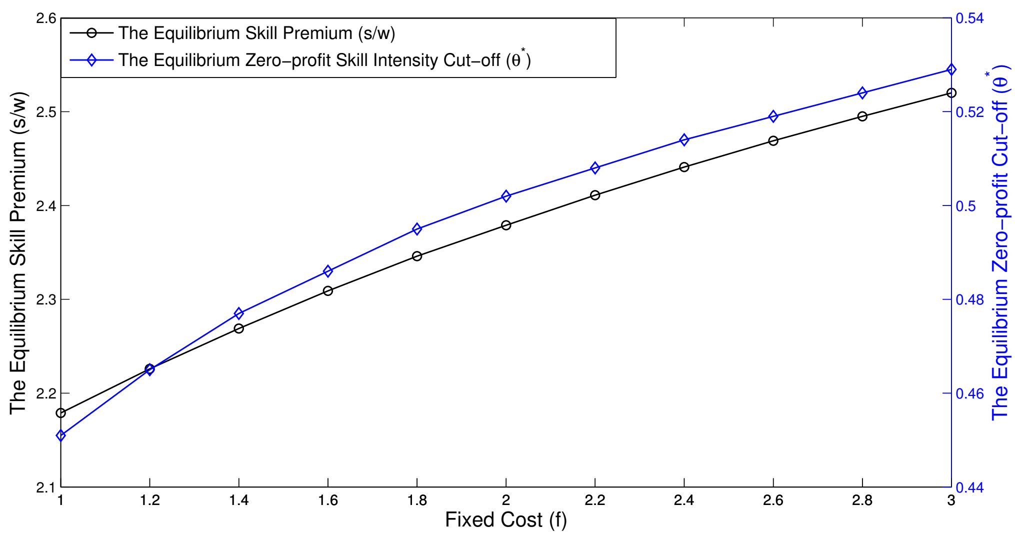


Figure 2.2: Zero-profit Skill Intensity and Skill Premium in Response to Different Fixed Costs

Second, *ceteris paribus*, the increase in the relative endowment of skilled labor, H/L, leads to a decline in the skill premium, while it increases the threshold of skill intensity.[21] Intuitively, the increase

[21] See also Figure B.1 in Appendix A.1, which illustrates that the intersection of the two curves (these curves are based on the free entry condition and the labor market clearing condition) determines equilibrium θ^* and s/w as shown in Table 2.1. As illustrated

in H/L reduces the skill premium as a result of the less competitive labor market for skilled workers. The increase in the relative wage of unskilled workers forces less efficient firms (unskilled-labor intensive firms) out of the market, which raises the zero-profit skill intensity, θ^*.[22] Theoretically, the relatively skill-abundant countries enjoy the relatively low wage inequality between skill groups, whereas firms in these countries face tougher competition than ones in the relatively skill-scare countries. The evolution of both the skill premium and the skill intensity cut-off in response to the relative endowment of skilled labor is also illustrated graphically in Figure 2.3, for which the fixed costs of production are $f = 2$.

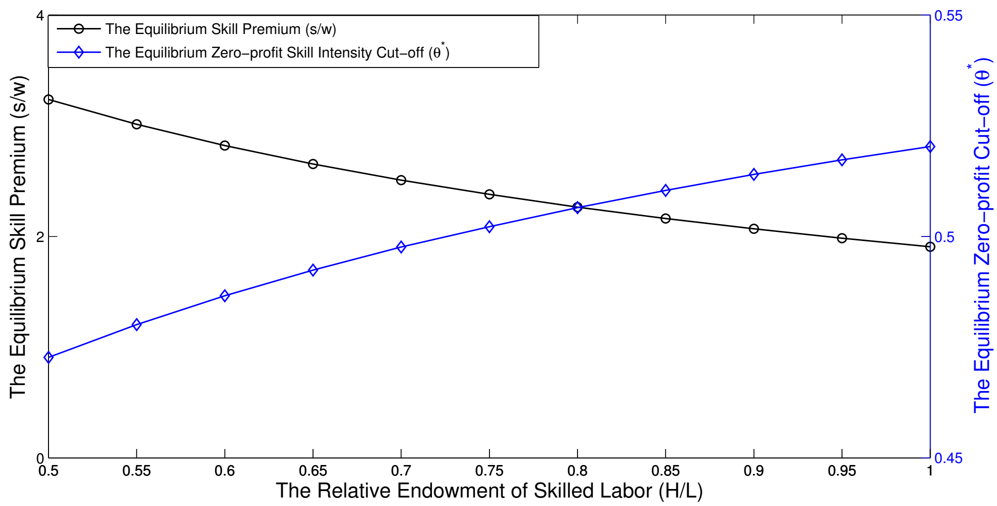


Figure 2.3: Zero-profit Skill Intensity and Skill Premium in Response to Different H/Ls

2.2.3 An Open Economy between Symmetric Countries

In this section, I consider an open economy model by introducing the fixed and variable costs of trade as in Bernard et al. (2007), Harrigan and Reshef (2011), and Melitz (2003). As in Melitz (2003), I assume that both countries are symmetric by assigning the same factor endowments H and L between countries. The symmetry assumption ensures that all countries have the same pattern of trade, the same return for both

in Figure B.1, the increase in the fixed production cost f, all else being equal, shifts the free entry curve to the right, so that both s/w and θ^* rise. On the other hand, all else being equal, the increase in the relative endowment of skilled labor, H/L, shifts the labor market clearing condition to the right, so s/w falls while θ^* rises.

[22] Although the increase in θ^* raises the skill premium, s/w, this positive effect is relatively small enough to be dominated by the negative effect of H/L on the skill premium, so that the increase in the relative endowment of skilled labor leads to a decline in the skill premium.

skilled and unskilled worker, and hence the same aggregate variables (the total revenue, the equilibrium mass of firms, and the industry price index). In the following discussion, without any loss of generality, I only consider that the world economy consists of two identical countries. In a later section, I extend the model to consider a costly trade between countries that differ in their relative factor endowment, H/L, by relaxing this symmetry assumption.

A firm must bear a fixed export cost $f_x\overline{w}$, measured by units of both skilled and unskilled labor, to sell its variety abroad. In addition, the firm faces iceberg-type variable trade costs, that is, $\tau > 1$ units of variety must be shipped for one unit to arrive in a foreign market. Given these types of trade costs, the only firms that are profitable enough can choose to export when they are in equilibrium. I analyze how trade liberalization (a reduction in trade costs) affects the skill intensity cut-off for domestic production, exporting, and the skill premium.

2.2.3.1 Firm Competition

With monopolistic competition, the export price of firms with θ is a constant mark-up over the marginal costs, which now includes the iceberg-type variable trade costs τ:

$$p_x(\theta) = \tau p_d(\theta) = \tau \left(\frac{\sigma}{\sigma-1}\right)\left(\frac{\phi}{\phi-1}\right) s^{\theta} w^{1-\theta}, \tag{2.22}$$

where p_x and p_d denote the export cost of insurance and freight (c.i.f.) and the domestic price, respectively. Hereafter, I use subscript d to indicate the domestic-related variable and x to indicate the export-related variable. Since the aggregate variables (for example, the total expenditure E and the aggregate price index $\tilde{P}$) between two identical countries are the same, the total revenue of firms with θ is

$$R(\theta) = \begin{cases} R_d(\theta) & \text{if it serves only the domestic} \\ \left(1+\tau^{1-\sigma}\right) R_d(\theta) & \text{if it exports,} \end{cases} \tag{2.23}$$

where the domestic revenue $R_d(\theta)$ is given in equation (2.8). Note that the export revenue, denoted by $R_x(\theta)$, is: $R_x(\theta) = \tau^{1-\sigma} R_d(\theta)$. The presence of fixed costs for both domestic production and exporting implies that the profit of firms with θ from domestic sales, $\pi_d(\theta)$, and foreign sales, $\pi_x(\theta)$, are

$$\begin{aligned}\pi_d(\theta) &= \frac{R_d(\theta)}{\sigma} - f\overline{w},\\ \pi_x(\theta) &= \frac{R_x(\theta)}{\sigma} - f_x\overline{w},\end{aligned} \tag{2.24}$$

where f and f_x denote the fixed costs for domestic production and exporting, respectively.

There are now two skill intensity cut-offs: i) the skill intensity cut-off for domestic sales (that is, the marginal skill intensity of surviving firms), θ_d^*, below which firms are forced to exit the market, and ii) the export skill intensity cut-off, θ_x^*, above which firms are profitable enough to send their products to foreign markets. These two skill intensity cut-offs and equation (2.24) give the zero-profit conditions for both domestic production and exporting: $R_x(\theta_x^*) = \sigma f_x \overline{w}$ and $R_d(\theta_d^*) = \sigma f \overline{w}$. Using two zero-profit conditions and equation (2.8), $R_x(\theta) = \tau^{1-\sigma} R_d(\theta)$ implies

$$\begin{aligned}\left(\frac{s}{w}\right)^{-\theta_x^*} (\theta_x^*)^{\frac{\alpha}{\phi}} &= \tau \left(\frac{f_x}{f}\right)^{\frac{1}{\sigma-1}} \left(\frac{s}{w}\right)^{-\theta_d^*} (\theta_d^*)^{\frac{\alpha}{\phi}},\\ \left(\frac{s}{w}\right)^{-(\theta_x^*-\theta_d^*)} \left(\frac{\theta_x^*}{\theta_d^*}\right)^{\frac{\alpha}{\phi}} &= \tau \left(\frac{f_x}{f}\right)^{\frac{1}{\sigma-1}}.\end{aligned} \tag{2.25}$$

Equation (2.25) shows a relationship between two thresholds of skill intensity in equilibrium. Note that $\left(\frac{s}{w}\right)^{-\theta} (\theta)^{\frac{\alpha}{\phi}}$ increases with θ.[23] For values of $\tau \left(\frac{f_x}{f}\right)^{\frac{1}{\sigma-1}} > 1$, therefore, the skill intensity cut-off for exporting is greater than the zero-profit skill intensity cut-off, that is $\theta_x^* > \theta_d^*$. This implies that some domestic firms are not efficient enough to serve the export market, so firms below θ_x^* but above θ_d^* will produce only for the domestic market. As suggested in a number of empirical findings, which show that firms with the relatively high skill intensity are more likely to be exporters, I assume that the condition, $\tau \left(\frac{f_x}{f}\right)^{\frac{1}{\sigma-1}} > 1$, holds, so I focus on the case that $\theta_x^* > \theta_d^*$.

2.2.3.2 Firm Entry, Exit, and the Free Entry Condition

The free entry condition implies that the expected value of entry is equal to the sunk entry cost. The expected value of entry consists of two components: the expected profit from domestic and foreign sales.

[23] Under the assumption of $\alpha > \phi ln(\frac{s}{w})$, which ensures that firms with a higher skill intensity produce a higher-quality product and become more profitable, it is easy to show that $\left(\frac{s}{w}\right)^{-\theta} (\theta)^{\alpha/\phi}$ increases with θ.

Thus, the free entry condition is[24]

$$\frac{1-G(\theta_d^*)}{\delta}\overline{\pi}_d+\frac{1-G(\theta_x^*)}{\delta}\overline{\pi}_x=f_e\overline{w}, \tag{2.26}$$

where the average profitability is equal to the profit of a firm with the weighted average skill intensity (that is, $\overline{\pi}_d=\pi_d(\tilde{\theta}_d)$ and $\overline{\pi}_x=\pi_d(\tilde{\theta}_x)$). The weighted-average skill intensity in each market is

$$\begin{aligned}\tilde{\theta}_d(\theta_d^*)&=\left[\frac{1}{1-G(\theta_d^*)}\int_{\theta_d^*}^{1}\theta^{\sigma-1}g(\theta)d\theta\right]^{\frac{1}{\sigma-1}},\\ \tilde{\theta}_x(\theta_x^*)&=\left[\frac{1}{1-G(\theta_x^*)}\int_{\theta_x^*}^{1}\theta^{\sigma-1}g(\theta)d\theta\right]^{\frac{1}{\sigma-1}}.\end{aligned} \tag{2.27}$$

Using the fact that $\overline{\pi}_d=\frac{R_d(\tilde{\theta}_d)}{\sigma}-f\overline{w}$, $\overline{\pi}_x=\frac{R_x(\tilde{\theta}_x)}{\sigma}-f_x\overline{w}$, $R_d(\theta_d^*)=\sigma f\overline{w}$, $R_x(\theta_x^*)=\sigma f_x\overline{w}$, and equation (2.8), we can rewrite the free entry condition (equation (2.26)) as a function of the skill premium, the two skill intensity cut-offs, and the two weighted-average skill intensities:

$$\begin{aligned}(1-G(\theta_d^*))f\left[\left(\frac{s}{w}\right)^{(\tilde{\theta}_d-\theta_d^*)(1-\sigma)}\left(\frac{\tilde{\theta}_d}{\theta_d^*}\right)^{\frac{\alpha(\sigma-1)}{\phi}}-1\right]+&\\ (1-G(\theta_x^*))f_x\left[\left(\frac{s}{w}\right)^{(\tilde{\theta}_x-\theta_x^*)(1-\sigma)}\left(\frac{\tilde{\theta}_x}{\theta_x^*}\right)^{\frac{\alpha(\sigma-1)}{\phi}}-1\right]&=\delta f_e,\end{aligned} \tag{2.28}$$

where the weighted average skill intensity for domestic and exporting firms, $\tilde{\theta}_d$ and $\tilde{\theta}_x$, is given in equation (2.27).

2.2.3.3 Labor Market Equilibrium

The labor market equilibrium in an open economy will be similar to one in the autarky case. From the quantity demanded, the price level for each domestic and foreign market, and the optimal quality schedule, I give the total output of a firm with θ for domestic and foreign sales as follows:

$$x_d(\theta)=\gamma w^{-\sigma}\left(\frac{s}{w}\right)^{-\theta\sigma}\theta^{\frac{\alpha(\sigma-1)}{\phi}}\tilde{P}^{\sigma-1}E, \tag{2.29}$$

$$x_x(\theta)=\tau^{-\sigma}x_d(\theta), \tag{2.30}$$

[24] The expected value of entry for the domestic market (exporting) can be obtained by multiplying the *ex ante* probability of successful entry (exporting) by the expected domestic (exporting) profitability, and discounted by the exogenous probability of failure; that is, $\frac{1-G(\theta_d^*)}{\delta}\overline{\pi}_d$ and $\frac{1-G(\theta_x^*)}{\delta}\overline{\pi}_x$.

where $\gamma = \left(\frac{\sigma}{\sigma-1}\right)^{-\sigma}\left(\frac{\phi}{\phi-1}\right)^{-\sigma}\left(\frac{1}{\phi-1}\right)^{(\sigma-1)/\phi}$ is a positive constant. Using the unit labor demand for skilled and unskilled labor: $d_h\left(\theta, \frac{s}{w}\right) = \left(\frac{\phi}{\phi-1}\right)\theta\left(\frac{s}{w}\right)^{\theta-1}$ and $d_l\left(\theta, \frac{s}{w}\right) = \left(\frac{\phi}{\phi-1}\right)(1-\theta)\left(\frac{s}{w}\right)^{\theta}$, I obtain the total skilled and unskilled labor demand of firms with θ that only serves the domestic market:

$$\begin{aligned} D_{d,h}(\theta, \frac{s}{w}) &= \eta w^{-\sigma}\left(\frac{s}{w}\right)^{\theta(1-\sigma)-1}\theta^{\frac{\alpha(\sigma-1)}{\phi}}\theta\tilde{P}^{\sigma-1}E, \\ D_{d,l}(\theta, \frac{s}{w}) &= \eta w^{-\sigma}\left(\frac{s}{w}\right)^{\theta(1-\sigma)}\theta^{\frac{\alpha(\sigma-1)}{\phi}}(1-\theta)\tilde{P}^{\sigma-1}E, \end{aligned} \tag{2.31}$$

where $\eta = \left(\frac{\sigma}{\sigma-1}\right)^{-\sigma}\left(\frac{\phi}{\phi-1}\right)^{1-\sigma}\left(\frac{1}{\phi-1}\right)^{(\sigma-1)/\phi} > 0$ is constant. Following the same line of reasoning as for labor demand for domestic production, the total skilled and unskilled labor demand per firm with θ for export markets is

$$\begin{aligned} D_{x,h}(\theta, \frac{s}{w}) &= \tau^{-\sigma}D_{d,h}(\theta, \frac{s}{w}), \\ D_{x,l}(\theta, \frac{s}{w}) &= \tau^{-\sigma}D_{d,l}(\theta, \frac{s}{w}). \end{aligned} \tag{2.32}$$

Let M denote the equilibrium mass of incumbent firms, as in the previous section, and hence the mass of exporting firms, which is denoted by M_x, is equal to $[1-G(\theta_x^*)]/[1-G(\theta_d^*)]M$.[25] The aggregate labor demand in the variable costs can be obtained by integrating over the total labor demand of the mass of firms with the same θ. This gives the aggregate labor demand for skilled and unskilled labor corresponding to variable costs, which are

$$\begin{aligned} TD_h(\theta_d^*, \theta_x^*, \frac{s}{w}) &= \int_{\theta_d^*}^{1} D_{d,h}(\theta, \frac{s}{w})M\frac{g(\theta)}{1-G(\theta_d^*)}d\theta + \tau^{-\sigma}\int_{\theta_x^*}^{1} D_{d,h}(\theta, \frac{s}{w})M_x\frac{g(\theta)}{1-G(\theta_x^*)}d\theta, \\ TD_l(\theta_d^*, \theta_x^*, \frac{s}{w}) &= \int_{\theta_d^*}^{1} D_{d,l}(\theta, \frac{s}{w})M\frac{g(\theta)}{1-G(\theta_d^*)}d\theta + \tau^{-\sigma}\int_{\theta_x^*}^{1} D_{d,l}(\theta, \frac{s}{w})M_x\frac{g(\theta)}{1-G(\theta_x^*)}d\theta. \end{aligned} \tag{2.33}$$

As shown in the autarky case, the ratio of total skilled to unskilled labor demand in the fixed costs equals the ratio of the skilled to unskilled labor endowment, $FD_h/FD_l = H/L$, where FD_h and FD_l represents the aggregate skilled and unskilled labor demand in fixed costs which are as follows:

$$\begin{aligned} FD_h &= \left(\frac{H}{H+L}\right)M\left(f + \frac{1-G(\theta_x^*)}{1-G(\theta_d^*)}f_x + \frac{\delta}{1-G(\theta_d^*)}f_e\right), \\ FD_l &= \left(\frac{L}{H+L}\right)M\left(f + \frac{1-G(\theta_x^*)}{1-G(\theta_d^*)}f_x + \frac{\delta}{1-G(\theta_d^*)}f_e\right). \end{aligned} \tag{2.34}$$

[25] Given that the *ex ante* probability of the producing firms is $1-G(\theta_d^*)$, $[1-G(\theta_x^*)]/[1-G(\theta_d^*)]$ indicates the *ex ante* probability of being an exporter, conditional on successful entry.

Since $FD_h/FD_l = H/L$, the ratio of aggregate skilled to unskilled labor demand in the variable costs also equals the relative skilled-labor abundance, H/L. Equation (2.31), (2.33), and $M_x = [1-G(\theta_x^*)]/[1-G(\theta_d^*)]M$ gives the relative labor-market clearing condition,

$$\frac{\left(\frac{w}{s}\right)\left[\int_{\theta_d^*}^{1}\left(\frac{s}{w}\right)^{\theta(1-\sigma)}\theta^{\frac{\alpha(\sigma-1)}{\phi}}\theta g(\theta)d\theta+\tau^{-\sigma}\int_{\theta_x^*}^{1}\left(\frac{s}{w}\right)^{\theta(1-\sigma)}\theta^{\frac{\alpha(\sigma-1)}{\phi}}\theta g(\theta)d\theta\right]}{\left[\int_{\theta_d^*}^{1}\left(\frac{s}{w}\right)^{\theta(1-\sigma)}\theta^{\frac{\alpha(\sigma-1)}{\phi}}(1-\theta)g(\theta)d\theta+\tau^{-\sigma}\int_{\theta_x^*}^{1}\left(\frac{s}{w}\right)^{\theta(1-\sigma)}\theta^{\frac{\alpha(\sigma-1)}{\phi}}(1-\theta)g(\theta)d\theta\right]}=\frac{H}{L}. \tag{2.35}$$

2.2.3.4 Costly Trade Equilibrium under the Symmetric Assumption

To close this section, I determine the condition for costly trade equilibrium. Two equilibrium skill intensity cut-offs, θ_d^* and θ_x^*, and the skill premium s/w are derived jointly from equations (2.25), (2.27), (2.28), and (2.35).[26] All other aggregate variables in equilibrium can be expressed by s/w and θ_d^*, and θ_x^* by choosing a wage of the unskilled labor equals to one, $w = 1$, as a numeraire. In what follows, I determine the aggregate equilibrium variables: the total revenue E, the mass of the incumbent firms M, and the industry price index $\tilde{P}$.

As shown in autarky, the aggregate revenue E in equilibrium must equal the total payment for the production of resources (skilled and unskilled labor), that is, $E = wL + sH$. Since the total revenue in this economy must be equal to the revenue of the average firm multiplied by the mass of successful firms, that is, $E = M\bar{r}$, the mass of the producing incumbent firms is

$$M = \frac{E}{\bar{r}} = \frac{H+L}{\sigma[f + \frac{1-G(\theta_x^*)}{1-G(\theta_d^*)}f_x + \frac{\delta}{1-G(\theta_d^*)}f_e]}. \tag{2.36}$$

To derive the average revenue $\bar{r}$, I use the free entry condition, that is, the expected value of free entry equals the sunk fixed entry costs: $\frac{1-G(\theta_d^*)}{\delta}\left[\frac{\bar{r}}{\sigma} - \overline{w}\left[f + \frac{1-G(\theta_x^*)}{1-G(\theta_d^*)}f_x\right]\right] = f_e\overline{w}$. Here I also use the equation, $\overline{w} = \left(\frac{H}{H+L}\right)s + \left(\frac{L}{H+L}\right)w$ to obtain equation (2.36).

Lastly, the aggregate price index can be expressed as the weighted average price index of each do-

[26] We have 5 equations and 5 unknown variables, $\frac{s}{w}$, θ_d^*, θ_x^*, $\tilde{\theta}_d$, and $\tilde{\theta}_x$.

mestic and exporting firm, which is as follows:

$$\begin{aligned}\tilde{P} &= \left[M\int_{\theta_d^*}^{1}\left(\frac{p(\theta)}{q(\theta)}\right)^{1-\sigma}\frac{g(\theta)}{1-G(\theta_d^*)}d\theta + M_x\tau^{1-\sigma}\int_{\theta_x^*}^{1}\left(\frac{p(\theta)}{q(\theta)}\right)^{1-\sigma}\frac{g(\theta)}{1-G(\theta_x^*)}d\theta\right]^{\frac{1}{1-\sigma}} \\ &= \left[M\left(\frac{p(\tilde{\theta}_d)}{q(\tilde{\theta}_d)}\right)^{1-\sigma} + M_x\tau^{1-\sigma}\left(\frac{p(\tilde{\theta}_x)}{q(\tilde{\theta}_x)}\right)^{1-\sigma}\right]^{\frac{1}{1-\sigma}} \\ &= \left[M\lambda w^{1-\sigma}\left(\frac{s}{w}\right)^{\tilde{\theta}_d(1-\sigma)}\tilde{\theta}_d^{\frac{\alpha(\sigma-1)}{\phi}} + \frac{1-G(\theta_x^*)}{1-G(\theta_d^*)}M\tau^{1-\sigma}\lambda w^{1-\sigma}\left(\frac{s}{w}\right)^{\tilde{\theta}_x(1-\sigma)}\tilde{\theta}_x^{\frac{\alpha(\sigma-1)}{\phi}}\right]^{\frac{1}{1-\sigma}},\end{aligned} \tag{2.37}$$

where $\lambda = \left[\left(\frac{\sigma}{\sigma-1}\right)\left(\frac{\phi}{\phi-1}\right)\left(\frac{1}{\phi-1}\right)^{-1/\phi}\right]^{1-\sigma}$ is a positive constant. The weighted average skill intensity for each market, $\tilde{\theta}_d$ and $\tilde{\theta}_x$ are given in equation (2.27).

Proposition 2.2.2. *There exists a unique costly trade equilibrium in which the zero-profit skill intensity cut-off, θ_d^*, the skill intensity cut-off for exporting, θ_x^*, and the skill premium, $\frac{s}{w}$, are determined.*

Proof. See Appendix A.2. ■

Proposition 2.2.3. *As trade costs, τ and/or f_x, fall, the skill premium, $\frac{s}{w}$, increases.*

Proof. See Appendix A.3. ■

Whether the skill intensity cut-off for domestic production and exporting increases or decreases in response to a reduction in trade costs is illustrated in Figure 2.4. As the trade costs fall, the zero-profit skill intensity cut-off, θ_d^*, increases (the least efficient firms are forced to exit in the face of increased import competition), while the skill intensity cut-off for exporting, θ_x^*, decreases (more firms tend to be exporters as a result of the reduced trade costs). Furthermore, these two skill intensity cut-offs converge as the variable cost of trade approaches one $\tau = 1$. That is, $\theta_d^* = \theta_x^*$ once any barriers to trade disappear (i.e., $\theta_d^* = \theta_x^*$ when $\tau = 1$ and $f = f_x$).[27] As also shown in Figure 2.4, the zero-profit skill intensity cut-off for autarky, denoted by θ_A^*, is lower than the zero-profit skill intensity cut-off for free trade, θ_F^*. Since free trade induces an increase in import competition, fewer firms will survive under free trade compared to under a condition of autarky.

[27] When $\tau\left(\frac{f_x}{f}\right)^{1/(\sigma-1)}$ equals one (e.g., $\tau = 1$ and $f = f_x$), the two skill intensity thresholds must be equal, that is $\theta_d^* = \theta_x^*$. See Equation (2.25) for this relationship between the two skill intensity cut-offs.

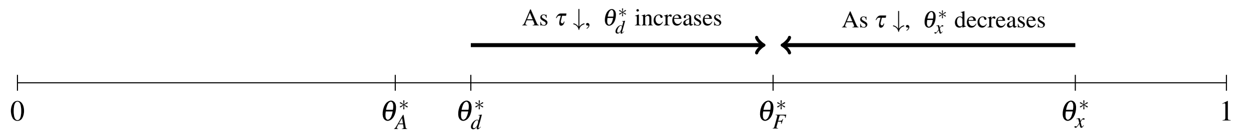


Figure 2.4: Autarky, Zero Profit and Exporting Skill Intensity Cut-offs, and Free Trade Cut-off

2.2.3.5 A Numerical Exercise of Costly Trade Under the Symmetric Assumption

The basic set-up for the parameters is the same as in the previous section for autarky. In addition, the fixed export costs, f_x, and the variable trade costs τ are used to find the zero-profit skill intensity cut-off, θ_d^*, the skill intensity cut-off for exporting, θ_x^*, and the skill premium, s/w, in equilibrium. I set $f_x = 2$, which is the same as the fixed costs for domestic production f. I first exploit $\phi = 1.1$ and $\alpha = 1.5$, and then I use different values of ϕ and α (e.g., $\phi = 1.5$ and $\alpha = 2$) to show how different sets of ϕ and α will affect the skill premium s/w and the two skill intensity cut-offs, θ_d^* and θ_x^*.

Figure 2.5 plots the skill premium, the two skill intensity cut-offs, and the weighted average skill intensities for both surviving and exporting firms against the variable costs of trade τ. For these plots, I use different sets of ϕ and α: I set $\phi = 1.1$ and $\alpha = 1.5$ for Panels A and B, and $\phi = 1.5$ and $\alpha = 2$ for Panels C and D.

Panels A and C in Figure 2.5 show that the relative wage of skilled labor decreases with a increase in the variable trade costs τ, that is, there is an increase in wage inequality as a result of a reduction in the variable costs of trade. When τ is large enough, no firms can export, therefore the skill premium, s/w will be the same as the one under the condition of autarky equilibrium. As the variable trade costs fall, the relative wage of skilled labor rises because of the reallocation of workers towards relatively high skill intensive firms. To be more specific, the inter-firm reallocation of resources has an effect on the skill premium through three different channels. First, a fall in the trade costs makes exporting easier, and allows existing exporters to increase their labor demand so as to increase production and make additional sales in export markets. This is accompanied by an increase in the relative demand for skilled workers because they are, on average, relatively more skill intensive. As shown in Panels B and D of Figure 2.5, the weighted average skill intensity of exporting firms is higher than that of one of the surviving firms. Second, the relatively unskilled-labor intensive non-exporters are forced to exit the market in the face of the increased import competition from successful foreign firms that export to the unsuccessful firms' domestic market. Under the condition of the perfectly competitive labor market, their labor force would be reallocated towards more efficient, relatively high skill intensive firms, so that the relative demand for skilled workers increases, and hence the wage inequality also increases. These two effects unambiguously increase the between-group wage inequality.

In contrast to the first two effects, the relative skill intensity of firms, that become new exporters as a result of lowering barriers to trade, is ambiguous. As a matter of fact, if the cost of trade are initially low, then the relative skill intensity of these new exporters would be higher than average, so that the skill premium would increase as a result of a fall in trade costs. On the other hand, if the initial level of trade barriers were high, the average skill intensity of firms newly entering the export market would be lower than that of surviving firms, which would result in a reduction in wage inequality. Panel B and D in Figure 2.5 illustrate the third effect, which depends on the initial level of trade openness. If the initial level of variable trade costs is higher than 1.15 (i.e., $\tau > 1.15$), the third effect also leads to an increase in the skill premium; otherwise, the skill premium decreases as the trade costs fall. However, the latter effect, which might decrease the skill premium, would not be big enough to overturn the first two effects, so that the skill premium unambiguously increases as the variable costs of trade fall. The overall effect of a reduction in the variable costs of trade on the skill premium is shown in Panels *A* and *C* of Figure 2.5.

As illustrated in Panels *B* and *D* of Figure 2.5, as τ falls, θ_x^* declines, while θ_d^* increases. A reduction in trade costs allows firms to export relatively easily, so that the skill intensity cut-off for exporting decreases. On the other hand, the relatively inefficient firms are forced out of the market in the face of the increased import competition that results from the reduced trading costs, so the zero-profit skill intensity cut-off θ_d^* increases. As noted in Figure 2.4, these two skill intensity cutoffs, θ_d^* and θ_x^*, converge to the same level, above which all producing firms will be exporters when $\tau = 1$ and $f = f_x$ (free trade).

As mentioned earlier, the increasing trend of the relative wage of skilled to unskilled workers following the reduction of trade costs is not affected by the values of ϕ and α as long as the following condition, $\alpha > \phi ln\left(\frac{s}{w}\right)$, holds. As illustrated in Panels *A* and *C* of Figure 2.5, different sets of ϕ and α only lead to different scales of skill premium. To be more specific, the skill premium rises from 2.37 to 2.64 in response to the reduction of the variable trade costs τ from 1.4 to 1, when $\phi = 1.1$ and $\alpha = 1.5$; whereas the skill premium, s/w, increases by about 12% from 2.43 to 2.72, when the economy moves from autarky (that is, when $\tau > 1.45$) to free trade ($\tau = 1$), in the case of $\phi = 2$ and $\alpha = 1.5$. In the same fashion, the patterns of two skill intensity cut-offs are also not affected by different sets of ϕ and α: the zero-profit skill intensity cut-off increases, while its cut-off for exporting decreases as trade costs fall, which are shown in Panels *B* and *D* of Figure 2.5.

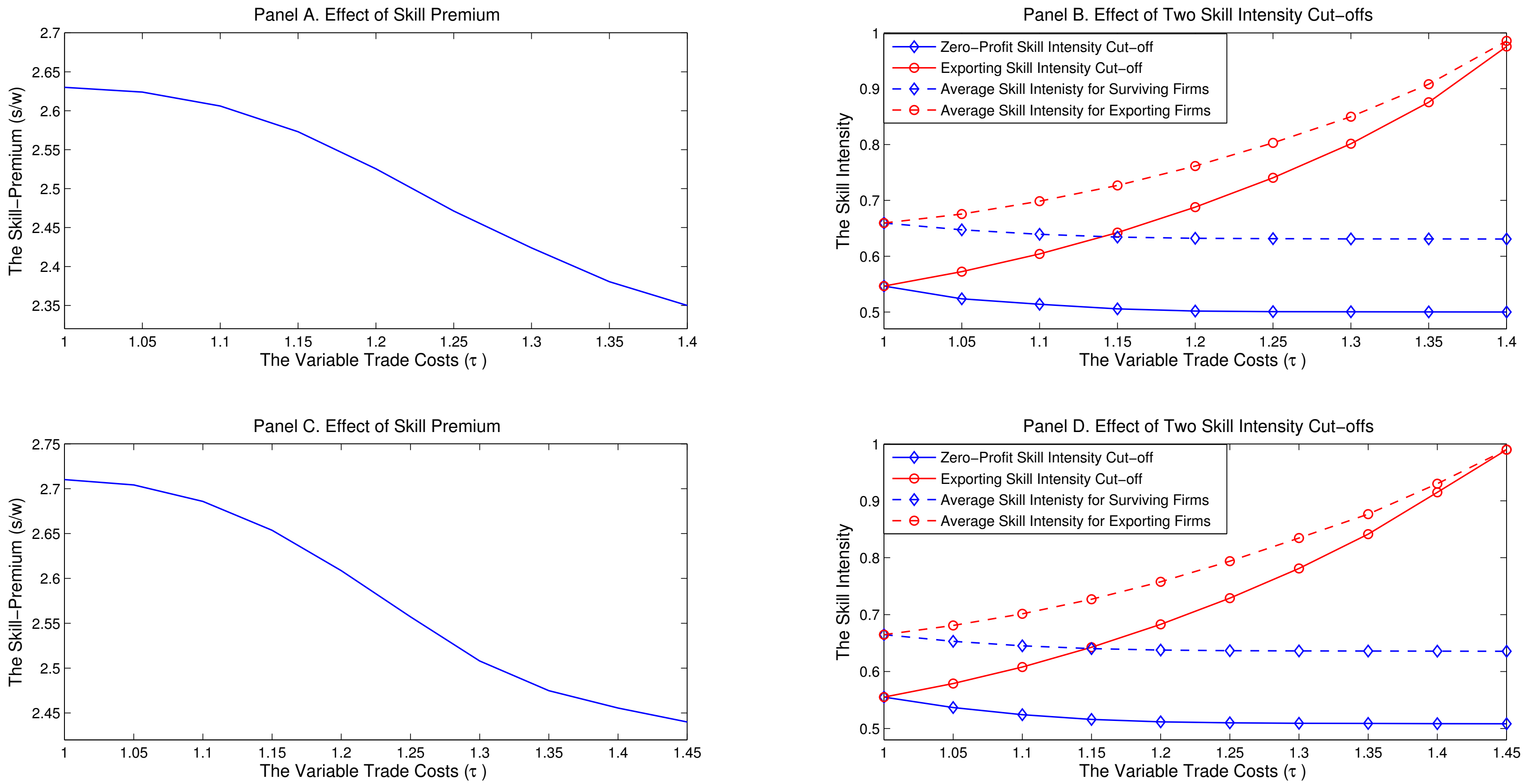


Figure 2.5: The Evolution of the Skill Premium and Two Skill Intensity Cut-offs corresponding to the Variable Trade Costs

Note: Panels *A* and *B* of this figure plot the skill premium, the two skill intensity cut-offs, and the weighted average skill intensity for domestic production and exporting against the variable trade costs, τ, when $\phi = 1.1$ and $\alpha = 1.5$. Panels *C* and *D* plot s/w, θ_d^*, θ_x^*, $\tilde{\theta}(\theta_d^*)$, and $\tilde{\theta}(\theta_x^*)$ against the variable trade costs in the case of $\phi = 1.5$ and $\alpha = 2$. For remaining parameters, I set $(H,L) = (1500,2000)$, $\sigma = 3.8$, $\delta = 0.025$, $f_e = 20$, and $f = f_x = 2$.

Since an arbitrary set of parameters for ϕ and α is used to show the pattern of variables (s/w, θ_d^* and θ_x^*) in response to the reduction of trade costs, it remains unclear how the skill premium and the two skill intensity cut-offs are affected by each parameter, ϕ and α. As a result, I numerically examine the partial effects of ϕ and α on the skill premium and the zero-profit skill intensity cut-off. Table 2.2 presents that, all else being equal, the increase in the quality elasticity of the marginal costs ϕ reduces the zero-profit skill intensity cut-off, θ_d^*, and leads to a decrease in the skill premium. Note that $\phi > 1$. The intuition behind this result stems from the fact that the higher level of ϕ makes high skill intensive firms, that produce high-quality varieties, relatively less efficient compared to low skill intensive firms, and this allows relatively low skill intensive firms to enter the market. Therefore, the zero-profit skill intensity cut-off decreases, resulting in the decline in the skill premium.

Table 2.2: Partial Effects of ϕ and α on the skill premium and skill intensity cut-offs

<table>
<tr><td rowspan="3"></td><td colspan="6">$\alpha = 2$</td></tr>
<tr><td colspan="2">$\phi = 1.1$</td><td colspan="2">$\phi = 1.2$</td><td colspan="2">$\phi = 1.5$</td></tr>
<tr><td>*Free Trade* ($\tau = 1$)</td><td>*Autarky* ($\tau > 1.65$)</td><td>*Free Trade* ($\tau = 1$)</td><td>*Autarky* ($\tau > 1.60$)</td><td>*Free Trade* ($\tau = 1$)</td><td>*Autarky* ($\tau > 1.50$)</td></tr>
<tr><td>s/w</td><td>3.15</td><td>2.83</td><td>3.01</td><td>2.71</td><td>2.72</td><td>2.44</td></tr>
<tr><td>θ_d^*</td><td>0.59</td><td>0.55</td><td>0.58</td><td>0.53</td><td>0.55</td><td>0.51</td></tr>
<tr><td>θ_x^*</td><td>0.59</td><td>1</td><td>0.58</td><td>1</td><td>0.55</td><td>1</td></tr>
<tr><td rowspan="3"></td><td colspan="6">$\phi = 1.1$</td></tr>
<tr><td colspan="2">$\alpha = 1.5$</td><td colspan="2">$\alpha = 1.7$</td><td colspan="2">$\alpha = 2$</td></tr>
<tr><td>*Free Trade* ($\tau = 1$)</td><td>*Autarky* ($\tau > 1.40$)</td><td>*Free Trade* ($\tau = 1$)</td><td>*Autarky* ($\tau > 1.45$)</td><td>*Free Trade* ($\tau = 1$)</td><td>*Autarky* ($\tau > 1.65$)</td></tr>
<tr><td>s/w</td><td>2.63</td><td>2.37</td><td>2.76</td><td>2.49</td><td>3.15</td><td>2.83</td></tr>
<tr><td>θ_d^*</td><td>0.54</td><td>0.50</td><td>0.56</td><td>0.51</td><td>0.59</td><td>0.55</td></tr>
<tr><td>θ_x^*</td><td>0.54</td><td>1</td><td>0.56</td><td>1</td><td>0.59</td><td>1</td></tr>
</table>

Note: For the remaining parameters, I set $(H,L) = (1500,2000)$, $\sigma = 3.8$, $\delta = 0.025$, $f_e = 20$, and $f = f_x = 2$.

All else being equal, on the other hand, the zero-profit skill intensity cut-off increases with α. Thus, the skill premium also increases with α. Note that α measures the degree of skilled workers' efficiency on quality-related tasks. With a higher α, skilled workers become more efficient relative to unskilled workers, so that less competitive firms, which use unskilled-labor more intensively, are driven out of the market. As a result, the increase in α raises the skill premium as well as the marginal skill intensity for surviving firms, which are shown in Table 2.2.

Instead of reducing the variable trade costs, I examine how the fixed export costs affect the skill intensity cut-offs, and hence wage inequality. Figure 2.6 plots the skill premium, the two skill intensity cut-offs, and the two weighted-average skill intensities for domestic production and exporting firms against the level of the fixed trade costs f_x, while maintaining the same level of variable trade costs τ.[28] As illustrated in Figure 2.6, the export skill intensity cut-off θ_x^* declines as the fixed trade costs fall, while the zero-profit skill intensity cut-off θ_d^* increases as the fixed costs of trade decreases.

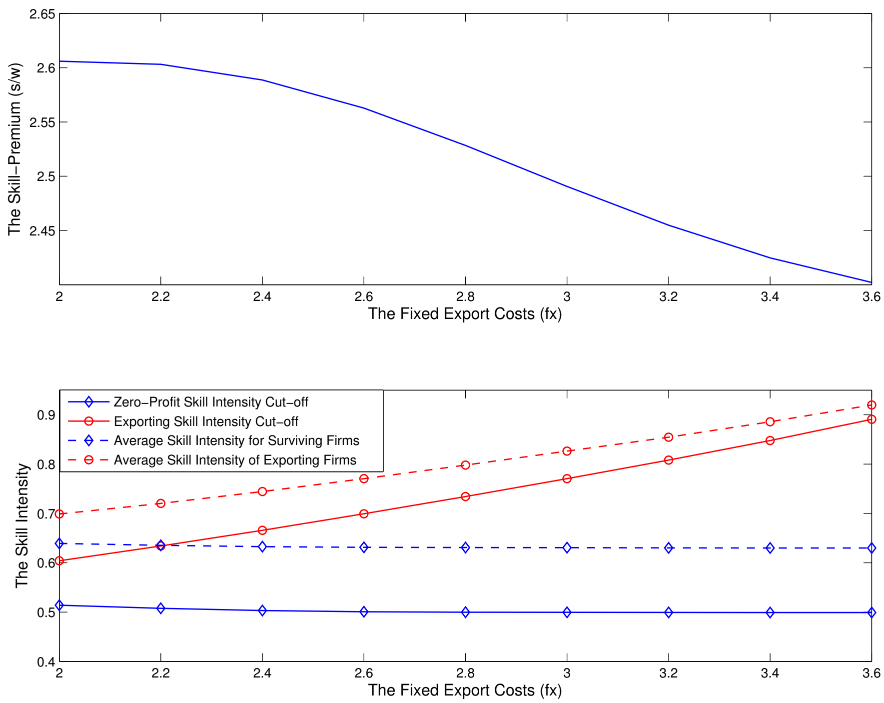


Figure 2.6: The Relationship Between the Skill Premium and the Fixed Costs of Trade

With regard to the skill premium, I show a similar trend when I reduce the fixed exporting costs, f_x, instead of lowering the variable trade costs, τ, which is also shown in Figure 2.6. As with the effect of the variable trade costs, the decline in the fixed costs for exporting ambiguously raises the skill premium. The intuition behind of this result is in line with the case of lowering the variable costs of trade. As outlined earlier, as the fixed export costs fall, the existing exporters increase their labor demand, while the relatively

[28] For Figure 2.6, I set $H = 1500, L = 2000$, $f_e = 20$, $f = 2$, $\tau = 1.1$, $\phi = 1.1$, and $\alpha = 1.5$.

inefficient non-exporters are driven out of the markets. These two mechanisms lead to the reallocation of production resources towards firms that have relatively higher than average skill intensity, so that the wage inequality between groups increases. In contrast, the average skill intensity of firms that become new exporters may be lower than the average skill intensity of surviving firms when the initial level of fixed costs are relatively low (that is, when $f_x < 2.2$ as shown in Figure 2.6); as a result, this drives the skill premium down. Nevertheless, the latter effect, that forces the skill premium to fall, cannot overturn the former effects, so that the between-group wage inequality unambiguously increases.

2.2.4 An Open Economy between Asymmetric Countries

Lastly, I extend the model to consider a situation of costly trade between asymmetric countries that differ in their relative factor endowment, H/L. As in the previous section, the world economy consists of two countries: country A and B. The only difference between these countries is their comparative endowments of skilled and unskilled labor: H_A, L_A, H_B and L_B.

2.2.4.1 Firm Competition

Given firms' pricing rules, the optimal quality and quantity of good produced, the equilibrium revenue of firms with θ in the domestic market is

$$R_d^i(\theta) = \lambda w_i^{1-\sigma} \left(\frac{s_i}{w_i}\right)^{\theta(1-\sigma)} \theta^{\frac{\alpha(\sigma-1)}{\phi}} \tilde{P}_i^{\sigma-1} E_i \quad \text{for } i \in \{A,B\}, \tag{2.38}$$

where $\lambda = \left[\left(\frac{\sigma}{\sigma-1}\right)\left(\frac{\phi}{\phi-1}\right)\left(\frac{1}{\phi-1}\right)^{-1/\phi}\right]^{1-\sigma} > 0$ is constant. $R_d^i(\theta)$ denotes the domestic revenue of firms with θ in country i. The export revenues of firms with θ in country A and B are

$$\begin{aligned} R_x^A(\theta) &= \lambda \tau^{1-\sigma} w_A^{1-\sigma} \left(\frac{s_A}{w_A}\right)^{\theta(1-\sigma)} \theta^{\frac{\alpha(\sigma-1)}{\phi}} \tilde{P}_B^{\sigma-1} E_B, \\ R_x^B(\theta) &= \lambda \tau^{1-\sigma} w_B^{1-\sigma} \left(\frac{s_B}{w_B}\right)^{\theta(1-\sigma)} \theta^{\frac{\alpha(\sigma-1)}{\phi}} \tilde{P}_A^{\sigma-1} E_A. \end{aligned} \tag{2.39}$$

Note that, in equilibrium, the export revenue is proportional to the domestic revenue. The relationship between these two revenues can be obtained from equations (2.38) and (2.39), which is

$$\begin{aligned} R_x^A(\theta) &= \tau^{1-\sigma}\left(\frac{\tilde{P}_B}{\tilde{P}_A}\right)^{\sigma-1}\left(\frac{E_B}{E_A}\right) R_d^A(\theta), \\ R_x^B(\theta) &= \tau^{1-\sigma}\left(\frac{\tilde{P}_A}{\tilde{P}_B}\right)^{\sigma-1}\left(\frac{E_A}{E_B}\right) R_d^B(\theta). \end{aligned} \tag{2.40}$$

The export revenue of firms in home country A, relative to the domestic revenue, decreases with variable trade costs τ and the relative market size of the home country, $\frac{E_A}{E_B}$, while it increases with the relative price level in the foreign market $\frac{\tilde{P}_B}{\tilde{P}_A}$.

In the presence of fixed costs for both domestic production (f) and for exporting (f_x), a firm's profit from domestic sales, denoted by $\pi_d(\theta)$, and foreign sales $\pi_x(\theta)$ are

$$\begin{aligned} \pi_d^i(\theta) &= \frac{R_d^i(\theta)}{\sigma} - f\overline{w}_i \quad \text{for } i \in \{A,B\}, \\ \pi_x^i(\theta) &= \frac{R_x^i(\theta)}{\sigma} - f_x\overline{w}_i \quad \text{for } i \in \{A,B\}. \end{aligned} \tag{2.41}$$

Using the zero-profit condition of marginal firms in each market, that is $R_d^i(\theta_d^{i*}) = \sigma f\overline{w}_i$ and $R_x^i(\theta_x^{i*}) = \sigma f_x\overline{w}_i$, equation (2.38), (2.39) and (2.40) give

$$\begin{aligned} \left(\frac{s_A}{w_A}\right)^{-(\theta_x^{A*}-\theta_d^{A*})}\left(\frac{\theta_x^{A*}}{\theta_d^{A*}}\right)^{\frac{\alpha}{\phi}} &= \tau\left(\frac{f_x}{f}\right)^{\frac{1}{\sigma-1}}\left(\frac{\tilde{P}_A}{\tilde{P}_B}\right)\left(\frac{E_A}{E_B}\right)^{\frac{1}{\sigma-1}}, \\ \left(\frac{s_B}{w_B}\right)^{-(\theta_x^{B*}-\theta_d^{B*})}\left(\frac{\theta_x^{B*}}{\theta_d^{B*}}\right)^{\frac{\alpha}{\phi}} &= \tau\left(\frac{f_x}{f}\right)^{\frac{1}{\sigma-1}}\left(\frac{\tilde{P}_B}{\tilde{P}_A}\right)\left(\frac{E_B}{E_A}\right)^{\frac{1}{\sigma-1}}. \end{aligned} \tag{2.42}$$

These two equality conditions in equation (2.42) show a relationship between two skill intensity cut-offs. Applying the same logic in the previous section under the symmetric assumption, the skill intensity cut-off for exporting firms is greater than the zero-profit skill intensity cut-off, that is, $\theta_x^{i*} > \theta_d^{i*}$ where $i \in \{A,B\}$, when the right hand side of equation (2.42) is greater than one. For the remainder of the paper, I assume that this condition holds so that only the most profitable firms tend to be exporters, which is consistent with a substantial amount of empirical evidence.[29]

[29] Theoretically, it is possible that the skill intensity cut-off for the domestic sales is larger than the export skill intensity cut-off, $\theta_d^{i*} > \theta_x^{i*}$, when two countries have different endowments (and hence different $\tilde{P}$ and E) and $\tau\left(\frac{f_x}{f}\right)^{\frac{1}{\sigma-1}} = 1$. This implies that the least efficient firms only serve the export market, while the most profitable firms serve both domestic and foreign markets. This possibility is shown in Table 2.3 in the following numerical exercise.

2.2.4.2 Firm Entry, Exit, and the Free Entry Condition

Since the free entry condition, that is, the expected value of entry equals the sunk fixed entry cost, is basically the same as in the case of symmetric countries, I quickly move through this section by expressing equations that are necessary to determine the equilibrium variables of interest. The free entry condition in each country A and B in equilibrium follows equation (2.28), which is as follows:

$$\begin{aligned} &\left[1-G(\theta_d^{i*})\right] f \left[\left(\frac{s_i}{w_i}\right)^{(\tilde{\theta}_d^i-\theta_d^{i*})(1-\sigma)} \left(\frac{\tilde{\theta}_d^i}{\theta_d^{i*}}\right)^{\frac{\alpha(\sigma-1)}{\phi}} -1\right] + \\ &\left[1-G(\theta_x^{i*})\right] f_x \left[\left(\frac{s_i}{w_i}\right)^{(\tilde{\theta}_x^i-\theta_x^{i*})(1-\sigma)} \left(\frac{\tilde{\theta}_x^i}{\theta_x^{i*}}\right)^{\frac{\alpha(\sigma-1)}{\phi}} -1\right] = \delta f_e \quad \text{for } i \in \{A,B\}, \end{aligned} \tag{2.43}$$

where the weighted average skill intensities for surviving and exporting firms in each country A and B, denoted by $\tilde{\theta}_d^i$ and $\tilde{\theta}_x^i$, are given as

$$\begin{aligned} \tilde{\theta}_d^i(\theta_d^{i*}) &= \left[\frac{1}{1-G(\theta_d^{i*})}\int_{\theta_d^{i*}}^1 \theta^{\sigma-1} g(\theta)d\theta\right]^{1/(\sigma-1)} \quad \text{for } i \in \{A,B\}, \\ \tilde{\theta}_x^i(\theta_x^{i*}) &= \left[\frac{1}{1-G(\theta_x^{i*})}\int_{\theta_x^{i*}}^1 \theta^{\sigma-1} g(\theta)d\theta\right]^{1/(\sigma-1)} \quad \text{for } i \in \{A,B\}. \end{aligned} \tag{2.44}$$

The free entry condition in equation (2.43) seems to be independent of the aggregate variables (that is, the price index and the total expenditure) of a trading counterpart. It should be noted, however, that the skill intensity cut-off for domestic production and exporting, θ_d^{i*} and θ_x^{i*}, in equation (2.43) is a function of the relative market size and the price level of a trading partner under the assumption of asymmetricity, which is indicated in equation (2.42).

2.2.4.3 Labor Market Equilibrium

The labor market equilibrium conditions are similar to those in the previous section for the identical country case. The total skilled and unskilled labor demand of firms with θ corresponding to domestic sales are the same as in equation (2.31) with the appropriate country index $i \in \{A,B\}$ on the wage and the aggregate variables:

$$\begin{aligned} D_{d,h}^i(\theta,w_i,s_i) &= \eta w_i^{-\sigma}\left(\frac{s_i}{w_i}\right)^{\theta(1-\sigma)-1} \theta^{\frac{\alpha(\sigma-1)}{\phi}} \theta \tilde{P}_i^{\sigma-1} E_i \quad \text{for } i \in \{A,B\}, \\ D_{d,l}^i(\theta,w_i,s_i) &= \eta w_i^{-\sigma}\left(\frac{s_i}{w_i}\right)^{\theta(1-\sigma)} \theta^{\frac{\alpha(\sigma-1)}{\phi}} (1-\theta) \tilde{P}_i^{\sigma-1} E_i \quad \text{for } i \in \{A,B\}, \end{aligned} \tag{2.45}$$

where $\eta = \left(\frac{\sigma}{\sigma-1}\right)^{-\sigma}\left(\frac{\phi}{\phi-1}\right)^{1-\sigma}\left(\frac{1}{\phi-1}\right)^{(\sigma-1)/\phi} > 0$ is constant. $D^i_{d,h}(\theta, w_i, s_i)$ denotes the total labor demand for skilled workers by firms with the same θ in country i in response to domestic sales. $D^i_{d,l}(\theta, w_i, s_i)$ represents the total labor demand for unskilled labor of firms with θ in country i corresponding to domestic sales.

The total demand for skilled and unskilled labor of the exporting firms depends on a trading counterpart's relative price index and expenditure as well as on the variable costs of trade. Thus, the total skilled and unskilled labor demand per firm with θ corresponding to export sales are

$$\begin{aligned} D^A_{x,h}(\theta) &= \tau^{-\sigma}\left(\frac{\tilde{P}_B}{\tilde{P}_A}\right)^{\sigma-1}\left(\frac{E_B}{E_A}\right)D^A_{d,h}(\theta),\ D^A_{x,l}(\theta) = \tau^{-\sigma}\left(\frac{\tilde{P}_B}{\tilde{P}_A}\right)^{\sigma-1}\left(\frac{E_B}{E_A}\right)D^A_{d,l}(\theta), \\ D^B_{x,h}(\theta) &= \tau^{-\sigma}\left(\frac{\tilde{P}_A}{\tilde{P}_B}\right)^{\sigma-1}\left(\frac{E_A}{E_B}\right)D^B_{d,h}(\theta),\ D^B_{x,l}(\theta) = \tau^{-\sigma}\left(\frac{\tilde{P}_A}{\tilde{P}_B}\right)^{\sigma-1}\left(\frac{E_A}{E_B}\right)D^B_{d,l}(\theta). \end{aligned} \tag{2.46}$$

$D^i_{x,j}(\theta)$, where $i \in \{A, B\}$ and $j \in \{h, l\}$, denotes the total labor demand for j type of workers of firms with θ in country i in response to foreign sales. Note that the relative labor demand of export to domestic sales relies on the relative difficulty of the foreign market (that is, the relative market size and price level) as well as the variable trade costs.

Following the same procedure described in the symmetric-country case, the aggregate demand for skilled and unskilled workers in each country A and B corresponding to the variable input costs can be expressed by

$$
\begin{aligned}
TD_h^A &= \eta \frac{M^A}{1-G(\theta_d^{A*})} w_A^{-\sigma} \tilde{P}_A^{\sigma-1} E_A \left[\int_{\theta_d^{A*}}^{1} \left(\frac{s_A}{w_A}\right)^{\theta(1-\sigma)-1} \theta^{\frac{\alpha(\sigma-1)}{\phi}} \theta g(\theta) d\theta + \right. \\
&\qquad \left. \tau^{-\sigma} \left(\frac{\tilde{P}_B}{\tilde{P}_A}\right)^{\sigma-1} \left(\frac{E_B}{E_A}\right) \int_{\theta_x^{A*}}^{1} \left(\frac{s_A}{w_A}\right)^{\theta(1-\sigma)-1} \theta^{\frac{\alpha(\sigma-1)}{\phi}} \theta g(\theta) d\theta \right], \\
TD_l^A &= \eta \frac{M^A}{1-G(\theta_d^{A*})} w_A^{-\sigma} \tilde{P}_A^{\sigma-1} E_A \left[\int_{\theta_d^{A*}}^{1} \left(\frac{s_A}{w_A}\right)^{\theta(1-\sigma)} \theta^{\frac{\alpha(\sigma-1)}{\phi}} (1-\theta) g(\theta) d\theta + \right. \\
&\qquad \left. \tau^{-\sigma} \left(\frac{\tilde{P}_B}{\tilde{P}_A}\right)^{\sigma-1} \left(\frac{E_B}{E_A}\right) \int_{\theta_x^{A*}}^{1} \left(\frac{s_A}{w_A}\right)^{\theta(1-\sigma)} \theta^{\frac{\alpha(\sigma-1)}{\phi}} (1-\theta) g(\theta) d\theta \right], \\
TD_h^B &= \eta \frac{M^B}{1-G(\theta_d^{B*})} w_B^{-\sigma} \tilde{P}_B^{\sigma-1} E_B \left[\int_{\theta_d^{B*}}^{1} \left(\frac{s_B}{w_B}\right)^{\theta(1-\sigma)-1} \theta^{\frac{\alpha(\sigma-1)}{\phi}} \theta g(\theta) d\theta + \right. \\
&\qquad \left. \tau^{-\sigma} \left(\frac{\tilde{P}_A}{\tilde{P}_B}\right)^{\sigma-1} \left(\frac{E_A}{E_B}\right) \int_{\theta_x^{B*}}^{1} \left(\frac{s_B}{w_B}\right)^{\theta(1-\sigma)-1} \theta^{\frac{\alpha(\sigma-1)}{\phi}} \theta g(\theta) d\theta \right], \\
TD_l^B &= \eta \frac{M^B}{1-G(\theta_d^{B*})} w_B^{-\sigma} \tilde{P}_B^{\sigma-1} E_B \left[\int_{\theta_d^{B*}}^{1} \left(\frac{s_B}{w_B}\right)^{\theta(1-\sigma)} \theta^{\frac{\alpha(\sigma-1)}{\phi}} (1-\theta) g(\theta) d\theta + \right. \\
&\qquad \left. \tau^{-\sigma} \left(\frac{\tilde{P}_A}{\tilde{P}_B}\right)^{\sigma-1} \left(\frac{E_A}{E_B}\right) \int_{\theta_x^{B*}}^{1} \left(\frac{s_B}{w_B}\right)^{\theta(1-\sigma)} \theta^{\frac{\alpha(\sigma-1)}{\phi}} (1-\theta) g(\theta) d\theta \right].
\end{aligned}
\tag{2.47}
$$

The aggregate skilled and unskilled labor demand in country $i \in \{A,B\}$ corresponding to the sunk fixed costs are

$$
\begin{aligned}
FD_h^i &= \left(\frac{H_i}{H_i+L_i}\right) M^i \left[f + \frac{1-G(\theta_x^{i*})}{1-G(\theta_d^{i*})} f_x + \frac{\delta}{1-G(\theta_d^{i*})} f_e \right] \quad \text{for } i \in \{A,B\}, \\
FD_l^i &= \left(\frac{L_i}{H_i+L_i}\right) M^i \left[f + \frac{1-G(\theta_x^{i*})}{1-G(\theta_d^{i*})} f_x + \frac{\delta}{1-G(\theta_d^{i*})} f_e \right] \quad \text{for } i \in \{A,B\},
\end{aligned}
\tag{2.48}
$$

where M^i denotes the mass of incumbent firms in country i.

In a perfectly competitive labor market, the supply of skilled (unskilled) labor in equilibrium is equal to the sum of skilled (unskilled) labor demand in both the variable and fixed costs. Therefore, I have the following labor market clearing conditions in each country:

$$
\begin{aligned}
H^i &= TD_h^i + FD_h^i \quad \text{for } i \in \{A,B\}, \\
L^i &= TD_l^i + FD_l^i \quad \text{for } i \in \{A,B\}.
\end{aligned}
\tag{2.49}
$$

2.2.4.4 Costly Trade Equilibrium under the Asymmetric Assumption

To close this section, I need to determine the equilibrium aggregate variables in each country: the total revenue E, the mass of successful firms M, and the industry price index $\tilde{P}$. Under the asymmetric assumption between countries, all aggregate variables differ between countries.

The aggregate revenue E in equilibrium must equal the total payment to production resources (skilled and unskilled labor):

$$E_i = w_i L_i + s_i H_i \quad \text{for } i \in \{A, B\}. \tag{2.50}$$

Following the same logic of the previous section, the mass of incumbent firms in country i is

$$M^i = \frac{E_i}{\bar{r}_i} = \frac{H_i + L_i}{\sigma[f + \frac{1-G(\theta_x^{i*})}{1-G(\theta_d^{i*})} f_x + \frac{\delta}{1-G(\theta_d^{i*})} f_e]} \quad \text{for } i \in \{A, B\}. \tag{2.51}$$

Lastly, the aggregate price index can be expressed as the weighted average price index of each domestic and exporting firms, which is as follows:

$$\begin{aligned} \tilde{P}_A &= \left[\lambda M^A w_A^{1-\sigma} \left(\frac{s_A}{w_A} \right)^{\tilde{\theta}_d^A (1-\sigma)} (\tilde{\theta}_d^A)^{\frac{\alpha(\sigma-1)}{\phi}} + \frac{1 - G(\theta_x^{B*})}{1 - G(\theta_d^{B*})} M^B \lambda \tau^{1-\sigma} w_B^{1-\sigma} \left(\frac{s_B}{w_B} \right)^{\tilde{\theta}_x^B (1-\sigma)} (\tilde{\theta}_x^B)^{\frac{\alpha(\sigma-1)}{\phi}} \right]^{\frac{1}{1-\sigma}}, \\ \tilde{P}_B &= \left[\lambda M^B w_B^{1-\sigma} \left(\frac{s_B}{w_B} \right)^{\tilde{\theta}_d^B (1-\sigma)} (\tilde{\theta}_d^B)^{\frac{\alpha(\sigma-1)}{\phi}} + \frac{1 - G(\theta_x^{A*})}{1 - G(\theta_d^{A*})} M^A \lambda \tau^{1-\sigma} w_A^{1-\sigma} \left(\frac{s_A}{w_A} \right)^{\tilde{\theta}_x^A (1-\sigma)} (\tilde{\theta}_x^A)^{\frac{\alpha(\sigma-1)}{\phi}} \right]^{\frac{1}{1-\sigma}}, \end{aligned} \tag{2.52}$$

where $\lambda = \left[\left(\frac{\sigma}{\sigma-1}\right) \left(\frac{\phi}{\phi-1}\right) \left(\frac{1}{\phi-1}\right)^{-1/\phi} \right]^{1-\sigma}$ is a positive constant. Notice that $\frac{1-G(\theta_x^{B*})}{1-G(\theta_d^{B*})} M^B$ refers to the mass of country B's exporting firms that ship their varieties to country A. This term, thus, is included to determine country A's aggregate price index. The weighted-average skill intensities for domestic and exporting firms, $\tilde{\theta}_d^i$ and $\tilde{\theta}_x^i$, are given in equation (2.44).

The equilibrium under the asymmetric assumption consists of a vector of 7 variables in each country A and B: $\{w_i, s_i, \theta_d^i, \theta_x^i, \tilde{\theta}_d^i, \tilde{\theta}_x^i, \tilde{P}_i\}$ for $i \in \{A, B\}$. These equilibrium variables are determined by 7 equations for each country: the equations that links the two skill intensity cut-offs (equation (2.42)), the free entry condition (equation (2.43)), the weighted-average skill intensities (equation (2.44) for the domestic and foreign market, the labor market clearing conditions (equation (2.51) for each skilled and unskilled labor) and the aggregate price index (equation (2.52)). The remaining aggregate variables, M^i and E_i, are determined as functions of these vectors of the equilibrium variables (equation (2.50) and (2.51)).

Proposition 2.2.4. *As trade costs, τ and/or f_x, fall, the relative wage of skilled to unskilled worker in both countries increases.*

Proof. Proven numerically in the following section. ■

2.2.4.5 Numerical Exercise of Costly Trade between Two Different Countries

The basic set-up for the parameters is the same as in the previous section for the symmetric-country case: $\sigma = 3.8$, $\delta = 0.025$, $f_e = 20$, $f = f_x = 2$, $\phi = 1.1$, and $\alpha = 1.5$. The equilibrium variables for interest depend on the degree of trade liberalization as well as on a trading partner's endowment of skilled and unskilled labor. Table 2.3 summarizes the evolution of the skill premium, the skill intensity cut-offs for both domestic production and exporting in response to variable trade costs, and the country's resource endowment.

As shown in Table 2.3, the relative wage of the skilled worker, s/w, in both countries increases with the reduction in variable trade costs τ. That is, when two asymmetric countries trade with each other, the reduction of variable trade costs increases the skill premium in both countries. The increased wage inequality that followed globalization is due to the reallocation of production resources towards more profitable firms, which produce higher-quality products using higher skill intensive technology.

Table 2.3 also indicates that two skill intensity cut-offs move in opposite directions as trade costs fall. That is, the skill intensity cut-off for domestic production increases, while the export skill intensity cut-off decreases as trade costs fall. Lowering trade barriers allows firms to export relatively easily, which results in a decline of the skill intensity cut-off for exporting. On the other hand, the reduction in trade barriers leads to an increase in import competition, so that the least efficient firms are forced to exit the market, which causes the zero-profit skill intensity cut-off to rise.

Another interesting fact, presented in Table 2.3, is that a high enough trade barrier between two countries creates a regime where one-way trade, from the relatively skill-abundant to the relatively skill-scarce country, occurs. For instance, when country A is more skilled labor abundant than country B (that is, $A(H,L) = (1500, 2000)$ & $B(H,L) = (1300, 2000)$) and the variable trade cost is high enough (so, $\tau = 1.33$), the export skill intensity cut-off in country B is closed to one, $\theta_x^{B*} = 1$, whereas the export skill intensity cut-off in country A is 0.79, that is $\theta_x^{A*} = 0.79$. This implies that some firms with $\theta \in [.79, 1]$ in country A are efficient enough to send their varieties to country B, while no firms in country B benefit from selling their products in country A.

Furthermore, when the barrier to trade is high enough, two-way trade between similar economies, in terms of factor endowment, is more prevalent than trade between asymmetric countries.[30] This phenomenon is consistent with the well-known stylized fact that the large volume of world trade is associated with trade among similar economies (e.g., Linder's hypothesis).

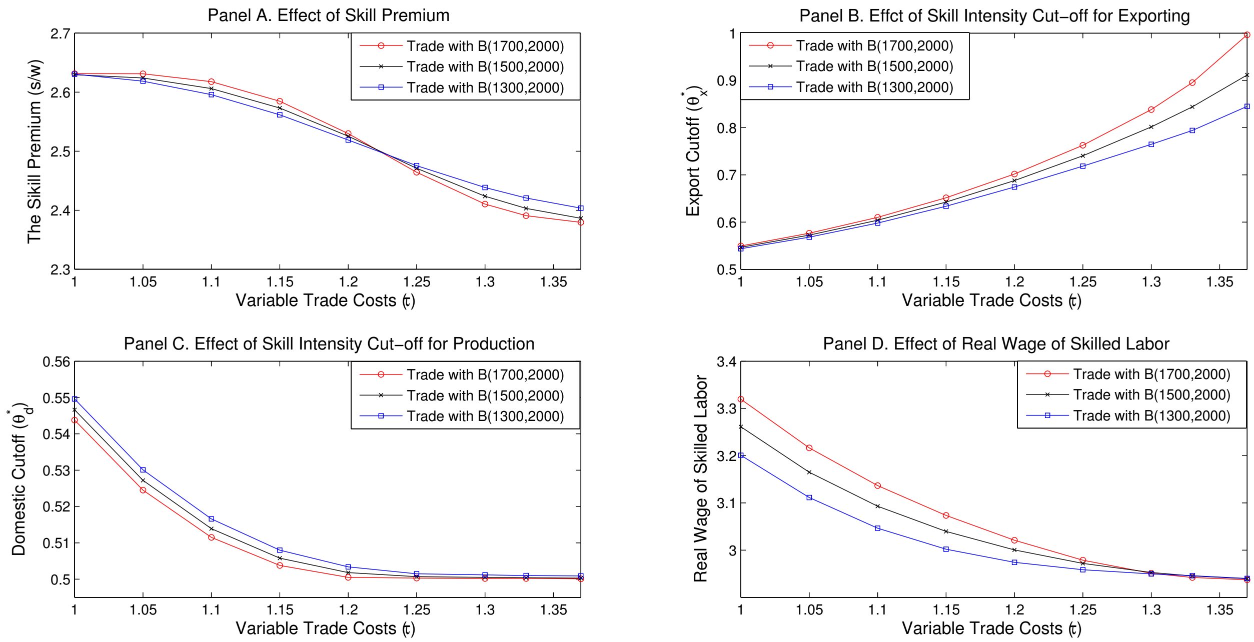
When two different countries trade with each other, the skill premium in the relatively skill-abundant country is much higher and increases faster, as trade costs fall, than in the relatively skill-scare country. For instance, the skill premium in country A is increased by 11% from 2.37 (autarky) to 2.63 (free trade); whereas it increases 10% from 2.23 (autarky) to 2.45 (free trade) in country B when country A trades with country B, where $A:(H,L)=(1500,2000)$ and $B:(H,L)=(1700,2000)$. This relationship is illustrated in Figure 2.8 as well as in Table 2.3. This conflicts with the well-known Stolper-Samuelson theorem in Heckscher-Ohlin-type trade theory.

[30] When one observes both exports and imports of the same good, this pattern of flow is described as two-way or intra-industry trade.

Table 2.3: Equilibrium Zero-profit, (θ_d^*), Export Skill Intensity Cut-off, (θ_x^*), and Skill Premium (s/w) between Asymmetric Countries

		$A(H,L)=(1500,2000)$ $B(H,L)=(1300,2000)$		$A(H,L)=(1500,2000)$ $B(H,L)=(1500,2000)$		$A(H,L)=(1500,2000)$ $B(H,L)=(1700,2000)$	
		Country A	*Country B*	*Country A*	*Country B*	*Country A*	*Country B*
Skill Premium $(\frac{s}{w})$	$\tau=1$	2.631	2.844	2.630	2.630	2.631	2.450
	$\tau=1.1$	2.596	2.833	2.606	2.606	2.617	2.418
	$\tau=1.2$	2.519	2.729	2.525	2.525	2.530	2.350
	$\tau=1.3$	2.438	2.592	2.423	2.423	2.410	2.275
	$\tau=1.33$	2.420	2.579	2.403	2.403	2.391	2.258
	$\tau=1.37$	-	-	2.386	2.386	2.374	2.234
	$\tau=1.4$	-	-	2.379	2.379	-	-
Domestic skill intensity Cut-off (θ_d^*)	$\tau=1$	0.549	0.536	0.546	0.546	0.543	0.555
	$\tau=1.1$	0.516	0.502	0.514	0.514	0.512	0.524
	$\tau=1.2$	0.503	0.492	0.502	0.502	0.501	0.510
	$\tau=1.3$	0.501	0.491	0.502	0.502	0.501	0.508
	$\tau=1.33$	0.501	0.491	0.501	0.501	0.500	0.508
	$\tau=1.37$	-	-	0.501	0.501	0.500	0.507
	$\tau=1.4$	-	-	0.501	0.501	-	-
Export skill intensity Cut-off (θ_x^*)	$\tau=1$	0.544	0.542	0.546	0.546	0.549	0.550
	$\tau=1.1$	0.598	0.607	0.603	0.603	0.610	0.602
	$\tau=1.2$	0.674	0.711	0.687	0.687	0.702	0.672
	$\tau=1.3$	0.764	0.891	0.802	0.802	0.838	0.755
	$\tau=1.33$	0.794	0.996	0.844	0.844	0.895	0.781
	$\tau=1.37$	-	-	0.911	0.911	0.997	0.820
	$\tau=1.4$	-	-	0.975	0.975	-	-

Note: For the remaining parameters, I set $\sigma=3.8$, $\delta=0.025$, $f_e=20$, $f=f_x=2$, $\phi=1.1$, and $\alpha=1.5$.



Note: For these plots, I use the following parameter values: $\sigma = 3.8$, $\delta = 0.025$, $f_e = 20$, $f = f_x = 2$, $\phi = 1.1$, and $\alpha = 1.5$. Also I set $A(H,L) = (1500, 2000)$ for a country A's endowment of skilled and unskilled labor.

Figure 2.7: The Evolution of Country A's Variables corresponding to τ

Figure 2.7 plots four different variables of interest against variable trade costs τ. They are the relative wage of skilled labor, the zero-profit and export skill intensity cut-offs, and the real wage of skilled labor. Panel A in Figure 2.7 illustrates country A's skill premium increases in response to a reduction in trade costs, regardless of its trading partner's endowment of skilled and unskilled labor. In addition, the impact of the lower trade costs on the skill premium is larger when a country trades with a relatively skill-abundant country than when it trades with a relatively skill-scare one.

Panels B and C in Figure 2.7 show that the two skill intensity cut-offs move in opposite directions as τ falls and that these trends occur regardless of the trading partner's labor endowment. Lastly, Panel D illustrates that the real wage of skilled labor increases with the reduction of variable trade costs.[31] As τ falls, the growth rate of the real wage of skilled workers is larger when a country trades with a relatively skill-abundant country, which is closely related to the pattern of the skill premium.

[31] The effect of the reduction of trade costs on the real wage of unskilled workers is relatively small compared to the impact on the real wage for skilled labor. The real wage for country A's skilled labor is calculated by $\frac{s_A}{P_A}$.

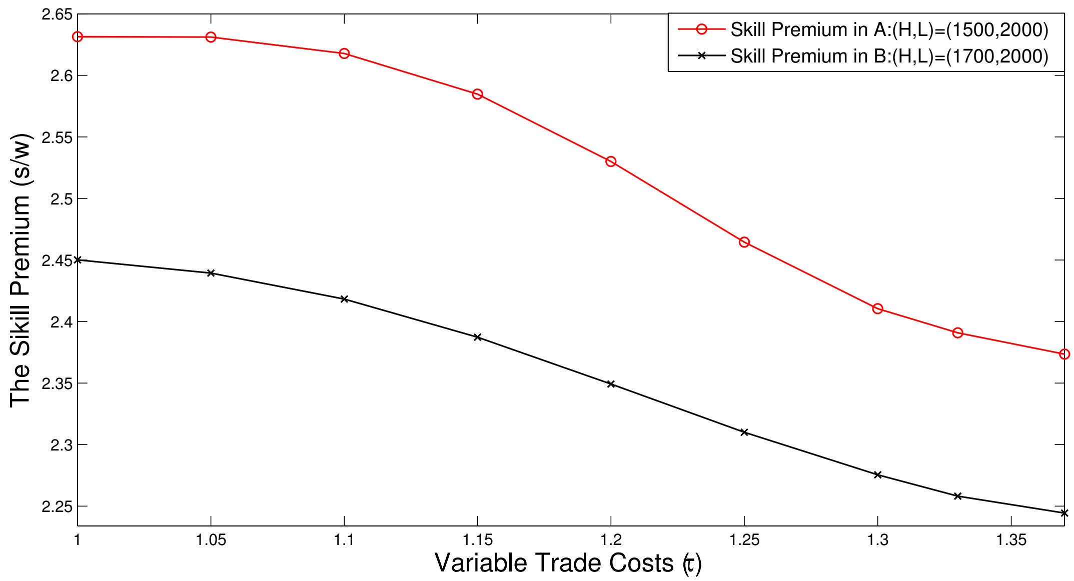


Figure 2.8: The Evolution of the Skill Premium corresponding to τ: $\left(\frac{H_A}{L_A}\right) < \left(\frac{H_B}{L_B}\right)$

2.3 Concluding Remarks

This paper has constructed a general equilibrium model to demonstrate that trade liberalization is accompanied by wage inequality where differences in skill intensity across firms and "quality competition" in a differentiated products market play a key role in determining the pattern of wage inequality following a reduction in trade costs. As trade costs fall, the relative demand for skilled labor increases, resulting in the rise in wage inequality. This is, because production resources are reallocated to the relatively higher-skill-intensive firms, which are more competitive/profitable as they choose to produce higher-quality products. To account for the link between the skill premium and trade liberalization, some well-established stylized facts in the line of firm heterogeneity are used as a component of the theoretical framework. They include: i) differences in skill intensity across firms, ii) the more skill intensive firms are the more likely they are to be exporters, and iii) the positive association between a firm's skill intensity and its product quality. The rise in wage inequality occurs regardless of whether factor endowments differ between trading countries. The effect of lowering trade costs on the skill premium is larger, however, when a country trades with the relatively skill-abundant country rather than with the relatively skill-scarce one. Furthermore, when countries differ in their resource endowment, the skill premium in the relatively skill-scare country is much higher and increases at a faster rate, as trade costs fall, than in the relatively skill-abundant country.

This paper has focused on a single sector model to illustrate that the within-sector relative wage of skilled labor increases as a result of a trade liberalization, that relies on across-firms reallocations of productive resources in a perfectly competitive labor market. Within-industry wage inequality, however, cannot be fully described the overall wage inequality in a country where production resources may be allocated between sectors of the economy as well as within sectors. In fact, Redding et al. (2012), found that about two-thirds of Brazil's overall wage inequality can be explained by the within-sector wage inequality. In addition, as noted in Goldberg and Pavcnik (2007), the lack of labor reallocation across sectors is found in most studies on the impact of trade liberalization on developing countries. Nevertheless, to fully understand a link between globalization and wage inequality, one must consider between-industry allocation of resources as a source of the remaining wage inequality. To incorporate multiple industries in a model of within-sector heterogeneity, it may be necessary to consider either neoclassical trade theory or a search and matching mechanism under the assumption of labor market friction in the spirit of firm heterogeneity.

An increasing number of studies also use linked employer-employee data to explore the wage distribution over a continuum of different types of workers. This allows researchers to capture the different effects of trade integration on within-group wage inequality, which is an important issue for policy makers. This, however, cannot be addressed in the model of two types of worker, so it would be informative to extend the research to a model that considers a continuum of workers.

Lastly, the present study has focused on between-skill-group wage inequality, but did not consider the possibility of wage dispersion within skill groups by assuming a perfectly competitive labor market; hence, the effect of trade openness on overall wage inequality cannot be fully demonstrated. In line with the recent empirical findings, which show a significant correlation between the exporter wage premium conditional on workers' skill level and trade liberalization (see., e.g., Baumgarten 2013), however, one should possibly extend a model of firm heterogeneity by introducing labor market frictions so that the effect of trade openness on within-sector wage inequality can be accounted for by both within- and between-skill-group channels.

Chapter 3

Structural Transformation and Comparative Advantage: Implications for Small Open Economies

3.1 Introduction

Some rich countries seem to have high productivity in agriculture than in nonagriculture (e.g., Australia, New Zealand, and US). Several Latin American countries (e.g., Argentina, Brazil, Chile, Mexico, and Uruguay), however, failed to achieve a high level of income during the past half-century despite relatively high agricultural productivity, whereas some East Asian countries (e.g., Korea and Japan) successfully transformed the economy into industrialization despite lower agricultural productivity. To explain this pattern, economists have taken one of two approaches. Most studies consider closed-economy models where rich countries are relatively more productive in agriculture than in nonagriculture (e.g., Caselli 2005; Restuccia et al. 2003), whereas a smaller set of studies consider explicitly an open-economy model where the driving force is the law of comparative advantage (e.g., Matsuyama 1992). In this article, we refine the second stream of literature and investigate its quantitative implications for small open economies.

A starting point for this paper is Matsuyama (1992), which suggests that the relationship between agricultural productivity and industrialization could be negative because a low agricultural productivity implies a comparative advantage in nonagricultural sector.[1] Matsuyama's model has been lacking solid empirical support. For instance, McMillan and Rodrik (2011) show that the labor productivity in agricultural sector relative to nonagricultural sector exhibits a U-shaped pattern as the economy develops. Specifically, they show that data from India exhibit the downward sloping part of the curve, whereas French data shows

[1] Matsuyama's argument was based on historical evidence from Belgium and the Netherlands (Mokyr 1974) as well as New England and the South (Field 1978; Wright 1979).

the upward sloping part. This paper offers a revised Matsuyama model to show that the predictions of the open-economy model are more complicated; however, Matsuyama's theoretical results continue to hold qualitatively, and more importantly we show through our model calibration that the quantitative effect of comparative advantage and learning-by-doing in open economy can be substantial.

We consider a two-sector Ricardian model similar to the one considered by Lucas (1988) and Matsuyama (1992), where due to learning-by-doing technology the manufacturing sector's total factor productivity (TFP) grows with its scale of production. Following Gollin et al. (2007) and Restuccia et al. (2003), we allow agricultural sector to be modernized by using manufacturing output as an intermediate input to its production. Different from these articles, however, we focus on the role of comparative advantage as the driving force behind structural transformation and growth. By showing that the model can plausibly explain the (un)successful patterns of structural transformation in small open economies with different comparative advantages, we argue in this paper that the open-economy view of structural transformation has a sound quantitative basis and to more completely capture the real world can complement the dominant view discussed in the literature that the poor countries are relatively unproductive in agriculture.

In Section 2, to motivate our study, we construct an index of revealed comparative advantage (RCA) in agriculture as well as manufacturing, as proposed by Balassa (1965), and show that there is a strong negative (positive) relationship between RCA in agriculture (manufacturing) and the growth rate of decline in agriculture's labor share in a cross-section of countries. This relationship holds for each of the 5-year period from 1965 to 2000, for which data are available. Although this correlation is only suggestive, it is consistent with the theoretical result in Matsuyama (1992) that there could be a negative relationship between agricultural productivity and speed of industrialization.

In Section 3, we present our theoretical model, show conditions for industrialization to begin in a subsistence economy, and characterize the equilibrium and the time path of a small open economy's structural transformation, which depends on the growth rate of world labor share in manufacturing, the labor elasticity of output in manufacturing, and the speed of learning-by-doing in manufacturing. In Section 4, we calibrate our model to match the US and the UK data on agriculture's employment share. The calibrated model, despite being simple, accounts fairly well for the long-run growth patterns, such as the evolution of agriculture's share of total output in the US and the UK.

Using the 50 largest countries' labor share data from 1961 to 2003 as a benchmark, we then quantitatively analyze the effect of comparative advantage on structural changes. Our numerical experiments show that a mere four percent initial comparative advantage in manufacturing leads to a factor difference of three in agriculture's employment share, and accounts for roughly 15 percent difference in the aggregate output. Further, a five percent increase in the speed of learning-by-doing can account for a factor difference of three in agriculture's employment share, and about 18 percent increase in aggregate output during the sample period, while learning has little effect in a closed economy.

This paper is related to the strand of literature that numerically investigates the effect of trade on industrialization (e.g., Echevarria 1995; Stokey 2001; Teignier 2012). For instance, Teignier simulates a neoclassical growth model to the structural transformation of the U.S., the U.K., and South Korea and estimates the effect of trade on consumer welfare. The difference is that in our model productivities evolve endogenously and we focus on the effect of comparative advantage as well as learning in a small open economy, while in the above papers productivity growth or technological changes are exogenous and the authors compare free trade with autarky using the estimates of productivities.

As mentioned above, this paper aims to combine two streams of literature. One is the literature on learning-by-doing in the models of trade and growth (e.g., Krugman 1987; Boldrin and Scheinkman 1988; Lucas 1988; Matsuyama 1992; Wong and Yip 1999), and the other is the literature on economic growth that emphasizes the role of agricultural sector (e.g., Echevarria 1997, 2008; Laitner 2000; Kongsamut et al. 2001; Gollin et al. 2004, 2007; Restuccia et al. 2003). This paper is also related to the development literature on food problem, an observation that until countries can reliably meet their subsistence needs, they are unable to begin the process of industrialization (Schultz 1953).[2]

[2] See, also, Johnston and Mellor (1961); Fei and Syrquin (1964); Chenery and Syrquin (1975); Johnston and Kilby (1975); Hayami and Ruttan (1985); and Timmer (1988). The main difference is that these articles consider closed economy models. We show that their main argument that an increase in agricultural productivity is essential for industrialization to take off in the early stages of development holds in our subsistence economy (see Section 3.2) as one of two possible mechanisms.

3.2 Empirical Support

Matsuyama (1992) showed that in a small open economy agricultural productivity and industrialization can be negatively related because a productive agriculture sector squeezes out the manufacturing sector. One could relate agriculture's labor share with a value-added measure of (relative) agricultural productivity to test this prediction. Such testing, however, could be imprecise. As we will show below, relative productivity is but one factor determining a country's comparative advantage. For instance, if its agricultural sector uses intermediate inputs intensively and these are available at low costs, then the country can have a comparative advantage in agriculture. Figure 3.1 plots agricultural productivity relative to manufacturing, measured as the ratio of value-added per worker, against the growth rate of labor share in manufacturing.[3] In Figure 3.1, none of these coefficients are statistically significant at conventional levels.[4] Hence, we resort to a more direct measure of a country's comparative advantage.

[Figure 3.1 about here]

Therefore, we take an alternative approach to show the empirical correlation between comparative advantage and structural transformation, where we measure a country's comparative advantage using an index of revealed comparative advantage (RCA), as proposed by Balassa (1965). The RCA index is based on international comparisons of exports data and has been extensively used in empirical studies in the trade literature. Specifically, a country that exports a product relatively more intensively than the rest of the world does is defined as having a revealed comparative advantage in that sector. We construct two RCA indices for agriculture and manufacturing, respectively, using 53 countries for which export data are available in the UN Comtrade database for every five-year between 1965 and 2000. The index is given by

$$RCA_i^j = \frac{(\frac{EXP_i^j}{EXP_i})}{(\frac{EXP_W^j}{EXP_W})} \text{ for } j = A, M,$$

where $j = A$ stands for agricultural and $j = M$ for manufacturing sector, as defined by the SITC framework. EXP_i^j is country i's export value of sector j goods, and EXP_i is country i's total export value. Similarly,

[3] The value-added data, which is from the World Development Indicators (WDI), is only available from 1980 to 2000.

[4] In Figure 3.1, the slope coefficients are -.0059 for the period 1980-85; -.0040 for 1985-90; .0040 for 1990-95; and .0075 fir 1995-2000.

EXP_W^j is the value of the world's export in sector j, and EXP_W is the value of the world's total export trade, where the world consists of the 53 countries in the sample. When we match up these data with agriculture's labor share over the same 5-year periods, the sample size is reduced to 42 countries.[5]

Our measure of structural transformation is the (negative) growth rate of the labor share in agriculture. To be clear, although our calibrated model economy grows due to the learning-by-doing effect, the empirical predictions in the literature on structural transformation are formulated in terms of labor shares. Notice that our measure is not the absolute decline in the fraction of the labor force in agriculture, so that a decline from 0.8 of the labor force in agriculture to 0.6 is a smaller decline in terms of growth rate than one from 0.3 to 0.1. Further, the countries that experienced large declines are not necessarily those that had large initial shares in agriculture. For instance, in 1965, Japan and Korea had a labor share of 0.26 and 0.55, respectively, and these two countries experienced the fastest decline in agriculture's labor share.

Figure 3.2 plots the RCA index in manufacturing against the growth rate of decline in agriculture's labor share. In each subpanel, there is a clear, positive cross-sectional correlation between the two variables, where all the slope coefficients are trivially significant at the conventional level. As a robustness check, we plot in Figure 3.3 the RCA index in agriculture against the rate of decline in agriculture's labor share. This time there is a clear, negative correlation in each sub-panel of the figure, where the slopes are again statistically significant. While we clearly do not make any causal interpretations, these simple correlations indicate that the law of comparative advantage may play an important role in some countries' structural transformation at least in the second half of the twentieth century, when countries became more open.

[Figure 3.2 about here]

[Figure 3.3 about here]

One might wonder if these empirical correlations may arise because the countries that experience large declines in agriculture's labor share are countries that had large initial shares of the labor force in agriculture, and therefore overwhelmingly poor countries. However, this is not the case in the data. Figure 3.4 plots the RCA index in agriculture against per capita income and shows that there is a strong negative

[5] Data on agriculture's labor share (as a percentage of the total labor force) come from the World Resources Institute (WRI).

relationship between the two; that is, the countries that have a low RCA index in agriculture (hence comparative advantage in manufacturing) are not at all poor countries of the world. As can be readily seen, several European countries as well as Japan and US are among those in the lower right corner of the graphs. Hence, high income countries do not necessarily have comparative advantage in agriculture as measured by RCA.

[Figure 3.4 about here]

3.3 A Theoretical Model

3.3.1 Basic Structure

The economy has two sectors, agriculture and manufacturing.[6] In each sector, competitive firms produce output according to Cobb-Douglas technologies. Specifically, the agricultural sector has two types of technologies for producing output–traditional and modern. The traditional agricultural technology produces output using land and labor while the modern technology uses intermediate inputs, such as chemical fertilizers and harvesting equipment, that are produced in the manufacturing sector (see, e.g., Gollin et al. 2007). That is, agricultural production using the traditional technology is given by

$$Y_t^a = AF(L, N_t^a) = AL^{1-\alpha}(N_t^a)^{\alpha},$$

where L is land (normalized to one) and N^a is the fraction of total labor employed in the agricultural sector. A represents country-specific agricultural TFP parameter that is affected by several factors such as government policy, institution, and climate. We assume that A is constant over time so that the increase in agricultural productivity is driven by the intermediate input use (see, e.g., Restuccia et al. 2003 for the correlation between intermediate inputs and agricultural productivity).

As we will show below, it is necessary for the economy to start using modern agricultural technology in order to begin industrialization process in our model. Hence, for the most part of this paper, we will consider the modern agricultural technology, where we substitute land with intermediate input, X_t, so output

[6] We abstract from non-tradable service sectors. Yi and Zhang (2011) analyze structural change in an open economy model with three sectors, where the manufacturing employment share exhibits a hump-shaped pattern as a country develops (see also Buera and Kaboski 2009; and Moro 2012).

is given by

$$Y_t^a = AF(X_t, N_t^a) = AX_t^{1-\alpha}(N_t^a)^{\alpha}.$$

Following Lucas (1988) and Matsuyama (1992), for the sake of simplicity, we assume that the manufacturing sector produces output using only labor. Although it would be more realistic to incorporate capital accumulation, this assumption has proved to be useful in analyzing structural transformation and findings relatively robust to capital accumulation (see, e.g., Restuccia et al. 2003; Alvarez-Cuadrado and Poschke 2009).

The production function in the manufacturing sector is given by

$$Y_t^m = M_t F(K, N_t^m) = M_t K^{1-\beta}(N_t^m)^{\beta},$$

where K is capital (normalized to one), M_t represents knowledge capital, which is predetermined but endogenous. Knowledge capital M_t (or total factor productivity in manufacturing) accumulates as a by-product of manufacturing. Specifically, we assume that $\dot{M}_t = \delta Y_t^m$, so that $\dot{M}_t / M_t = \delta (N_t^m)^{\beta}$, where δ is the (country-specific) parameter that reflects the speed of learning-by-doing.[7] The learning process is exogenous to individual firms, so that each firm treats M_t as given when making production decisions.

We assume that one unit of manufacturing output is required to produce $1/\theta$ units of X. Under competitive factor and output markets, θ is the price of intermediate inputs relative to manufactured goods (see, e.g., Restuccia et al. 2003). Hence, the representative farmer's and the firm's profit maximization problems are given by

$$\max_{X_t, N_t^a} \; p_t A X_t^{1-\alpha}(N_t^a)^{\alpha} - \theta X_t - w_{a,t} N_t^a,$$

and

$$\max_{N_t^m} \; M_t (N_t^m)^{\beta} - w_{m,t} N_t^m,$$

respectively, where p_t is the price of agricultural goods relative to manufactured goods (which is the numeraire good in this paper), θ is the price of intermediate goods, and $w_{a,t}$ ($w_{m,t}$) is the agricultural (manu-

[7] For instance, the speed of learning-by-doing can be influenced by government policies on human capital investment that impact worker's learning on the job site.

facturing) wage rate. Using the optimality condition, we have

$$w_{m,t} = \beta M_t (N_t^m)^{\beta-1} \tag{3.1}$$

$$w_{a,t} = \alpha A p_t X_t^{1-\alpha} (N_t^a)^{\alpha-1} \tag{3.2}$$

$$\theta = (1-\alpha) A p_t X_t^{-\alpha} (N_t^a)^{\alpha}. \tag{3.3}$$

On the demand side, there is an infinitely-lived representative consumer, who inelastically supply one unit of labor in each period. Labor is perfectly mobile across sectors within a country (but immobile across countries), and factor market clearing condition ensures $N_t^a + N_t^m = 1$. Thus, we will often denote $N_t^m = N_t$ and $N_t^a = 1 - N_t$ in the following.

To incorporate the basic mechanism of structural change, we assume a functional form for preferences of the Stone-Geary variety, where the income elasticity of demand for agricultural goods is less than unity.[8] Specifically, the representative consumer's per-period utility is given by: for an exogenous constant $\bar{c}$,

$$U(c_t^a, c_t^m) = \begin{cases} c_t^a & \text{if } c_t^a \leq \bar{c} \\ \phi \log(c_t^a - \bar{c}) + \log c_t^m + \bar{c} & \text{if } c_t^a > \bar{c}, \end{cases}$$

where c_t^a and c_t^m denote the consumption of agricultural and manufactured goods at time t, and $\phi \in (0,1)$ is a relative weight on food consumption.[9] There is no storage, so intertemporal consumption smoothing is not possible. Thus, the representative consumer maximizes the discounted sum of utility, $\sum_{t=0}^{\infty} \xi^t U(c_t^a, c_t^m)$, subject to the usual budget constraint, where $\xi \in (0,1)$ is the discount factor.

The optimality condition for the representative consumer is straightforward. When $c_t^a \leq \bar{c}$, individuals only consume food. When $c_t^a > \bar{c}$ (that is, once output in the agricultural sector reaches $\bar{c}$), the representative consumer first allocates income I to meet $\bar{c}$, and then the remaining to both goods, so that

$$c_t^a = \bar{c} + \frac{\phi}{p_t(1+\phi)}(I - p_t\bar{c})$$
$$c_t^m = \frac{1}{1+\phi}(I - p_t\bar{c}).$$

[8] The observation that the slope of the Engel curve for agricultural goods is less than unity is a well-established empirical regularity both in cross sections of countries and in time-series data (see, e.g., Bils and Klenow 1998; Kongsamut et al. 2001).

[9] As is common in this literature, we ignore the problem that the instantaneous utility is lowered when c_t^a increases from $\bar{c}$ to a slightly higher number. See Laitner (2000) and Gollin et al. (2002) for similar types of consumer preference.

Hence, assuming that the consumer has enough income to purchase more than $\bar{c}$ unit of food, the optimality condition is given by

$$c_t^a = \bar{c} + \frac{\phi}{p_t} c_t^m. \qquad (3.4)$$

3.3.2 Subsistence Economy

In this subsection, we briefly discuss how a country starts the development process in our model. There are two possibilities for allocating labor in the subsistence economy.[10] One possibility is that farmers produce agricultural output using the traditional technology. Since consumers derive no utility from consuming manufactured goods in this state, there is no labor allocation in the manufacturing sector. The other possibility is that farmers produce agricultural goods using the modern technology, in which case there will be some labor allocation in the manufacturing sector; however, all manufactured goods will be used as intermediate inputs to agricultural production in a closed economy.

Hence, a subsistence economy will optimally adopt the modern technology if and only if the consumer's lifetime utility from using the modern agricultural technology is greater than that from using the traditional technology. This holds if

$$M_0 \geq \left(\frac{\beta(1-\alpha)+\alpha}{\beta(1-\alpha)} \right)^{\beta} \left(\frac{\beta(1-\alpha)+\alpha}{\alpha} \right)^{\frac{\alpha}{1-\alpha}}, \qquad (3.5)$$

the derivation of which is relegated to the Appendix C.1.[11]

The above condition implies that if the initial value of manufacturing productivity, M_0, is sufficiently large, then even though a country's initial agricultural productivity is relatively low, labor force will flow out of agriculture before agricultural productivity rises above $\bar{c}$. To be precise, the labor allocation during this gestation period will be constant, $N_t^m / N_t^a = (\beta - \beta\alpha)/\alpha$, while food consumption level increases gradually as M_t grows over time. Once consumption reaches $\bar{c}$, consumers begin to consume manufactured goods and additional labor will flow out of agriculture into manufacturing sector.[12]

[10] For convenience, I use the term "subsistence economy" when the level of food consumption is less than $\bar{c}$.

[11] This makes the conservative assumption that the learning-by-doing parameter δ is sufficiently small, so that the lifetime utility from using the modern agricultural technology will not go to infinity. If δ is large enough to satisfy $\xi \left(1 + \delta \left(\frac{\beta(1-\alpha)}{\beta(1-\alpha)+\alpha}\right)^{\beta}\right)^{1-\alpha} \geq 1$, then this suffices to use the modern agricultural technology under subsistence conditions.

[12] This argument seems consistent with the finding by Alvarez-Cuadrado and Poschke (2009) that productivity improvements in the nonagricultural sector were the main driver of structural change before 1960.

If the above inequality is not satisfied, then labor would be entirely devoted to the traditional agricultural sector, and we need an exogenous increase in either agricultural productivity or manufacturing productivity to jump-start industrialization. In particular, as in the conventional arguments, whenever the increase in agricultural productivity pushes the economy above $\bar{c}$, structural transformation will begin. However, in light of the empirical evidence suggested above, early manufacturing productivity seems to play an important role in explaining relatively recent development experiences of some small open economies.

3.3.3 Closed Economy

Here we characterize the equilibrium path after a country begins structural transformation moving beyond an exogenous level, $\bar{c}$. Agricultural production uses the modern technology, so the representative consumer consumes both agricultural and manufactured goods. Since the economy is closed, the following market clearing conditions hold.

$$\begin{aligned} c_t^a &= Y_t^a = AX_t^{1-\alpha}(1-N_t)^{\alpha} \\ c_t^m &= Y_t^m - \theta X_t = M_t N_t^{\beta} - \theta X_t. \end{aligned}$$

Combining these with equation (3.4) yields

$$AX_t^{1-\alpha}(1-N_t)^{\alpha} = \bar{c} + \frac{\phi}{p_t}\left(M_t N_t^{\beta} - \theta X_t\right). \tag{3.6}$$

The no-arbitrage condition in the competitive labor market holds in each period (i.e., $w_{m,t} = w_{a,t}$ for all t), so that

$$\beta M_t (N_t)^{\beta-1} = \alpha A p_t X_t^{1-\alpha}(1-N_t)^{\alpha-1}. \tag{3.7}$$

Equations (3.3), (3.6), and (3.7) may now be solved for the three unknowns $\{X_t, p_t, N_t\}$. From (3.3) and (3.7), we have

$$p_t = \frac{1}{A}\left(\frac{1-\alpha}{\theta}\right)^{\alpha-1}\left(\frac{\beta}{\alpha}\right)^{\alpha} M_t^{\alpha} N_t^{(\beta-1)\alpha} \tag{3.8}$$

$$X_t = \left(\frac{1-\alpha}{\theta}\right)\left(\frac{\beta}{\alpha}\right) M_t N_t^{\beta-1}(1-N_t). \tag{3.9}$$

Substituting (3.6) with (3.8) and (3.9) yields

$$(1-N_t)N_t^{(\beta-1)(1-\alpha)}\left(\frac{\beta}{\alpha}\right)^{1-\alpha}[1+\phi(1-\alpha)]-\phi\left(\frac{\beta}{\alpha}\right)^{-\alpha}N_t^{(\beta-1)(1-\alpha)+1}=\frac{\bar{c}}{A}\left(\frac{1-\alpha}{\theta}\right)^{\alpha-1}M_t^{\alpha-1}. \quad (3.10)$$

Notice that the left-hand side of equation (3.10) is strictly decreasing in N_t, and the right-hand side is a positive number. Further, the left-hand side tends to infinity as N_t approaches zero, and it is negative at $N_t = 1$. Since M_t on the right-hand side grows over time at a rate δN_t^{β}, equation (3.10) has a unique solution in $N_t \in (0,1)$, which depends on the parameters of the model, $\{A, \bar{c}, \theta, \alpha, \beta, \phi\}$, and M_t.

Since $\dot{M}_t/M_t = (M_{t+1} - M_t)/M_t = \delta N_t^{\beta}$, it follows that $M_t = M_0 \prod_{\tau=1}^{t}(1+\delta N_{\tau-1}^{\beta})$ for $t \geq 1$. Therefore, the labor share in manufacturing in each period t after industrialization can be written as

$$N_t = v\left[M_t(M_0, \delta, \beta); A, \bar{c}, \theta, \alpha, \beta, \phi\right].$$

The function v exhibits standard features that explain a country's structural transformation. For instance, holding other factors constant, a higher initial manufacturing productivity, M_0, pulls the labor force from the agricultural sector. A higher agricultural productivity, A, increases the labor share in manufacturing as well because it substitutes for the labor demand in agriculture. Relatedly, the labor's share in manufacturing is negatively related to θ, the efficiency parameter or the conversion ratio of manufacturing output to intermediate inputs, and $\bar{c}$. A technological progress in the intermediate-input production, through lower θ, can push labor into the manufacturing sector.

It is also true that a country with more efficient learning technology, δ, can experience more rapid industrialization in which labor flows out of agriculture to manufacturing sector. However, as we will show in our calibration, the quantitative effect of learning-by-doing is limited in a closed economy whereas a relatively small difference in δ can lead to a large difference in a country's structural transformation in an open economy setting. Even if knowledge spillovers across countries occur over time (Lucas 2009), so the country that starts industrialization later tends to have a higher value of δ, our analysis below suggests that the convergence effect may be attenuated by comparative advantage in agriculture.

3.3.4 Open Economy

Consider a small open economy (called home), which is the country described above, while the rest of the world has the same preferences and production functions as home and its variables are labeled by an asterisk (*). The two countries only differ by agricultural productivity, A, initial knowledge capital in manufacturing, M_0, and the intermediate input price, θ. The home country takes prices as given, and this means that the technology to transform intermediate inputs to agricultural output is the same at home and in the rest of the world. Labor is immobile across countries, and we assume that learning-by-doing effects do not spill over across countries.

Suppose that these countries are allowed to trade with each other. In the absence of international capital market, the world economy evolves just as we described in the previous subsection. Consumers maximize their instantaneous utility, and firms in each sector maximize profit in the competitive factor and output markets. Characterizing the equilibrium quantities, however, is unnecessary for this section's purpose. Instead, we focus on the equilibrium path of structural transformation in terms of labor share in agriculture. Denoting the world (relative) prices of agricultural goods and intermediate inputs as p_t^* and θ^*, respectively, the following first-order conditions hold.

$$\beta M_t^* (N_t^*)^{\beta-1} = \alpha A^* p_t^* X_t^{*1-\alpha}(1-N_t^*)^{\alpha-1} \tag{3.11}$$

$$\theta^* = (1-\alpha) A^* p_t^* X_t^{*-\alpha}(1-N_t^*)^{\alpha}. \tag{3.12}$$

Given the properties of the production functions, trading partners will not completely specialize. Under the assumption of free trade (which we discuss below), the home country's labor share in manufacturing is determined by the two equations above together with equation (3.3) and (3.7). Specifically, combining equation (3.11) and (3.7) yields

$$\frac{M_t}{AX_t^{1-\alpha}} \frac{N_t^{\beta-1}}{(1-N_t)^{\alpha-1}} = \frac{M_t^*}{A^* X_t^{*1-\alpha}} \frac{N_t^{*\beta-1}}{(1-N_t^*)^{\alpha-1}}. \tag{3.13}$$

From equation (3.12) and (3.3), we have

$$\frac{X_t}{X_t^*} = \left(\frac{A}{A^*}\right)^{\frac{1}{\alpha}} \left(\frac{1-N_t}{1-N_t^*}\right). \tag{3.14}$$

Finally, combining equation (3.13) and (3.14) yields

$$\left(\frac{N_t}{N_t^*}\right)^{\beta-1} = \left(\frac{A}{A^*}\right)^{\frac{1}{\alpha}} \frac{M_t^*}{M_t}. \tag{3.15}$$

Suppose at time t the home country opens up to trade. Our measure of comparative advantage is the ratio of Hicks-neutral TFP in the two sectors, which is based on the gross output production model. That is, the intermediate input is not explicitly separated from TFP parameters. Given that the intermediate input prices are equalized in our simple model, the standard definition of comparative advantage applies as long as input conversion technologies are the same across countries (see, e.g., Jones 1961). Therefore, the home country has a comparative advantage in manufacturing if and only if

$$\frac{M_t}{AX_t^{1-\alpha}} > \frac{M_t^*}{A^* X_t^{*1-\alpha}}.$$

From equation (3.13), we conclude that

$$N_t \gtreqless N_t^* \quad \text{if and only if} \quad \frac{M_t}{AX_t^{1-\alpha}} \gtreqless \frac{M_t^*}{A^* X_t^{*1-\alpha}}.$$

That is, the labor's share in manufacturing sector must be greater for the home country than that for the rest of the world, so that the home country can have a comparative advantage in manufactured goods. Notice that the comparative advantage term is influenced by the intermediate input use as well as relative productivity as we discussed in the previous section.

From the free trading equilibrium condition (3.15), we find the time path of the labor share in the home country by differentiating equation (3.15) with respect to time.[13]

$$\begin{aligned} \frac{\dot{N}_t}{N_t} &= \frac{\dot{N}_t^*}{N_t^*} + \frac{1}{1-\beta}\left(\frac{\dot{M}_t}{M_t} - \frac{\dot{M}_t^*}{M_t^*}\right) \\ &= \frac{\dot{N}_t^*}{N_t^*} + \frac{\delta}{1-\beta}(N_t^{\beta} - N_t^{*\beta}). \end{aligned} \tag{3.16}$$

Thus, in a small open economy, the growth rate of labor share in manufacturing sector depends on the growth rate of the world's labor share in manufacturing and comparative (dis)advantage in manufacturing. The labor share in manufacturing in the home country will increase at a faster rate than that in the rest of

[13] For more details, see Appendix C.2.

the world if its initial labor share in manufacturing is larger than that in the world (i.e., $N_t > N_t^*$), hence, a comparative advantage in manufacturing. The effect of comparative advantage depends on the speed of learning-by-doing, δ, and the labor elasticity of output in manufacturing, β, (which are assumed to be identical across countries). In particular, if δ and β are sufficiently large, then the country that has a comparative advantage in agriculture can experience de-industrialization (i.e., $\dot{N}_t/N_t < 0$) as put forth by Matsuyama (1992).

Another difference from the closed economy models such as the one analyzed by Restuccia et al. (2003) is that in this paper export-oriented policies have no implication for small open economies' structural transformation. Specifically, the home country's time path of the labor share in manufacturing (i.e., equation (3.16) above) is unaffected by import tariffs (or export subsidies) on manufactured goods. That is, suppose the domestic price of manufactured goods (the numeraire good) increases from 1 to $1+\tau$, where τ represents the tax. Then the relative domestic prices of agricultural and intermediate goods will decrease to $p_t/(1+\tau)$ and $\theta/(1+\tau)$, respectively, so that in equilibrium $p_t = p_t^*(1+\tau)$ and $\theta = \theta^*(1+\tau)$ hold. It can be easily shown that the differential equation (3.16) remains the same as long as the tax is held constant across time.

The logic behind this result is that the optimal allocation of labor in a small open economy is completely determined by the world prices, which small open economies take as given. Hence, our model supports the view that the export-oriented government policies did not contribute much to the development experience of the Asian tigers (i.e., Hong Kong, Singapore, South Korea, and Taiwan). More importantly, the model predicts path dependence in economic development. That is, if whether industrialization begins depends on the level of initial manufacturing productivity relative to that of the rest of the world (which determines the comparative advantage), then as more countries become industrialized, it may become increasingly harder for the remaining agricultural economies to satisfy this initial condition for successful structural changes to take place.

3.4 Numerical Experiments

3.4.1 Closed Economy

The length of a time period is set to one year. To focus on the effect of comparative advantage on industrialization, we normalize the values of A, M_0, θ, and $\bar{c}$ to one, which means that if the agricultural sector uses the traditional technology it will produce exactly the subsistence needs of the population, and hence industrialization can begin.[14] The parameter ϕ determines the expenditure share as well as the long-run share of employment in agriculture. Following Gollin et al. (2004), we set $\phi = 0.003$. Next, we choose the value of $1-\alpha$ to match the intermediate-input-to-output ratio in agriculture. The data from the U.S. Department of Commerce's (1975) Historical Statistics suggest that this ratio is 0.39, so we set $\alpha = 0.61$. Accounting for intangible capital investment, we set the labor share parameter β in manufacturing equal to 0.5.[15]

Next, we estimate the value of δ such that the model matches the evolution of agriculture's employment share as accurately as possible. That is, given the data on employment shares, we calculate annual time series by cubic interpolation, and then choose the value of δ that minimizes the sum of squares of the distance between the data and the model's prediction during the time period when the labor's share in agriculture decreases from 70 to 20 percent. Admittedly, this may appear to be somewhat arbitrary, but it reflects a balance between power consideration and a desire to focus on the rapid industrialization period. Thus, $\delta = \arg\min \sum_{t \in \{t: 0.2 \leq S_t \leq 0.7\}} [S_t - N_t^a]^2$, where S_t is the labor share data and N_t^a is the value generated by the model. The employment as well as output share data are taken from Kuznets (1966) and International Historical Statistics (Mitchell 1992, 1993).[16]

First, we calibrate the model to UK data on labor's share in agriculture. The parameter δ is estimated to be 0.050. By construction, the calibrated model matches the data very well. Figure 3.5 plots the time-

[14] Different values of the subsistence level of consumption would have implicaitons for different starting date of structural transformation, the quantitative implication of which in this paper is straightforward and hence omitted. See also Gollin et al. (2007) for implications of agricultural productivity on the onset of industrialization.

[15] Corrado et al. (2009) estimate that the average investment in intangible capital was around 15% of the output during 2000-2003. Gollin et al. (2007) also set the (physical and intangible) capital share paramter equal to 0.5, which is higher than the conventional one-third level.

[16] In the data, manufacturing sector includes mining, public utilities, transportation, and communications. Services are not included in calculation.

series data on agriculture's labor share from 1775 to 1995 together with the time path predicted by the model. Given the parametrization chosen, the calibration implies that the first year in which labor started flowing out of agriculture is approximately 1700, which is in line with Gollin et al.'s (2007) estimate. The model performs fairly well in replicating the long-run pattern of agriculture's share of output even though the model was not calibrated to match this dimension. Figure 3.6 shows the output share of agriculture over time. Despite its parsimonious structure, the model appears to provide a good description of agriculture's share of labor and output in the UK data.

[Figure 3.5 about here]

[Figure 3.6 about here]

We also calibrated the model to US data on labor's share in agriculture. Following the same procedure as above, the parameter δ is estimated to be 0.062, which is greater than the δ in the U.K. Figure 3.7 plots the time-series labor share in agriculture in the U.S. from 1800 to 2000 and the model's prediction. The model predicts that the transition during which labor share in agriculture drops from 70 to 20 percent in the U.S. occurs between approximately 1860 and 1940, while the same structural change occurred in the calibrated UK economy between 1765 to 1878. Hence, the model can explain the fact that the US economy experienced structural changes in a shorter time period than the UK economy did. Figure 3.8 plots the agriculture's output share in the US data and the time path from the calibration. The model captures important aspects of structural transformation reasonably well.

[Figure 3.7 about here]

[Figure 3.8 about here]

3.4.2 Open Economy

We now use the model to examine the implications for small open economies, where we focus on the effect of comparative advantage and learning-by-doing. In what follows, we aggregate the 50 largest countries' labor share data over the period 1961-2003 and use it as representing the world economy. Each country's labor share data is taken from the World Resources Institute (WRI). During this period, the agriculture's labor share of the world economy decreased from 60 to 42 percent. Given the world's labor share in agriculture, the equilibrium path of a small open economy's labor share in agriculture is determined by equation (3.16) above. Figure 3.9 displays a series of numerical experiments where the home country differs from the rest of the world only by the initial value of manufacturing labor share. In what follows, we set $\delta^* = 0.055$ and $M_0^* = M_0 = 4$.[17]

[Figure 3.9 about here]

Figure 3.9 shows that comparative advantage alone can explain a large variation in the secular decline in agriculture's labor share. That is, holding constant other parameter values across countries, a small (in the range of one to four percent) difference in a country's initial comparative advantage leads to a dramatically different time trend of agriculture's labor share for a small open economy. Specifically, if a country has an initial, four percent comparative advantage in manufacturing relative to the world, then its employment share in agriculture will fall from 0.60 to 0.13 between 1961 and 2003. In contrast, a county with the same small comparative disadvantage in manufacturing can experience slowdown or even de-industrialization.

The simulation results seem to accord well with the actual data. In Figure 3.10, we plot the actual time path of the countries whose labor share in agriculture in 1961 is close to 0.6, the initial value of the simulated open economy above. These comprise 20 countries with agriculture's labor share between 0.55 and 0.65 in 1961. Figure 3.10 shows that the time path of structural transformation varies widely by countries, which can be at least partially accounted for by the simulated open economy in Figure 3.9. Given the empirical correlation presented in Section 2, this demonstrates that the forces of comparative advantage can plausibly explain the experience of some late-starting countries in the second half of the twentieth century.

[Figure 3.10 about here]

Given our characterization of structural transformation by equation (3.16), one might think that the data can also be explained by assuming differential TFP growth. It is partly true that different learning-

[17] The world's learning-by-doing parameter value is taken between the above two estimates for the US and the UK. The initial manufacturing productivity in 1960 for both home and the world reflects the equilibrium path of the benchmark closed economy, so that M_0^* is the implied productivity when the agriculture's labor share is 0.6.

by-doing parameters can generate similar patterns as explained by comparative advantage. However, the differential rate of learning (hence productivity growth) needed to explain the same amount of variation in closed-economy models would be much higher than that required in small open economies. To show this, suppose that the home country's initial labor share in manufacturing is the same as that of the rest of the world (i.e., $N_0 = N_0^*$), but its learning technology is different from the world's. In this case the equilibrium path of the home country's labor share in agriculture is still defined by equation (3.16), where the new differential equation is now given by

$$\frac{\dot{N}_t}{N_t} = \frac{\dot{N}_t^*}{N_t^*} + \frac{1}{1-\beta}(\delta N_t^{\beta} - \delta^* N_t^{*\beta}) \tag{3.17}$$

Figure 3.11 shows that a small (around five percent) increase in the speed of learning-by-doing can explain just as much variation in secular decline of agriculture's employment share in the absence of any initial comparative advantage in manufacturing. However, when we simulate a closed economy model where parameter values are the same as those used for the world economy except that δ is varied, learning-by-doing (hence productivity differential alone) could not generate a meaningful variation. Figure 3.12 shows the time path of this simulated closed economy, where a once-and-for-all increase in δ from 0.055 to 0.058 makes only a minor difference to the agriculture's share of employment, whereas in Figure 3.11 the same change leads to a factor difference of three in 40 years. Therefore, the above results cannot be explained away by differential TFP growth.

[Figure 3.11 about here]

[Figure 3.12 about here]

Figure 3.13 and Figure 3.14 show the total output or GDP of the home country (i.e., $p_t^* Y_t^a - \theta^* X_t + Y_t^m$) for the respective scenarios considered above. The model predicts that the small open economy's output increases almost fivefold between 1961 and 2003, with an average annual growth rate of four percent. This seems to be consistent with the development experience of the Newly Industrialized Economies. Further, starting with the same initial conditions, a relatively small difference in comparative advantage or learning technology can account for up to 15 percent difference in total output variation by the end of the 40-year period. This suggests that structural transformation has a modest but economically significant effect on growth.[18]

[Figure 3.13 about here]

[Figure 3.14 about here]

Finally, Figure 3.15 and Figure 3.16 display the value-added per worker in manufacturing relative to agriculture in the small open economy. Figure 3.15 shows that a comparative advantage in manufacturing has an initial, level effect on the relative productivity; however, it has little growth effect over time. On the other hand, Figure 3.16 shows that an increase in learning-by-doing parameter has some growth effect on relative productivity; however, the magnitude of this growth effect is much smaller than the effect of comparative advantage. This relatively small variation is also consistent with the observation that the relative productivity has been stable over time for developed countries like the US and UK (see, e.g., Gollin et al. 2004).

[Figure 3.15 about here]

[Figure 3.16 about here]

3.5 Conclusion

The literature has uncovered some of the most important mechanisms of structural transformation in a closed economy, such as an income elasticity of the demand for agricultural goods less than one and faster total factor productivity growth in agriculture relative to other sectors of the economy. Our results partly confirm this conventional wisdom, but we argue that these mechanisms may not completely capture structural transformation and lock-in in an increasingly globalized economy. In particular, after the onset of industrialization comparative advantage seems to be an important consideration, which we supported by showing that our simple calibrated open economy can generate a plausible time path of labor share in agriculture.

[18] These figures seem consistent with McMillan and Rodrik (2011)'s finding that holding constant sectoral productivity levels in poor countries counterfactual reallocation of labor that matches the pattern observed in the rich countries can account for as much as one fifth of the productivity gap.

Our quantitative analysis suggests that countries with relatively productive manufacturing sectors move rapidly to specialize in manufacturing, while those with comparative advantage in agriculture will experience little structural transformation. We believe that these account well for the growth miracles in the four East Asian tigers and the lock-in of several currently middle-income countries in Latin America and Southeast Asia. Our small open economy model is not at odds with (but rather complement) the development experience of the currently rich countries as this paper does not intend to explain the early industrialization before the 20th century, when closed economy models may do a better job of explaining structural transformation.

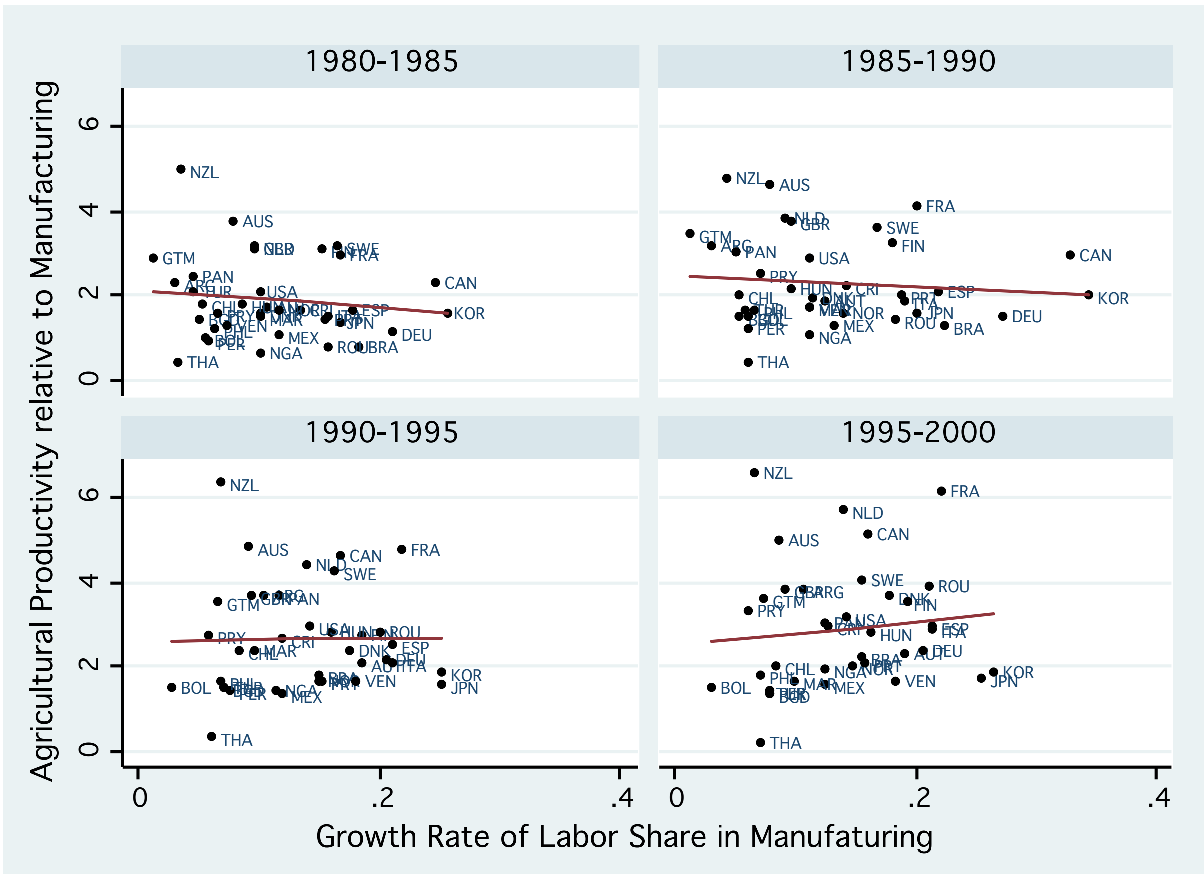


Figure 3.1: Relationship between RCA in Manufacturing and Growth Rate of Manufacturing Labor Share

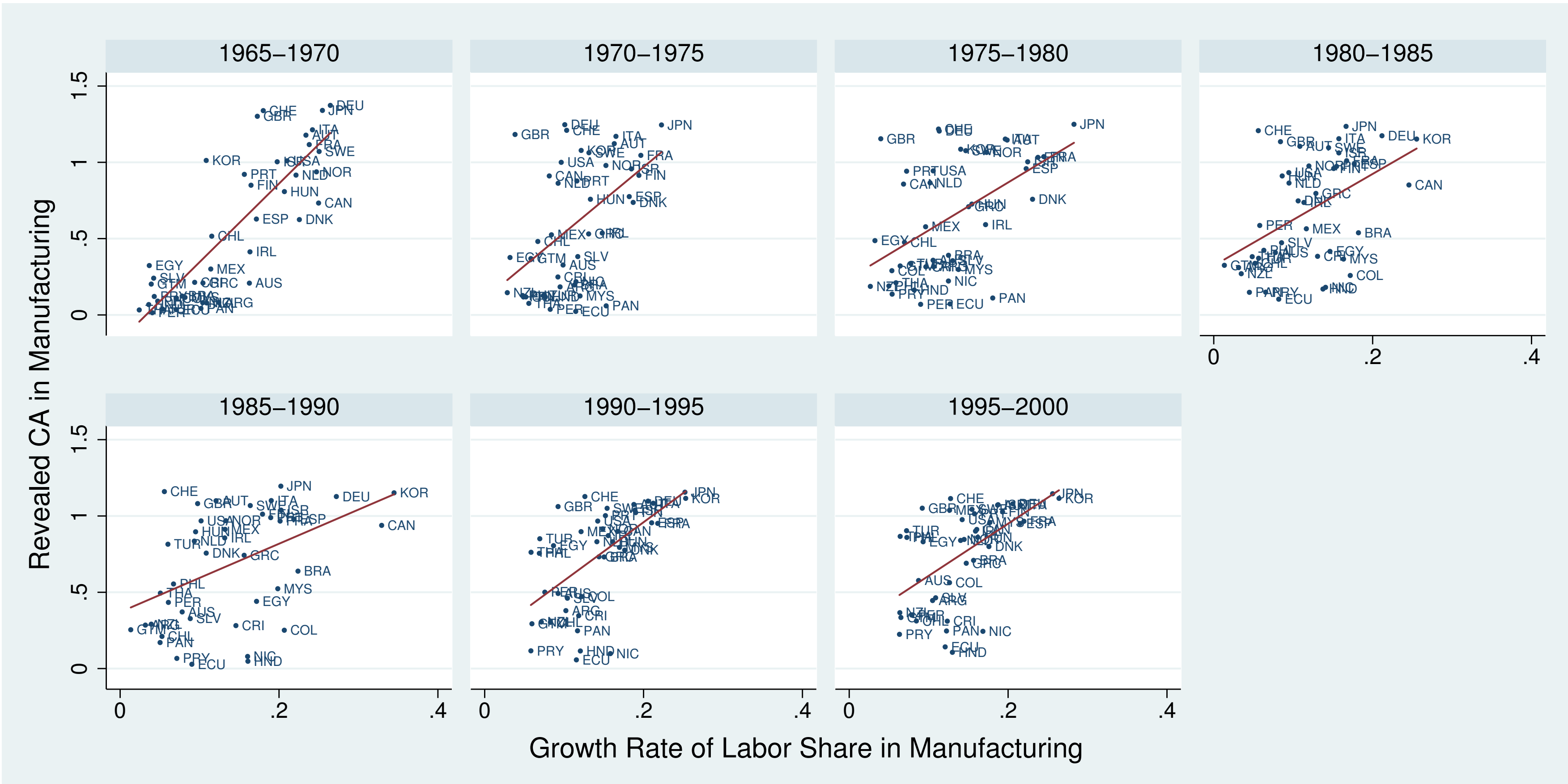


Figure 3.2: Relationship between RCA in Manufacturing and Growth Rate of Manufacturing Labor Share

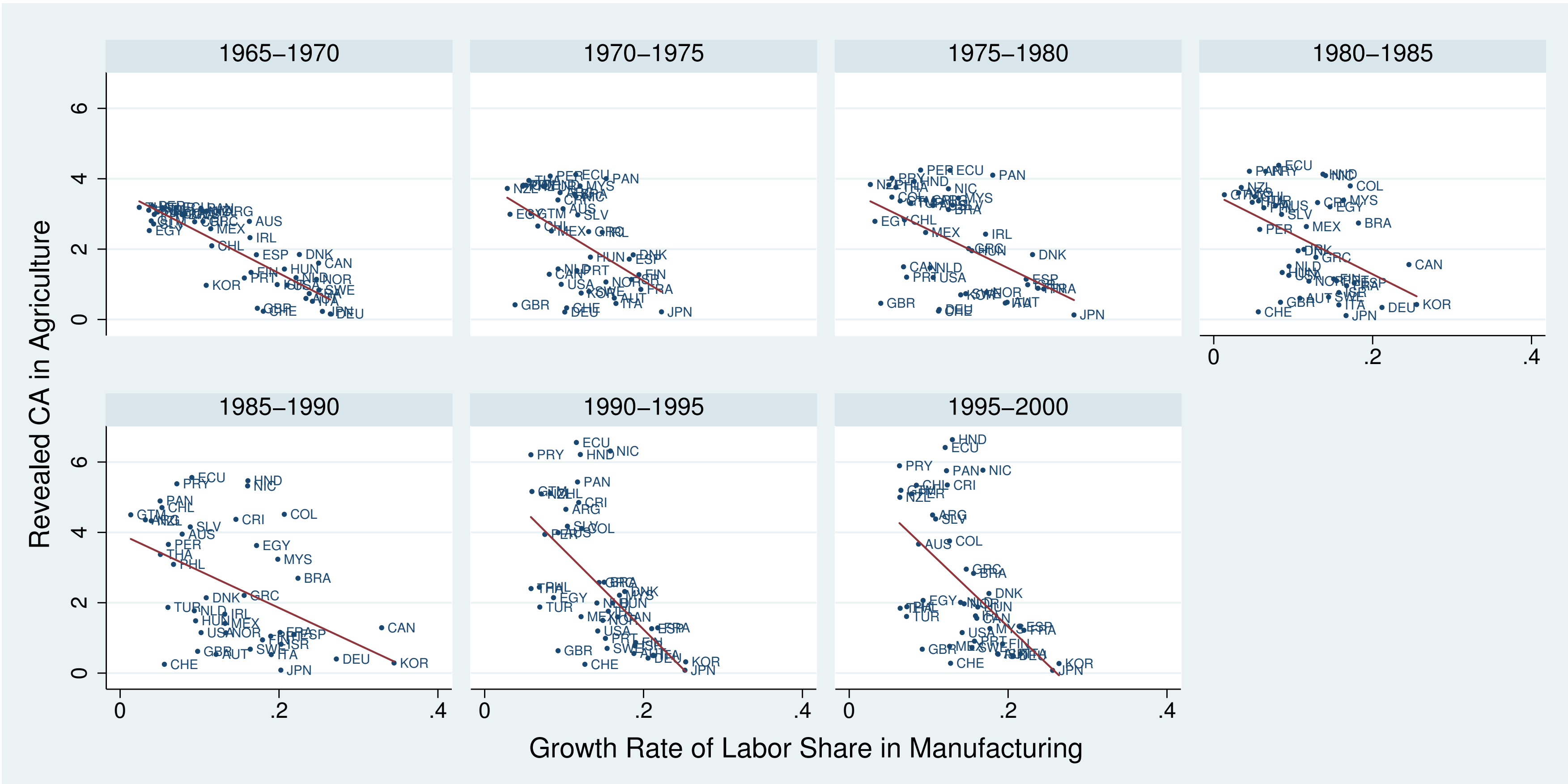


Figure 3.3: Relationship between RCA in Agriculture and Growth Rate of Manufacturing Labor Share

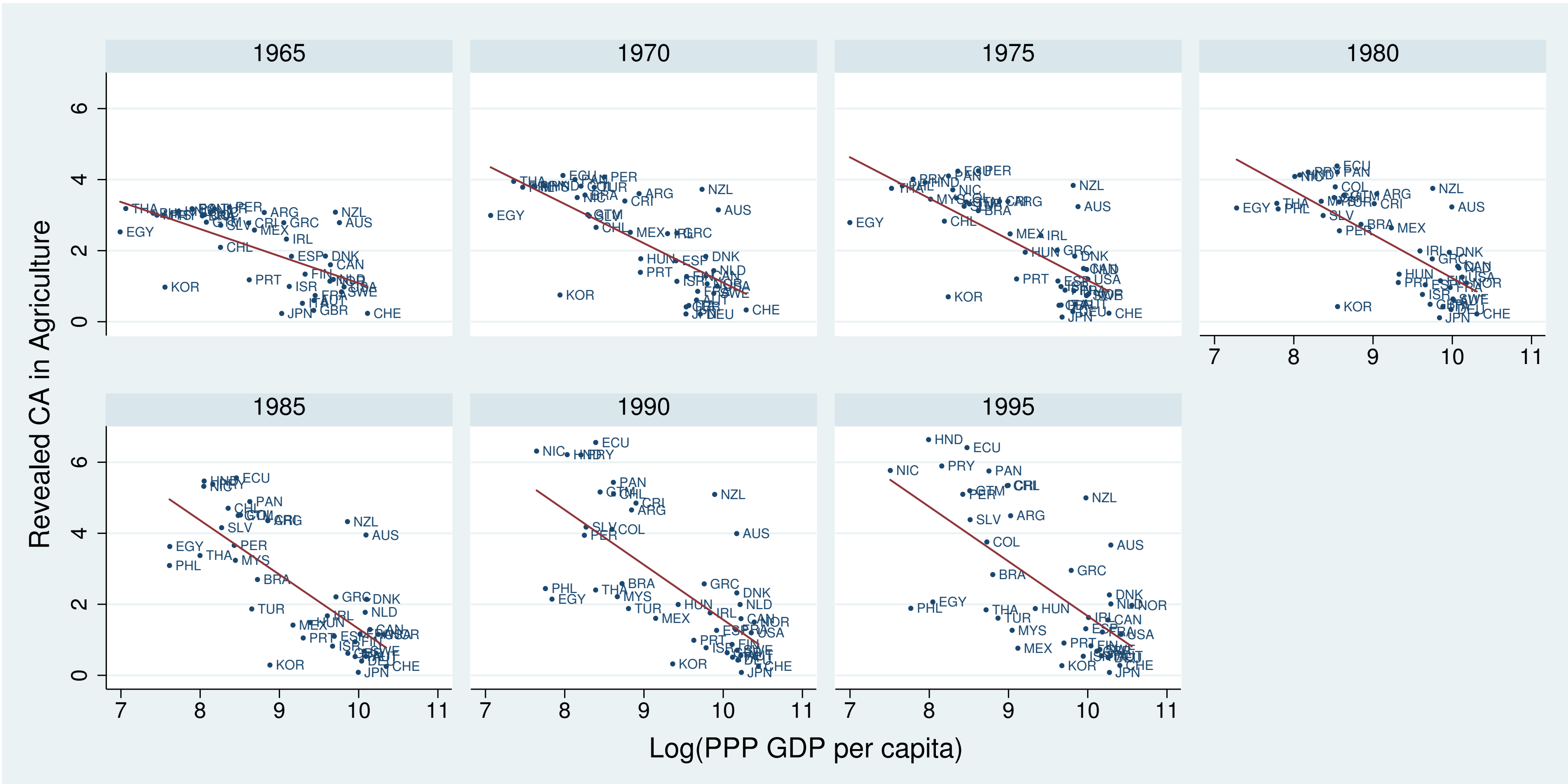


Figure 3.4: Relationship between RCA in Agriculture and Log of PPP GDP per capita

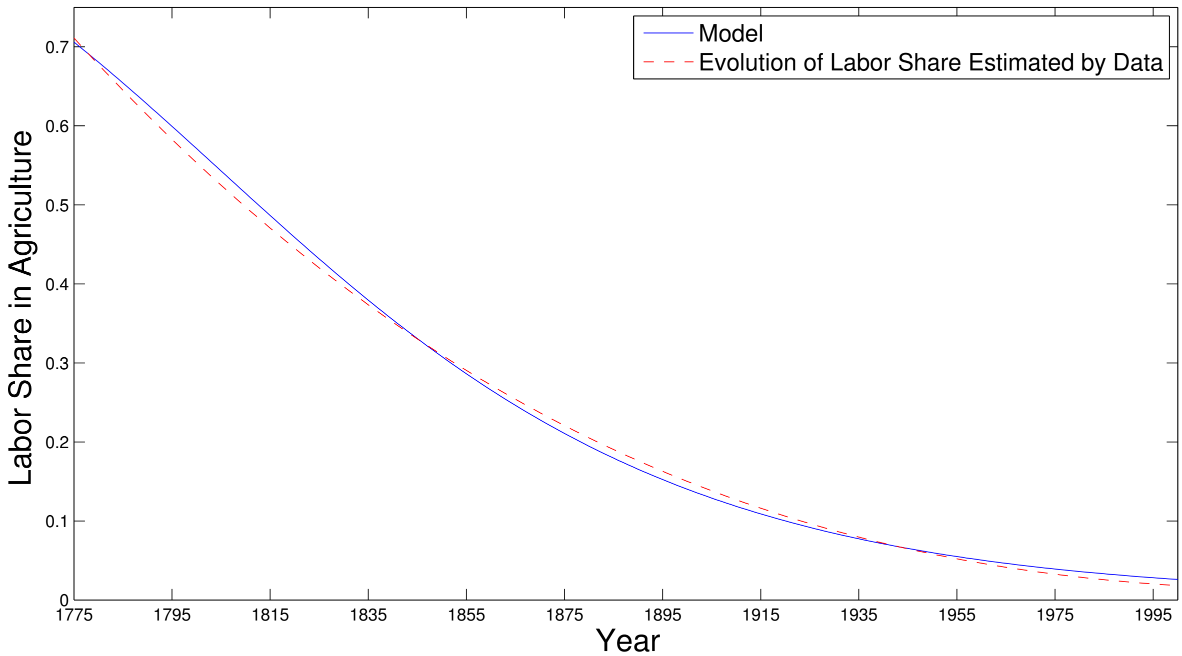


Figure 3.5: The Evolution of Labor Share in Agriculture for U.K.

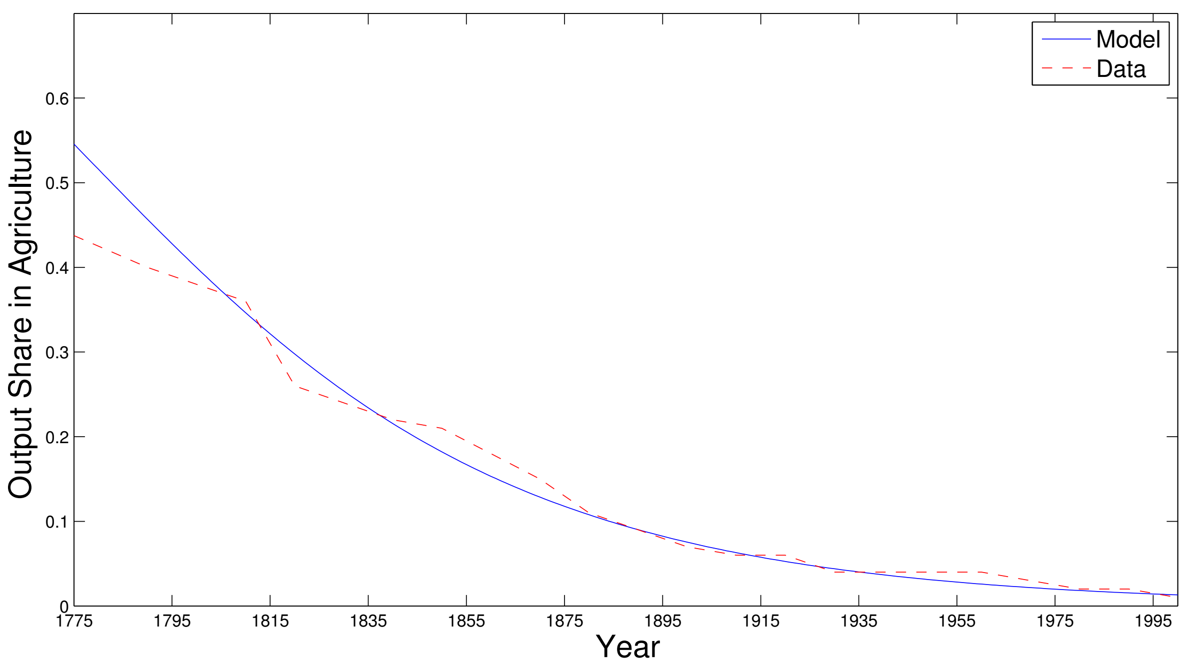


Figure 3.6: The Evolution of Output Share in Agriculture for U.K.

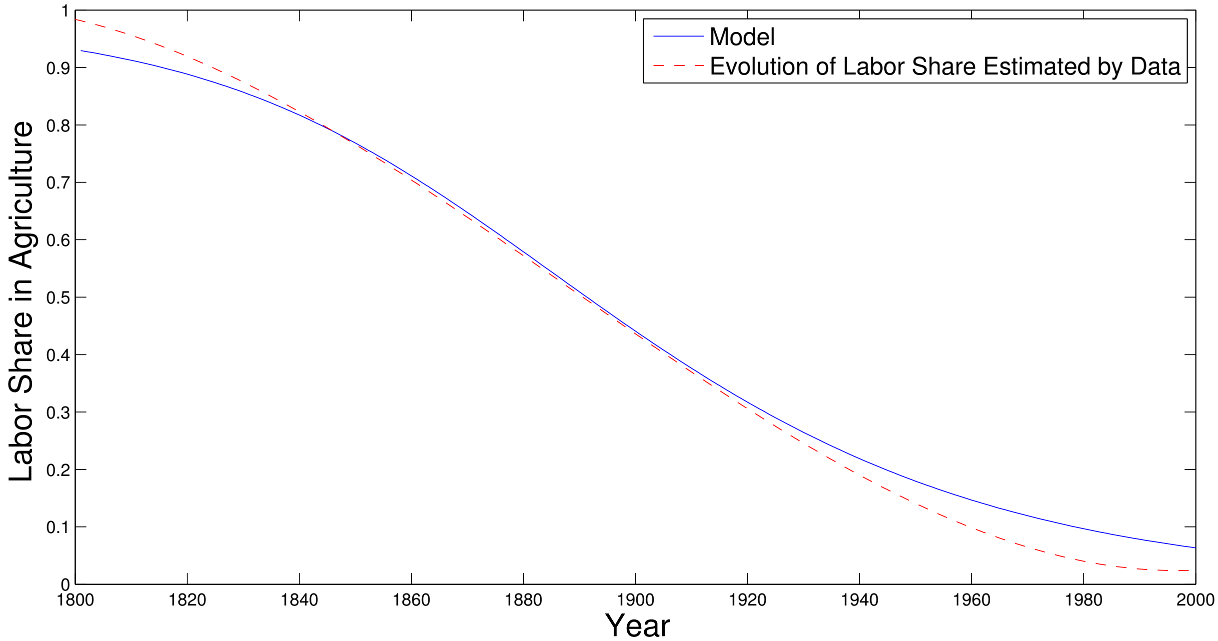


Figure 3.7: The Evolution of Labor Share in Agriculture for U.S.

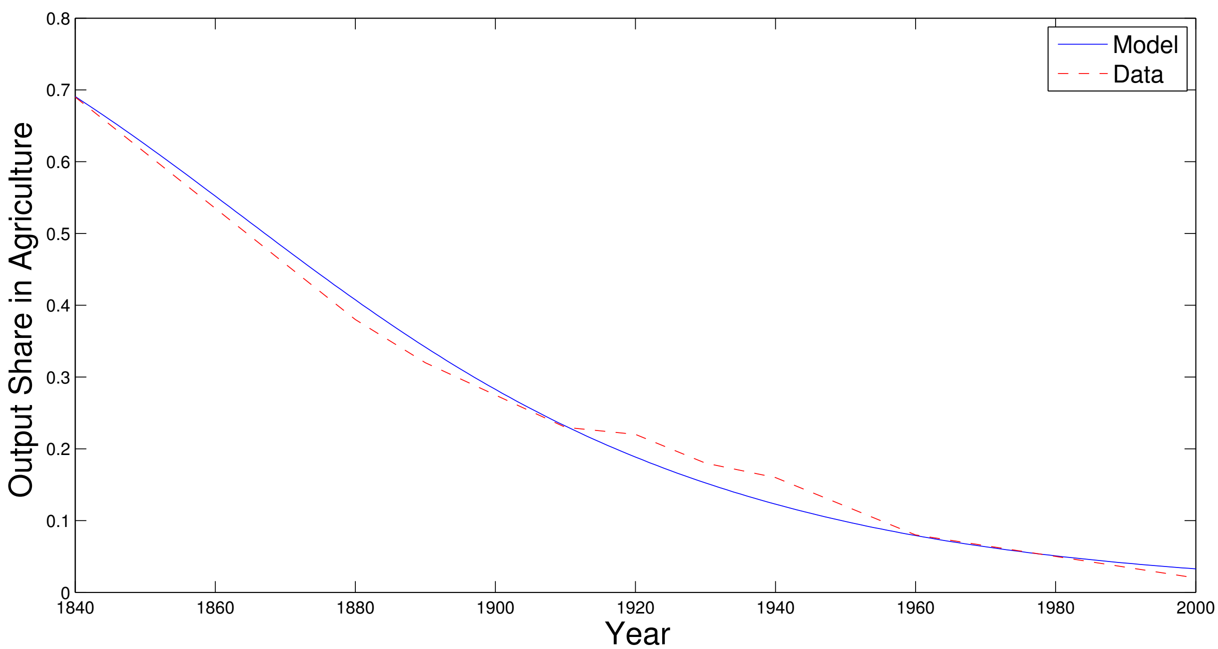


Figure 3.8: The Evolution of Output Share in Agriculture for U.S.

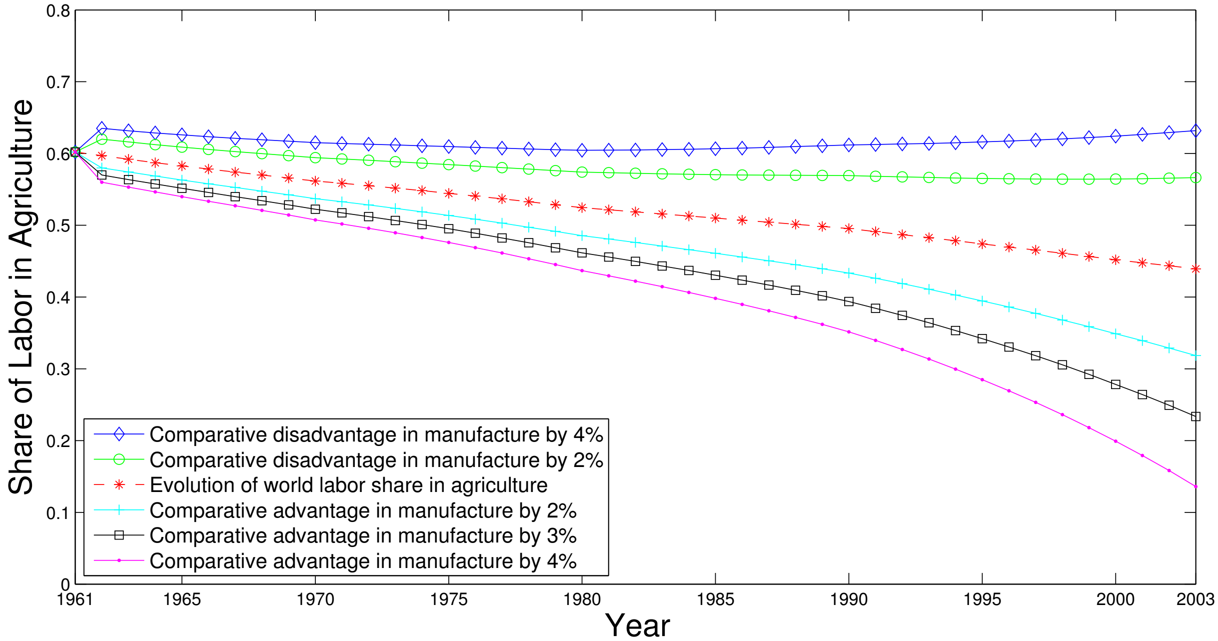


Figure 3.9: The Evolution of Labor Share in Agriculture corresponding to Comparative Advantage

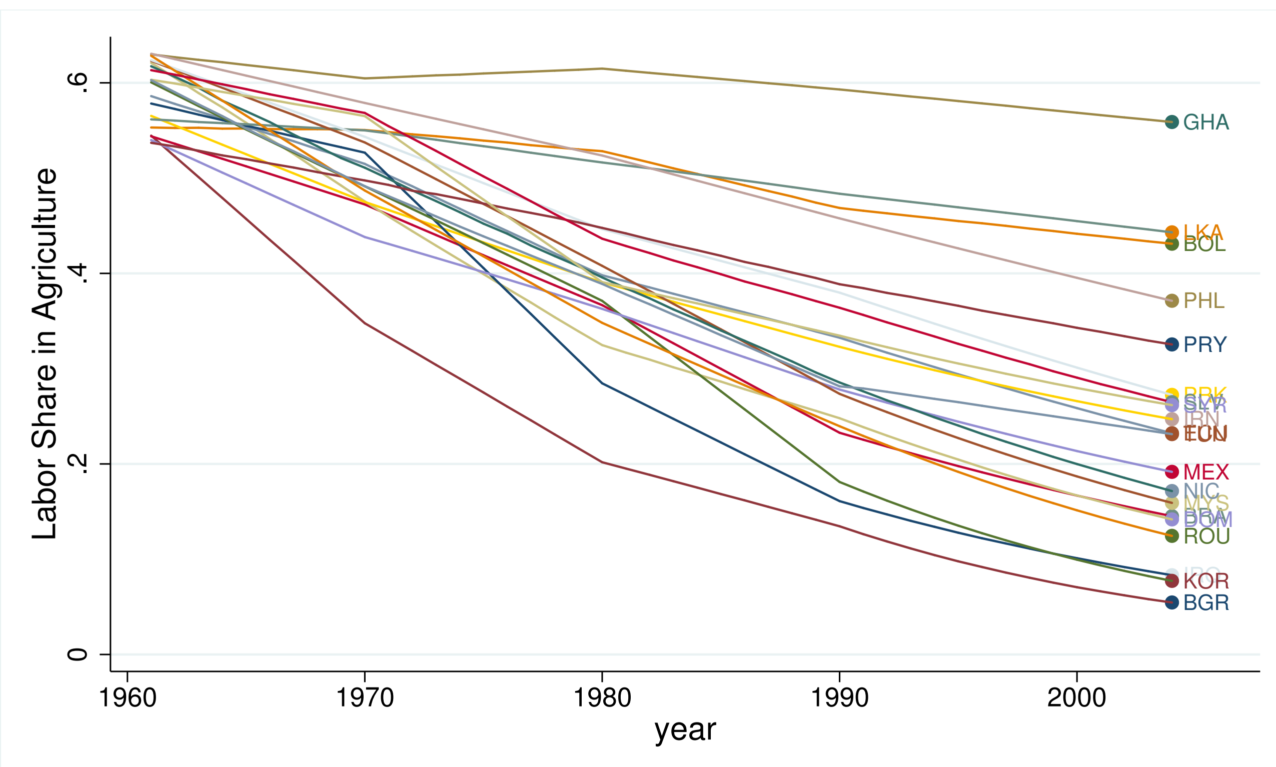


Figure 3.10: The Evolution of Labor Share in Agriculture across Countries

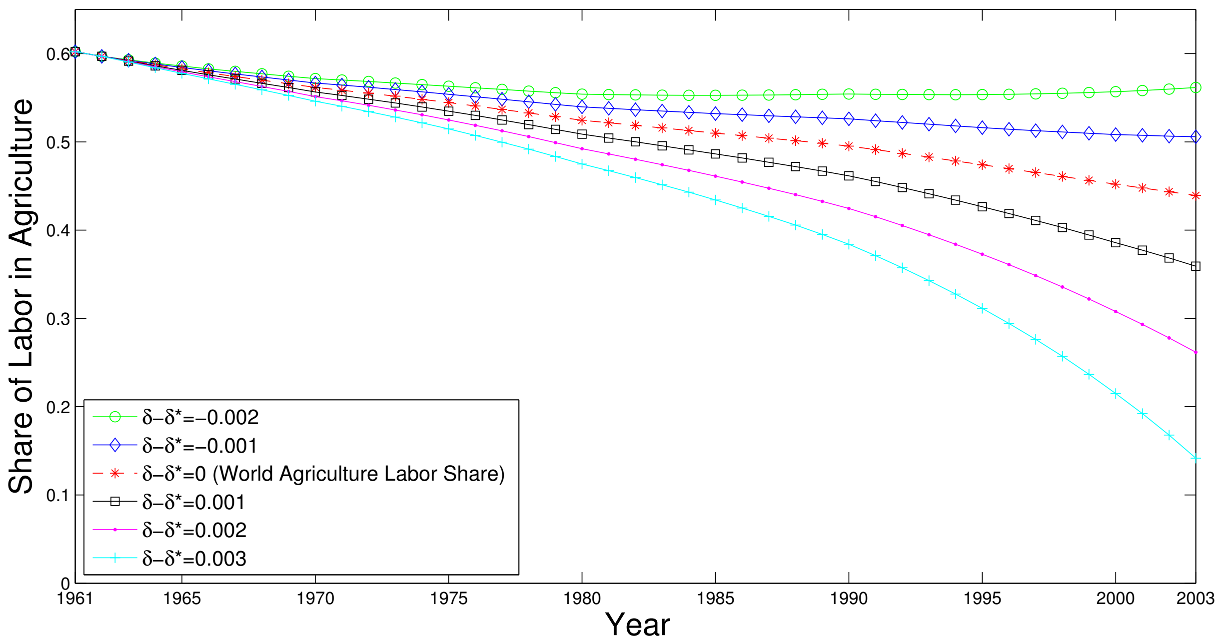


Figure 3.11: The Evolution of Labor Share in Agriculture corresponding to Different Learning-by-doing Parameters

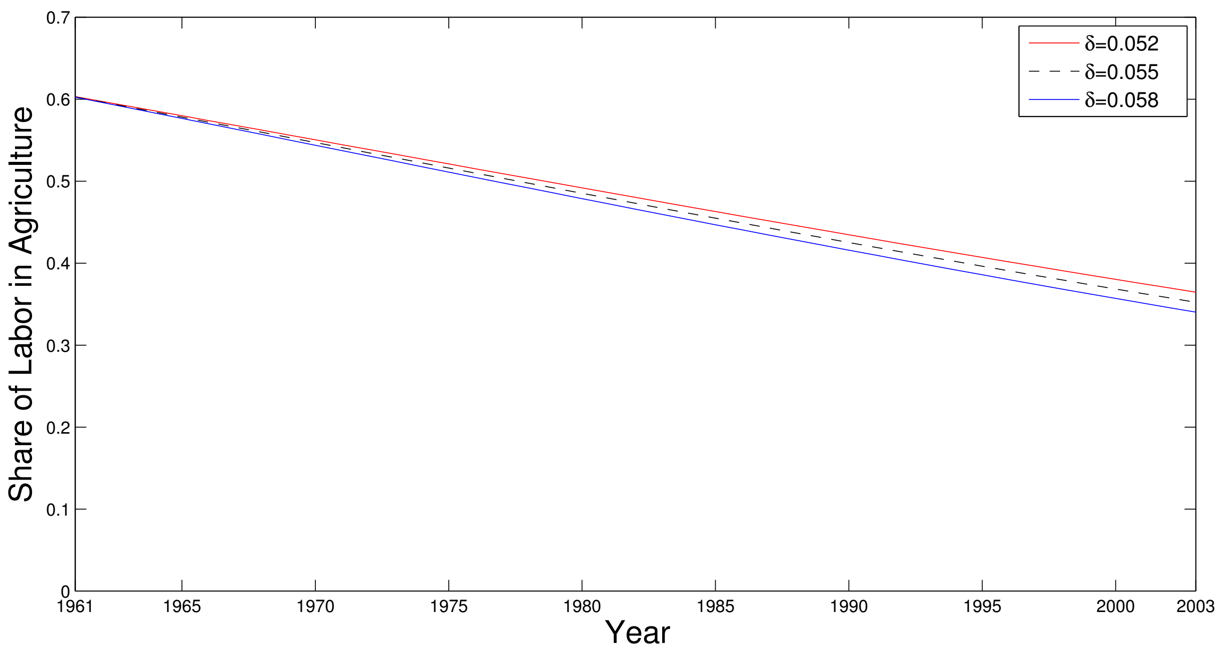


Figure 3.12: The Evolution of Labor Share in Agriculture under Closed Economy

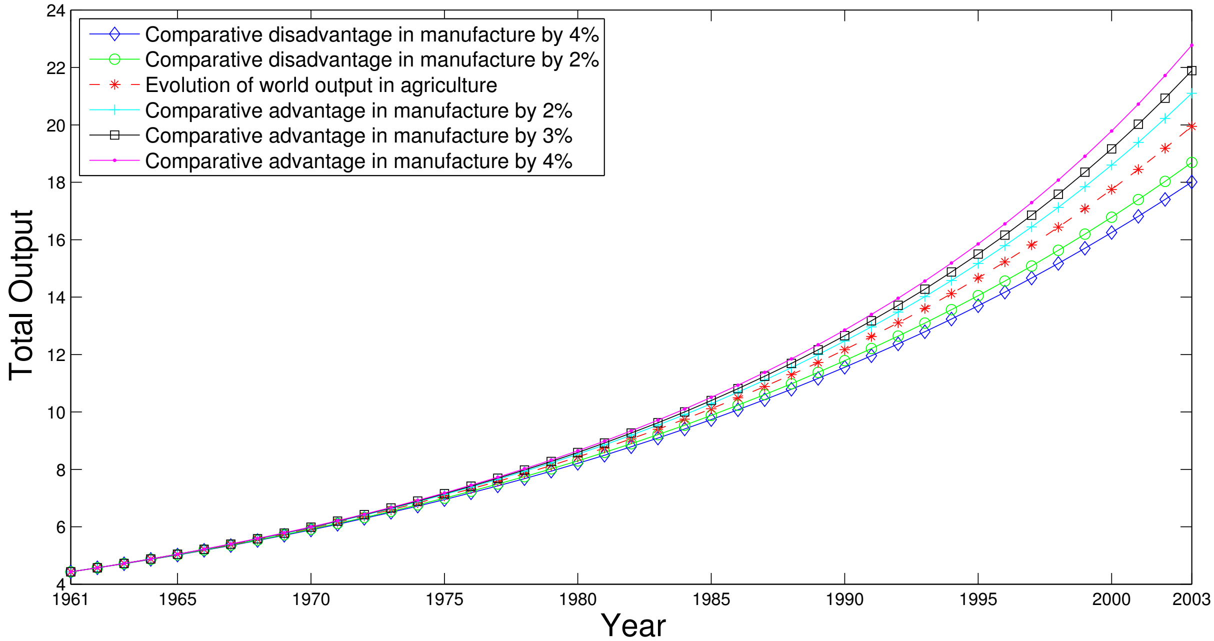


Figure 3.13: The Evolution of Total Output (GDP) corresponding to Comparative Advantage

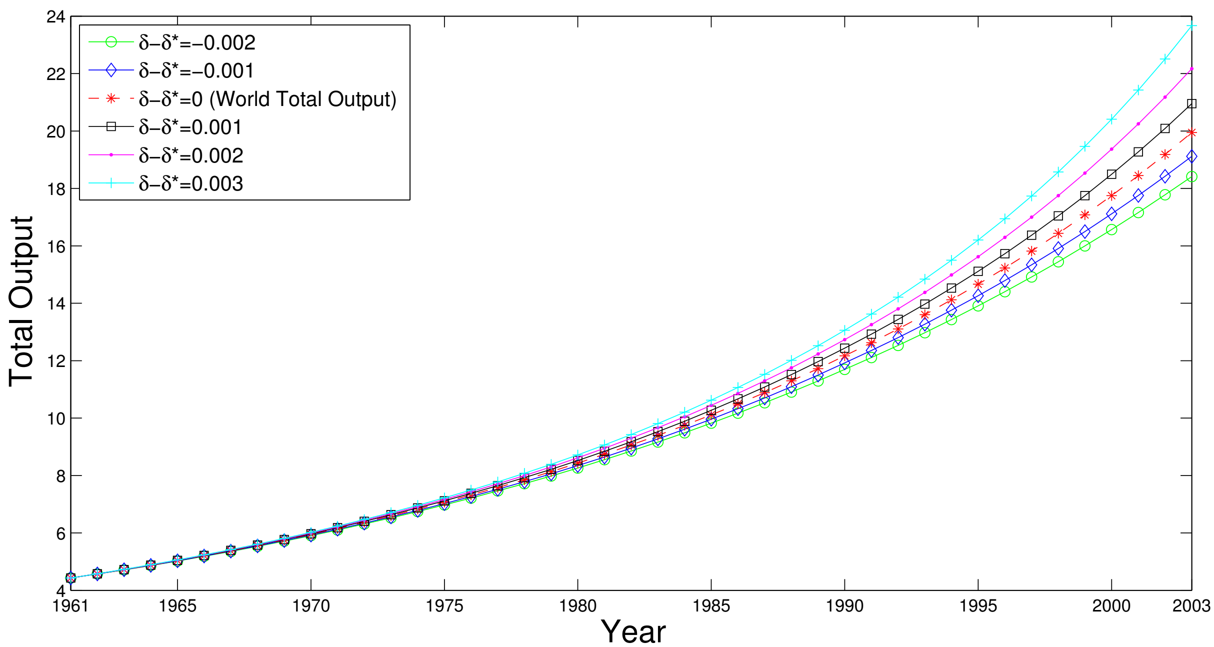


Figure 3.14: The Evolution of Total Output (GDP) corresponding to Different Learning-by-doing Parameters

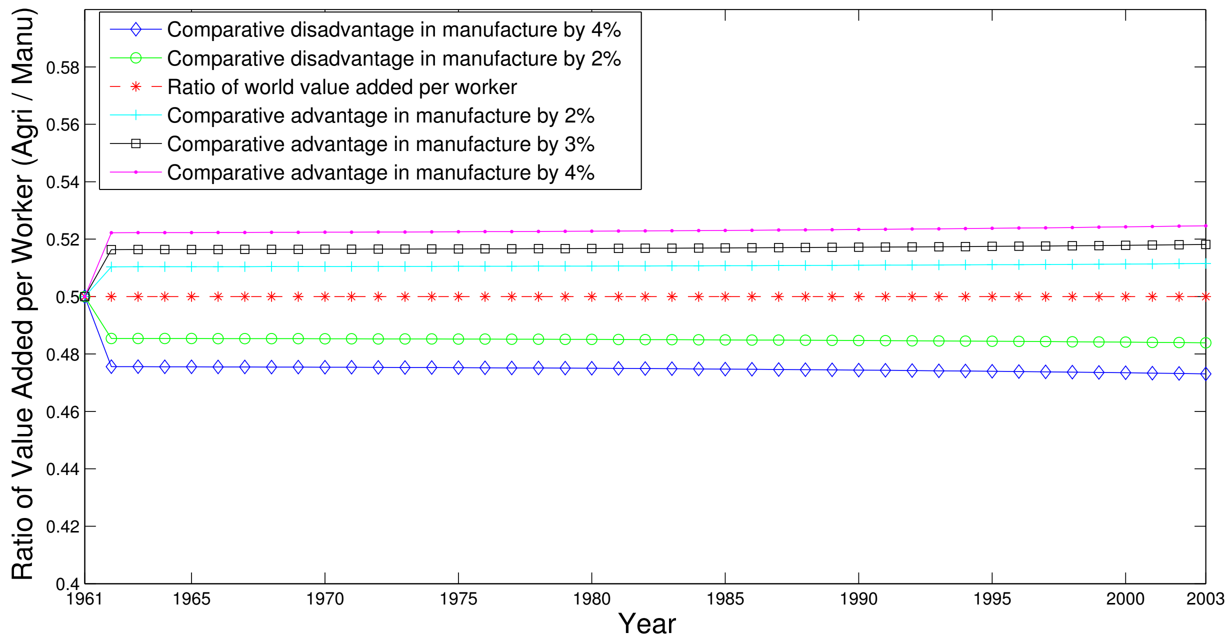


Figure 3.15: The Evolution of Value Added per worker corresponding to Comparative Advantage

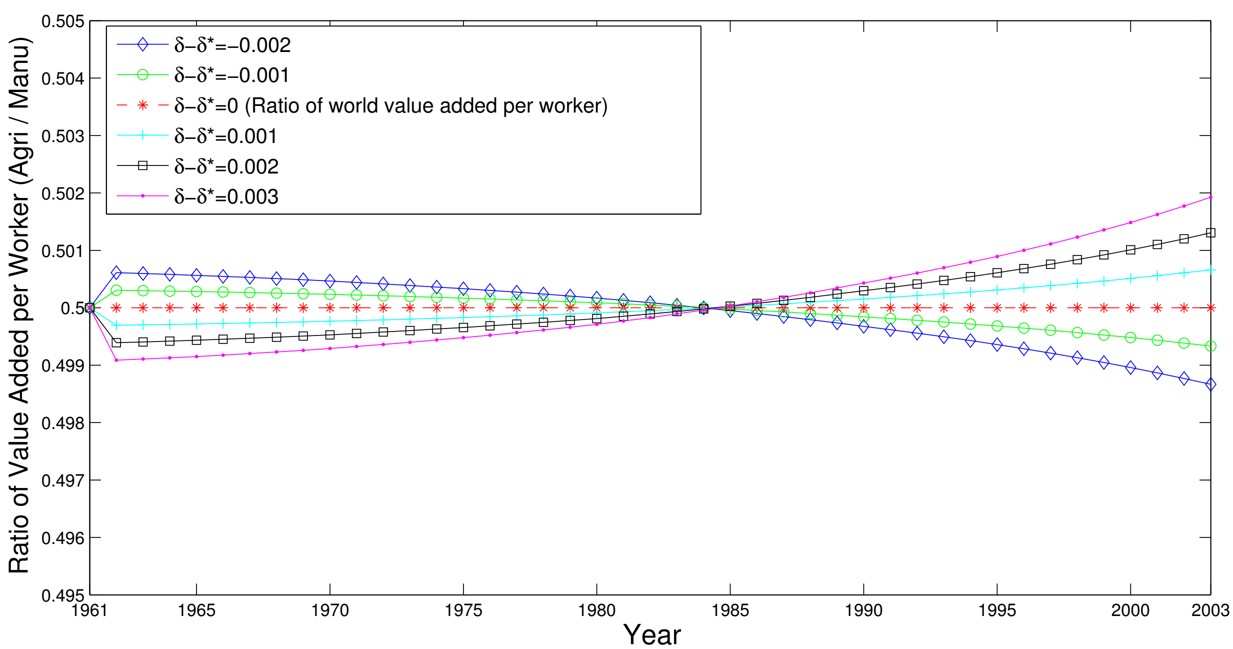


Figure 3.16: The Evolution of Value Added per worker corresponding to Different Learning-by-doing Parameters

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Appendix A

Appendix (For Chapter 1)

A.1 Estimation Results using the ten largest exporting countries

For only manufacturing sectors, I estimate the gravity equation (1.2) by country-product fixed effects. First, I use the full sample which is reported in column (1) below. In column (2), I restrict the sample by discarding export flows below 20 units as outliers. In column (3), observations in the full sample are restricted by only differentiated products. The estimation results are shown in Table A.1.

Table A.1: Estimation Results with Interaction Terms using the ten largest exporting countries

	Log(Unit Value) *(Full Sample)*	*Log(Unit Value)* *(Restricted Sample)*	*Log(Unit Value)* *(Only Differentiated Goods)*
Log(Y_j)	0.125^{***}(3.05)	0.127^{***}(3.45)	0.120^{***}(3.05)
Log(Y_j)*Log(Y/L)$_i$	-0.012^{***} (-3.36)	-0.013^{***}(-3.47)	-0.012^{***}(-2.90)
Log (Y/L)$_j$	-0.061(-1.07)	-0.038(-0.74)	-0.006(-0.12)
Log(Y/L)$_j$*Log(Y/L)$_i$	0.012^{**}(2.15)	0.010^{**}(2.04)	0.007(1.37)
Log (Dist)	-0.453^{***}(-4.75)	-0.485^{***}(-5.36)	-0.516^{***}(-5.10)
Log(Dist)*Log(Y/L)$_i$	0.051^{***}(5.79)	0.052^{***}(6.34)	0.054^{***}(5.88)
Landlocked	0.129^{***}(3.39)	0.113^{***}(3.25)	0.096^{***}(2.73)
Common Legal	-0.013(-1.01)	-0.003 (-0.30)	-0.009 (-0.79)
Common Language	-0.071^{***}(-3.99)	-0.054^{***}(-3.45)	-0.050^{***} (-3.04)
RTA	-0.108^{***}(-5.14)	-0.091^{***}(-5.03)	-0.089^{***}(-5.19)
WTO	-0.065^{***}(-3.83)	-0.038^{***}(-2.84)	-0.041^{***} (-2.97)
Common Currency	0.001(0.03)	-0.024 (-1.01)	-0.019(-0.79)
Number of observation	1238534	1129038	742243
Number of product	4208	4207	2373

Notes: The estimator is the OLS with exporting county-product fixed effects. Sample includes 10 largest exporting countries: Brazil, China, France, Germany, India, Japan, Korea, Mexico, UK, and US. Robust t-statistics clustered by importing country are in parentheses. ***, **, and * refer to statistical significance at the 1 %, 5 %, and 10 % level, respectively.

A.2 Firms' Maximization Problem

Here, I solve the firms' maximization problem which is given by equation (1.7) to obtain the condition (1.8). For convenience, I rewrite the the maximization problem of firms with skill intensity θ:

$$\begin{aligned} \max_{\{q\}} \quad & p(\theta,q)x(\theta,q) - f - w(\theta)\left[1+\frac{q^{\phi}}{\theta}\right]x(\theta,q) \\ \text{s.t.} \quad & x(\theta,q) = q^{\sigma-1}\left[p(\theta,q)\right]^{-\sigma}\tilde{P}^{\sigma-1}E \\ \text{and} \quad & p(\theta,q) = \left(\frac{\sigma}{\sigma-1}\right)w(\theta)\left[1+\frac{q^{\phi}}{\theta}\right]. \end{aligned} \tag{A.1}$$

By substituting demand $x(\theta,q)$ into the firms' profit, the equation (A.1) above can be reduced as follows.

$$\begin{aligned} \max_{\{q\}} \quad & q^{\sigma-1}p^{1-\sigma}\tilde{P}^{\sigma-1}E - f - w\left[1+\frac{q^{\phi}}{\theta}\right]q^{\sigma-1}p^{-\sigma}\tilde{P}^{\sigma-1}E \\ \text{s.t} \quad & p = \left(\frac{\sigma}{\sigma-1}\right)w\left[1+\frac{q^{\phi}}{\theta}\right]. \end{aligned} \tag{A.2}$$

Now, the equation (A.2) can be rewritten as follows:

$$\max_{\{q\}} \quad \frac{1}{\sigma}\left(\frac{\sigma}{\sigma-1}\right)^{1-\sigma}q^{\sigma-1}w^{1-\sigma}\left(1+\frac{q^{\phi}}{\theta}\right)^{1-\sigma}\tilde{P}^{\sigma-1}E - f. \tag{A.3}$$

Taking the derivative with respect to product quality q gives the following first order condition:

$$\begin{aligned} &(\sigma-1)\frac{1}{\sigma}\left(\frac{\sigma}{\sigma-1}\right)^{1-\sigma}q^{\sigma-1}w^{1-\sigma}\left(1+\frac{q^{\phi}}{\theta}\right)^{1-\sigma}\tilde{P}^{\sigma-1}E- \\ &\qquad (1-\sigma)\frac{1}{\sigma}\left(\frac{\sigma}{\sigma-1}\right)^{1-\sigma}q^{\sigma-1}w^{1-\sigma}\left(1+\frac{q^{\phi}}{\theta}\right)^{-\sigma}\tilde{P}^{\sigma-1}E\frac{\phi}{\theta}q^{\phi-1} = 0. \end{aligned}$$

Rearranging yields the equation (1.8): $q^{*}(\theta) = \left(\frac{1}{\phi-1}\right)^{1/\phi}\theta^{1/\phi}$.

Appendix B

Proof of Proposition 2. (For Chapter 2)

B.1 Proof of Proposition 2.2.1

To prove this, two curves defined by the equilibrium conditions (2.13) and (2.19) must be uniquely intersected in the $(s/w, \theta^*)$ space. For convenience, I rewrite two equilibrium conditions (the free entry condition and the labor market clearing condition) as follows:

$$FE(\frac{s}{w}, \theta^*) = \left\{ \left(\frac{s}{w}\right)^{(\tilde{\theta}(\theta^*)-\theta^*)(1-\sigma)} \left(\frac{\tilde{\theta}(\theta^*)}{\theta^*}\right)^{\frac{\alpha(\sigma-1)}{\phi}} - 1 \right\} - \frac{\delta}{1-G(\theta^*)}\frac{f_e}{f} = 0, \tag{B.1}$$

$$LE(\frac{s}{w}, \theta^*) = \frac{\left(\frac{w}{s}\right) \int_{\theta^*}^{1} \left(\frac{s}{w}\right)^{\theta(1-\sigma)} \theta^{\frac{\alpha(\sigma-1)}{\phi}} \theta g(\theta) d\theta}{\int_{\theta^*}^{1} \left(\frac{s}{w}\right)^{\theta(1-\sigma)} \theta^{\frac{\alpha(\sigma-1)}{\phi}} (1-\theta) g(\theta) d\theta} - \frac{H}{L} = 0, \tag{B.2}$$

where the weighted average skill intensity $\tilde{\theta}(\theta^*)$ is given by equation (2.10).

First, I show that the free entry condition (equation (B.1)) gives a negative association between s/w and θ^* using the implicit function theorem.

$$\frac{\partial FE(s/w, \theta^*)}{\partial (s/w)} = (1-\sigma)(\tilde{\theta}(\theta^*)-\theta^*)\left(\frac{s}{w}\right)^{(\tilde{\theta}(\theta^*)-\theta^*)(1-\sigma)-1}\left(\frac{\tilde{\theta}(\theta^*)}{\theta^*}\right)^{\frac{\alpha(\sigma-1)}{\phi}} < 0.$$

where the inequality holds because the constant term, $(1-\sigma)$, is negative. By the second fundamental theorem of calculus, taking the derivative with respect to θ^* gives

$$\begin{aligned}\frac{\partial FE(s/w, \theta^*)}{\partial \theta^*} =& \xi(s/w, \theta^*)\left\{ \tilde{\theta}'(\theta^*)\left[\frac{\alpha}{\tilde{\theta}(\theta^*)} - \ln(\frac{s}{w})\phi\right] - \left[\frac{\alpha}{\theta^*} - \ln(\frac{s}{w})\phi\right]\right\} \\ & - \delta\frac{f_e}{f}\frac{g(\theta^*)}{(1-G(\theta^*))^2} < 0,\end{aligned}$$

where $\xi(s/w, \theta^*) = \frac{\sigma-1}{\phi}\left(\frac{s}{w}\right)^{(\tilde{\theta}(\theta^*)-\theta^*)(1-\sigma)}\left(\frac{\tilde{\theta}(\theta^*)}{\theta^*}\right)^{\frac{\alpha(\sigma-1)}{\phi}}$ is positive. $\tilde{\theta}'(\theta^*)$ denotes the derivative of the weighted average skill intensity with respect to θ^*. By the second fundamental theorem of calculus, taking the derivative of equation (2.10) with respect to θ^* gives:

$$\tilde{\theta}'(\theta^*) = \frac{1}{1-\sigma}\left(\int_{\theta^*}^{1} \theta^{\sigma-1}\frac{g(\theta)}{1-G(\theta^*)}d\theta\right)^{\frac{1}{\sigma-1}-1}(\theta^*)^{\sigma-1}\frac{g(\theta^*)}{1-G(\theta^*)}.$$

Since $\sigma > 1$, $\tilde{\theta}'(\theta^*)$ is negative. Thus, the inequality, $\frac{\partial FE(s/w,\theta^*)}{\partial\theta^*} < 0$, holds because of the assumption that I take in the previous section, $\alpha > \ln(\frac{s}{w})\phi$, which implies that the firms revenue/profitability increases with the skill intensity as well as with product quality. Therefore, two equilibrium variables (s/w and θ^*) have a negative relationship, which is established by using the implicit function theorem:

$$\frac{d(\frac{s}{w})}{d\theta^*} = -\frac{\partial FE(\frac{s}{w},\theta^*)/\partial\theta^*}{\partial FE(\frac{s}{w},\theta^*)/\partial(\frac{s}{w})} < 0.$$

Second, the free entry condition (B.1) implies that $s/w \to \infty$ as $\theta^* \to 0$, while $s/w \to 0$ as $\theta^* \to 1$: as θ^* goes to zero, the skill premium s/w has to increase as much as possible for $FE(s/w,\theta^*) = 0$. As θ^* increases, on the other hand, s/w must decrease as quickly as possible for $FE(s/w,\theta^*) = 0$ so that s/w goes to zero.

To complete this proof, I need to show that the labor market clearing condition gives a positive link between θ^* and s/w. Unfortunately, equation (B.2) cannot be solved analytically using the implicit function theorem. To establish a positive link between θ^* and s/w, I follow the method introduced by Harrigan and Reshef (2011) where they effectively prove it. I begin with the labor market clearing condition, equation (2.19):

$$\frac{\int_{\theta^*}^{1} D_h(\theta,\frac{s}{w})g(\theta)d\theta}{\int_{\theta^*}^{1} D_l(\theta,\frac{s}{w})g(\theta)d\theta} = \frac{H}{L}.$$

Since $\frac{D_h(\theta,\frac{s}{w})}{D_l(\theta,\frac{s}{w})} = \frac{\theta}{1-\theta}\left(\frac{w}{s}\right)$, which is from equation (2.16), I can rewrite equation above as follows:

$$\frac{\left(\frac{w}{s}\right)\int_{\theta^*}^{1}\left(\frac{\theta}{1-\theta}\right)D_l(\theta,\frac{s}{w})g(\theta)d\theta}{\int_{\theta^*}^{1} D_l(\theta,\frac{s}{w})g(\theta)d\theta} = \frac{H}{L}.$$

where $\left(\frac{\theta}{1-\theta}\right)$ represents the ratio of skilled to unskilled labor employed by firms with θ. By defining $\Psi(\theta,s/w,\theta^*) = \frac{D_l(\theta,\frac{s}{w})}{\int_{\theta^*}^{1} D_l(\theta,\frac{s}{w})g(\theta)d\theta}$, the labor market clearing condition can be rewritten as:

$$\left(\frac{w}{s}\right)\int_{\theta^*}^{1}\left(\frac{\theta}{1-\theta}\right)\Psi(\theta,\frac{s}{w},\theta^*)g(\theta)d\theta = \frac{H}{L}.$$

where $\Psi(\theta,\frac{s}{w},\theta^*)$ can be interpreted as the share of unskilled labor that works for firms with θ. The above Equation indicates that the relative endowment of skilled labor (H/L) is equal to the average of the firm level skill ratios weighted by the firm's unskilled labor share. Now I examine how the increase in θ^* affects the skill premium, s/w. The increase in skill intensity θ^* implies that the least profitable firms, which are less skill intensive than average, exit so that the weighted average of the skill ratio of the surviving firms increases (i.e., $\int_{\theta^*}^{1}\left(\frac{\theta}{1-\theta}\right)\Psi(\theta,\frac{s}{w},\theta^*)g(\theta)d\theta \nearrow$). To keep the same level of the left hand side of equation above, the relative wage of skilled to unskilled labor (s/w) should be higher. Thus I confirm that the zero profit cut-off, θ^*, is positively associated with the skill premium s/w along the labor market clearing equation. The intuition behind the positive link between θ^* and s/w is that an increase in θ^* leads to an incipient relative excess in demand for skilled labor, which results in raising the relative skilled worker wage. Now I confirm that the equilibrium variables θ^* and s/w are determined uniquely. ■

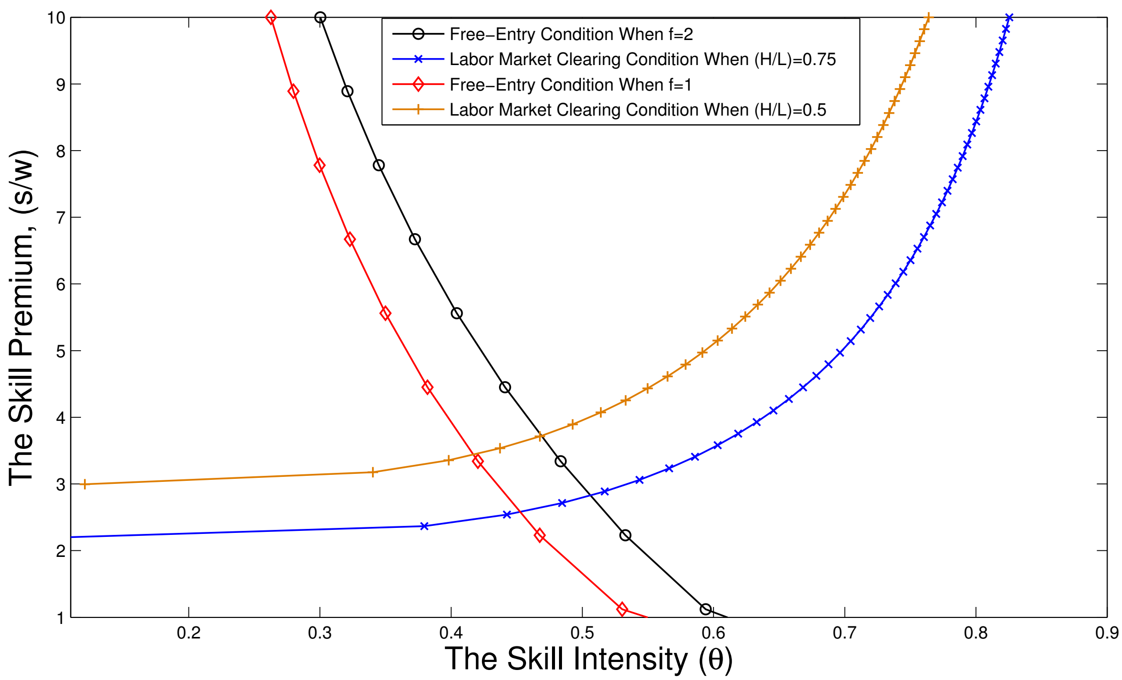

Figure B.1: Free Entry and Labor Market Equilibrium Curves in Autarky

Figure B.1 illustrates the existence of the equilibrium skill intensity cut-off, θ^*, and the skill premium, s/w, at which the free entry condition (equation (2.10) and (2.13)) and the labor market clearing condition (equation (2.19)) are intercepted. For Figure B.1, I assume that all parameters are the same as noted in the numerical exercise (section 2.3.4). In addition, I assume that the relative abundance of skilled labor H/L is either 0.5 or 0.75 and that the fixed production cost, f, is either 1 or 2.[1]

As shown in Figure B.1, the decline of fixed cost f shifts the free entry curve to the left and the increase in the relative abundance of skilled labor H/L shifts the labor market curve to the right. These are all four possible equilibria, which depend on the value of H/L and f. The equilibrium skill intensity cut-off and the skill premium, in each equilibrium, are also shown in Table 2.1.

B.2 Proof of Proposition 2.2.2

Conveniently, I rewrite the costly trade equilibrium conditions under the symmetric assumption as follows: First equation (B.3) links the equilibrium variables of interest (s/w, θ_d^* and θ_x^*), which depend on trade costs. Equations (B.4) and (B.5) represent the free entry condition and labor market clearing condition respectively.

$$\left(\frac{s}{w}\right)^{-(\theta_x^*-\theta_d^*)}\left(\frac{\theta_x^*}{\theta_d^*}\right)^{\frac{\alpha}{\phi}}=\tau\left(\frac{f_x}{f}\right)^{\frac{1}{\sigma-1}}. \tag{B.3}$$

$$\begin{aligned}FE(s/w,\theta_d^*)=&[1-G(\theta_d^*)]f\left[\left(\frac{s}{w}\right)^{(\tilde{\theta}_d(\theta_d^*)-\theta_d^*)(1-\sigma)}\left(\frac{\tilde{\theta}_d(\theta_d^*)}{\theta_d^*}\right)^{\frac{\alpha(\sigma-1)}{\phi}}-1\right]+\\&[1-G(\theta_x^*)]f_x\left[\left(\frac{s}{w}\right)^{(\tilde{\theta}_x(\theta_x^*)-\theta_x^*)(1-\sigma)}\left(\frac{\tilde{\theta}_x(\theta_x^*)}{\theta_x^*}\right)^{\frac{\alpha(\sigma-1)}{\phi}}-1\right]-\delta f_e.\end{aligned} \tag{B.4}$$

$$LE(s/w,\theta_d^*)=\frac{\left(\frac{w}{s}\right)\left[\int_{\theta_d^*}^1\left(\frac{s}{w}\right)^{\theta(1-\sigma)}\theta^{\frac{\alpha(\sigma-1)}{\phi}}\theta g(\theta)d\theta+\tau^{-\sigma}\int_{\theta_x^*}^1\left(\frac{s}{w}\right)^{\theta(1-\sigma-1)}\theta^{\frac{\alpha(\sigma-1)}{\phi}}\theta g(\theta)d\theta\right]}{\left[\int_{\theta_d^*}^1\left(\frac{s}{w}\right)^{\theta(1-\sigma)}\theta^{\frac{\alpha(\sigma-1)}{\phi}}(1-\theta)g(\theta)d\theta+\tau^{-\sigma}\int_{\theta_x^*}^1\left(\frac{s}{w}\right)^{\theta(1-\sigma)}\theta^{\frac{\alpha(\sigma-1)}{\phi}}(1-\theta)g(\theta)d\theta\right]}-\frac{H}{L}. \tag{B.5}$$

where the weighted average skill intensity for each market, $\tilde{\theta}_d(\theta_d^*)$ and $\tilde{\theta}_x(\theta_x^*)$ are given by equations (2.27). Note that the export skill intensity cut-off is a function of both the skill premium and the zero-profit skill intensity cut-off, that is, $\theta_x^*(s/w,\theta_d^*)$ given by equation (B.3). Based on equation (B.3), it can easily be shown that $\frac{\partial\theta_x^*}{\partial(s/w)}>0$ and $\frac{\partial\theta_x^*}{\partial\theta_d^*}>0$.

In the first step, I show that the free entry condition given by equation (B.4) has a downward slope in the $(s/w,\theta_d^*)$ space using the implicit function theorem: $\frac{d(\frac{s}{w})}{d\theta_d^*}=-\frac{\partial FE(\frac{s}{w},\theta_d^*)/\partial\theta_d^*}{\partial FE(\frac{s}{w},\theta_d^*)/\partial(\frac{s}{w})}<0$. A tedious amount of

[1] As noted in the section for the numerical exercise, I assume that the skill intensity is normally distributed with $\mu=.5$ and $s.d=0.15$ so that the skilled intensity θ is distributed over $[0,1]$.

manipulation gives

$$\begin{aligned}\frac{\partial FE(s/w,\theta_d^*)}{\partial s/w} =&[1-G(\theta_d^*)]f(1-\sigma)[\tilde{\theta}_d(\theta_d^*)-\theta_d^*]\left(\frac{s}{w}\right)^{(\tilde{\theta}_d(\theta_d^*)-\theta_d^*)(1-\sigma)-1}\left(\frac{\tilde{\theta}(\theta_d^*)}{\theta_d^*}\right)^{\frac{\alpha(\sigma-1)}{\phi}}\\ &-g(\theta_x^*)\frac{\partial\theta_x^*}{\partial(s/w)}f_x\left[\left(\frac{s}{w}\right)^{(\tilde{\theta}_x(\theta_x^*)-\theta_x^*)(1-\sigma)}\left(\frac{\tilde{\theta}_x(\theta_x^*)}{\theta_x^*}\right)^{\frac{\alpha(\sigma-1)}{\phi}}-1\right]\\ &+\psi(s/w,\theta_x^*)\left\{\tilde{\theta}_x'(\theta_x^*)\frac{\partial\theta_x^*}{\partial(s/w)}\left[\frac{\alpha}{\tilde{\theta}_x(\theta_x^*)}-\ln\left(\frac{s}{w}\right)\phi\right]-\right.\\ &\left.\frac{\partial\theta_x^*}{\partial(s/w)}\left[\frac{\alpha}{\theta_x^*}-\ln\left(\frac{s}{w}\right)\phi\right]-\left(\frac{s}{w}\right)(\tilde{\theta}_x(\theta_x^*)-\theta_x^*)\phi\right\}<0,\end{aligned}$$

where $\psi(s/w,\theta_x^*)=[1-G(\theta_x^*)]f_x\left(\frac{\sigma-1}{\phi}\right)\left(\frac{s}{w}\right)^{(\tilde{\theta}_x(\theta_x^*)-\theta_x^*)(1-\sigma)}\left(\frac{\tilde{\theta}_x(\theta_x^*)}{\theta_x^*}\right)^{\frac{\alpha(\sigma-1)}{\phi}}$ is positive. Note that $\phi>1$, $\sigma>1$, $\alpha>0$, and $\tilde{\theta}_x'(\theta_x^*)<0$. The inequality, $\frac{\partial FE(s/w,\theta_d^*)}{\partial(s/w)}<0$, holds, due to the assumption of $\alpha>\ln(\frac{s}{w})\phi$.

$$\begin{aligned}\frac{\partial FE(s/w,\theta_d^*)}{\partial\theta_d^*} =&-g(\theta_d^*)f\left[\left(\frac{s}{w}\right)^{(\tilde{\theta}_d(\theta_d^*)-\theta_d^*)(1-\sigma)}\left(\frac{\tilde{\theta}_d(\theta_d^*)}{\theta_d^*}\right)^{\frac{\alpha(\sigma-1)}{\phi}}-1\right]+\\ &\upsilon(s/w,\theta_d^*)\left\{\tilde{\theta}_d'(\theta_d^*)\left[\frac{\alpha}{\tilde{\theta}_d}-\ln\left(\frac{s}{w}\right)\phi\right]-\left[\frac{\alpha}{\theta_d^*}-\ln\left(\frac{s}{w}\right)\phi\right]\right\}\\ &-g(\theta_x^*)\frac{\partial\theta_x^*}{\partial\theta_d^*}f_x\left[\left(\frac{s}{w}\right)^{(\tilde{\theta}_x(\theta_x^*)-\theta_x^*)(1-\sigma)}\left(\frac{\tilde{\theta}_x(\theta_x^*)}{\theta_x^*}\right)^{\frac{\alpha(\sigma-1)}{\phi}}-1\right]+\\ &\psi(s/w,\theta_x^*)\left\{\tilde{\theta}_x'(\theta_x^*)\frac{\partial\theta_x^*}{\partial\theta_d^*}\left[\frac{\alpha}{\tilde{\theta}_x}-\ln\left(\frac{s}{w}\right)\phi\right]-\frac{\partial\theta_x^*}{\partial\theta_d^*}\left[\frac{\alpha}{\tilde{\theta}_x}-\ln\left(\frac{s}{w}\right)\phi\right]\right\}<0,\end{aligned}$$

where $\upsilon(s/w,\theta_d^*)$ and $\psi(s/w,\theta_x^*)$ are both positive.[2] Since $\frac{\partial\theta_x^*}{\partial\theta_d^*}>0$ and $\alpha>\ln\left(\frac{s}{w}\right)\phi$, $\frac{\partial FE(s/w,\theta_d^*)}{\partial\theta_d^*}<0$. By the implicit function theorem, the free entry condition implies a negative relationship between θ_d^* and s/w, that is, $\frac{d(\frac{s}{w})}{d\theta_d^*}=-\frac{\partial FE(\frac{s}{w},\theta_d^*)/\partial\theta_d^*}{\partial FE(\frac{s}{w},\theta_d^*)/\partial(\frac{s}{w})}<0$. In addition, applying the same logic in the proof of the proposition 2.2.1, $s/w\to\infty$ as θ_d^* approaches to zero, while s/w approaches to zero as θ_d^* goes to one.

Second, to complete the proof, I need to show a positive relationship between θ_d^* and s/w. Applying the same logic presented in the proof of proposition 2.2.1, the equation (B.5) can be rewritten as:

$$\left(\frac{w}{s}\right)\left[\int_{\theta_d^*}^1\left(\frac{\theta}{1-\theta}\right)\Psi(\theta,\frac{s}{w},\theta_d^*)g(\theta)d\theta+\tau^{-\sigma}\int_{\theta_x^*(\theta_d^*)}^1\left(\frac{\theta}{1-\theta}\right)\Psi(\theta,\frac{s}{w},\theta_d^*)g(\theta)d\theta\right]=\frac{H}{L}.$$

Now it can be easily shown that the zero-profit skill intensity θ_d^* is positively associated with the skill premium s/w on the $(\theta_d^*,s/w)$ space using the same logic as in the proof of proposition 2.2.1. Thus equilibrium

[2] $\upsilon(s/w,\theta_d^*)=\left(\frac{\sigma-1}{\phi}\right)[1-G(\theta_d^*)]f\left(\frac{s}{w}\right)^{(\tilde{\theta}_d(\theta_d^*)-\theta_d^*)(1-\sigma)}\left(\frac{\tilde{\theta}_d(\theta_d^*)}{\theta_d^*}\right)^{\frac{\alpha(\sigma-1)}{\phi}}$ and $\psi(s/w,\theta_x^*)=\left(\frac{\sigma-1}{\phi}\right)[1-G(\theta_x^*)]f_x\left(\frac{s}{w}\right)^{(\tilde{\theta}_x(\theta_x^*)-\theta_x^*)(1-\sigma)}\left(\frac{\tilde{\theta}_x(\theta_x^*)}{\theta_x^*}\right)^{\frac{\alpha(\sigma-1)}{\phi}}$.

exists and is unique in the costly trade between symmetric countries. ■

B.3 Proof of Proposition 2.2.3

Now, I prove that the skill premium s/w increases as trade costs (i.e., τ and/or f_x) fall. To do this, I examine the shifts in each FE and LE curve in response to a reduction in trade costs. Without any loss of generality, I compare two curves in the autarky regime with ones in the costly trade condition. In this way, one can analyze the effect of lowering trade costs on the skill premium. First, I compare the free entry condition under autarky with the free entry condition with costly trade. Conveniently, I rewrite the free entry equation in costly trade, which is from equation (2.28).

$$\begin{aligned}(1-G(\theta_d^*))f\left[\left(\frac{s}{w}\right)^{(\tilde{\theta}_d-\theta_d^*)(1-\sigma)}\left(\frac{\tilde{\theta}_d}{\theta_d^*}\right)^{\frac{\alpha(\sigma-1)}{\phi}}-1\right]+\\ (1-G(\theta_x^*))f_x\left[\left(\frac{s}{w}\right)^{(\tilde{\theta}_x-\theta_x^*)(1-\sigma)}\left(\frac{\tilde{\theta}_x}{\theta_x^*}\right)^{\frac{\alpha(\sigma-1)}{\phi}}-1\right]=\delta f_e.\end{aligned} \tag{B.6}$$

Note that equation (B.6) reduces to $(1-G(\theta_d^*))f\left[\left(\frac{s}{w}\right)^{(\tilde{\theta}_d-\theta_d^*)(1-\sigma)}\left(\frac{\tilde{\theta}_d}{\theta_d^*}\right)^{\frac{\alpha(\sigma-1)}{\phi}}-1\right]=\delta f_e$, which is the first term on the left-hand side of equation (B.6), in the closed economy. When trade costs are low enough for some firms to engage in exporting, the first term in the left-hand side of equation B.6 must be smaller than the one in autarky, because the second term in the left-hand side is positive and the right-hand side of equation B.6, δf_e, does not depend on trade costs. Notice that the first term in the left-hand side of equation (B.6) will decrease as s/w increases, while θ_d^* is fixed. Thus, the free entry curve (FE) will shift upward (that is, shifts to the right) as trade costs fall.

Second, the upward-sloping labor market curve (LE) also shifts upward (that is, shifts to the left) as a result of the reduction in trade costs. For convenience, I rewrite the labor market equilibrium condition under costly trade that is given in the proof of proposition 2.2.2:

$$\left(\frac{w}{s}\right)\left[\int_{\theta_d^*}^1\left(\frac{\theta}{1-\theta}\right)\Psi(\theta,\frac{s}{w},\theta_d^*)g(\theta)d\theta+\tau^{-\sigma}\int_{\theta_x^*(\theta_d^*)}^1\left(\frac{\theta}{1-\theta}\right)\Psi(\theta,\frac{s}{w},\theta_d^*)g(\theta)d\theta\right]=\frac{H}{L}. \tag{B.7}$$

where $\Psi(\theta,\frac{s}{w},\theta_d^*)$ denotes the share of unskilled workers employed by firms with θ out of the total endowment of unskilled labor. Now consider either the movement from autarky to costly trade or the reduction of trade costs under the condition of costly trade. Note that autarky regime reduces equation

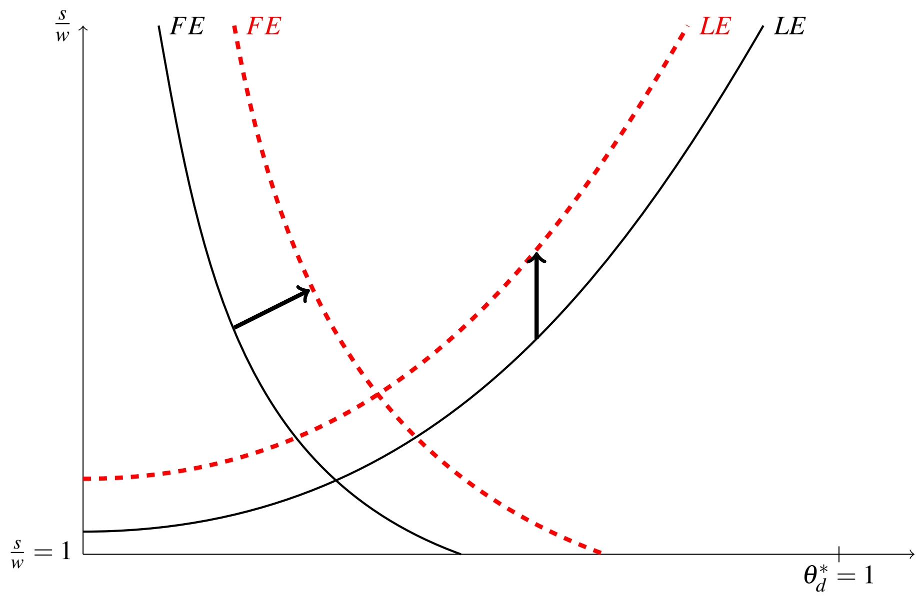

Figure B.2: FE and LE curves in autarky and costly trade

(B.7) to $\left(\frac{w}{s}\right)\left[\int_{\theta_d^*}^{1}\left(\frac{\theta}{1-\theta}\right)\Psi(\theta,\frac{s}{w},\theta_d^*)g(\theta)d\theta\right]=\frac{H}{L}$. Either the movement from autarky to the costly trade or the reduction of trade costs increases the second integral in the left-hand side of equation (B.7). Thus $\left(\frac{w}{s}\right)\left[\int_{\theta_d^*}^{1}\left(\frac{\theta}{1-\theta}\right)\Psi(\theta,\frac{s}{w},\theta_d^*)g(\theta)d\theta\right]$ must be decreased with lowering trade costs because the right hand side of equation (B.7), H/L, is constant. Holding θ_d^* fixed, the skill premium s/w must increase in order to keep the left hand side of equation (B.7) constant because of the definition of $\Psi(\theta,\frac{s}{w},\theta_d^*)$: as the relative price of a skilled worker increases, $\Psi(\theta,\frac{s}{w},\theta_d^*)$ decreases. As a result, the *LE* curve also shifts up, as trade costs fall. Since both the FE and *LE* curves shift upward the relative wage of skilled labor s/w will be higher when trade costs fall.

Figure B.2 illustrates that the skill premium increases as trade costs fall. When trade costs decrease, both the free trade FE and the labor market curve, *LE*, shift upward, which results in increasing wage inequality, s/w. ■

Appendix C

Appendix (For Chapter 3)

C.1 Proof of Condition 3.5

Condition (5), which is sufficient to start industrialization, is derived from comparing the lifetime utility from consuming agricultural goods using only the traditional technology with that from consuming agricultural goods using the modern technology where all manufactured goods are used as intermediate inputs. This gives a sufficient condition because if the modern technology is used in agriculture, then there will be some finite time at which the consumer starts consuming manufactured goods and achieve a higher level of utility.

In the former case, since all labor is allocated to agricultural sector (i.e., $N_t = 0$ for all t), agricultural output is $Y_t^a = A(1-N_t)^\alpha = A$. The lifetime utility is thus $U = \sum_{t=0}^{\infty} \xi^t c_t^a = \sum_{t=0}^{\infty} \xi^t A = A/(1-\xi)$. In the latter case, agricultural output is $Y_t^a = AX_t^{1-\alpha}(1-N_t)^\alpha = A(M_t N_t^\beta)^{1-\alpha}(1-N_t)^\alpha$. The first welfare theorem, that competitive equilibrium is efficient, implies that the consumer's lifetime utility is maximized with respect to labor allocation. Hence, the maximization problem, max $\sum_{t=0}^{\infty} \xi^t A(M_t N_t^\beta)^{1-\alpha}(1-N_t)^\alpha$, yields optimal labor allocation in the manufacturing sector,

$$N_t = \frac{\beta(1-\alpha)}{\beta(1-\alpha)+\alpha}.$$

Notice that $\dot{M}_t/M_t = (M_{t+1}-M_t)/M_t = \delta N_t^\beta$. Rearranging yields

$$M_{t+1} = M_t\left(1+\delta\left(\frac{\beta(1-\alpha)}{\beta(1-\alpha)+\alpha}\right)^\beta\right).$$

Therefore, the lifetime utility is

$$\begin{aligned} U &= A\left(\frac{\beta(1-\alpha)}{\beta(1-\alpha)+\alpha}\right)^{\beta(1-\alpha)}\left(\frac{\alpha}{\beta(1-\alpha)+\alpha}\right)^{\alpha}\sum_{t=0}^{\infty}\xi^t M_t^{1-\alpha} \\ &= A\left(\frac{\beta(1-\alpha)}{\beta(1-\alpha)+\alpha}\right)^{\beta(1-\alpha)}\left(\frac{\alpha}{\beta(1-\alpha)+\alpha}\right)^{\alpha} M_0^{1-\alpha}\sum_{t=0}^{\infty}\xi^t\left[\left(1+\delta\left(\frac{\beta(1-\alpha)}{\beta(1-\alpha)+\alpha}\right)^{\beta}\right)^t\right]^{1-\alpha}. \end{aligned}$$

If $\xi\left(1+\delta\left(\frac{\beta(1-\alpha)}{\beta(1-\alpha)+\alpha}\right)^{\beta}\right)^{1-\alpha} \geq 1$, then the lifetime utility explodes to infinity.
If $\xi\left(1+\delta\left(\frac{\beta(1-\alpha)}{\beta(1-\alpha)+\alpha}\right)^{\beta}\right)^{1-\alpha} < 1$, then the lifetime utility is

$$U = \frac{A\left(\frac{\beta(1-\alpha)}{\beta(1-\alpha)+\alpha}\right)^{\beta(1-\alpha)}\left(\frac{\alpha}{\beta(1-\alpha)+\alpha}\right)^{\alpha} M_0^{1-\alpha}}{1-\xi\left(1+\delta\left(\frac{\beta(1-\alpha)}{\beta(1-\alpha)+\alpha}\right)^{\beta}\right)^{1-\alpha}}.$$

Therefore, the lifetime utility using the modern technology is greater than not using it if and only if

$$\frac{\left(\frac{\beta(1-\alpha)}{\beta(1-\alpha)+\alpha}\right)^{\beta(1-\alpha)}\left(\frac{\alpha}{\beta(1-\alpha)+\alpha}\right)^{\alpha} M_0^{1-\alpha}}{1-\xi\left(1+\delta\left(\frac{\beta(1-\alpha)}{\beta(1-\alpha)+\alpha}\right)^{\beta}\right)^{1-\alpha}} > \frac{1}{1-\xi}.$$

Since $1+\delta\left(\frac{\beta(1-\alpha)}{\beta(1-\alpha)+\alpha}\right)^{\beta} > 1$, a sufficient condition for the above inequality to hold is

$$\left(\frac{\beta(1-\alpha)}{\beta(1-\alpha)+\alpha}\right)^{\beta(1-\alpha)}\left(\frac{\alpha}{\beta(1-\alpha)+\alpha}\right)^{\alpha} M_0^{1-\alpha} \geq 1.$$

Rearranging yields condition (5).

C.2 The Derivation of Equation 3.16

The equation (3.16), which is the time path of the labor share in the home country, is derived from differentiating equation (3.15) with respect to time t. For convenience, I rewrite equation (3.15) as follows:

$$N_t^{\beta-1} M_t = \left(\frac{A}{A^*}\right)^{\frac{1}{\alpha}} N_t^{*\beta-1} M_t^*. \tag{C.1}$$

Taking the derivative of both sides of equation (C.1) with respect to time t gives

$$(\beta-1)N_t^{\beta-2} M_t \dot{N}_t + N_t\beta - 1\dot{M}_t = \left(\frac{A}{A^*}\right)^{\frac{1}{\alpha}}\left[(\beta-1)N_t^{*\beta-2} M_t^* \dot{N}_t^* + N_t^{*\beta-1}\dot{M}_t^*\right]. \tag{C.2}$$

Rearranging the equation (C.2) yields

$$N_t^{\beta-1}M_t\left[(\beta-1)\frac{\dot{N}_t}{N_t}+\frac{\dot{M}_t}{M_t}\right]=\left(\frac{A}{A^*}\right)^{\frac{1}{\alpha}}N_t^{*\beta-1}M_t^*\left[(\beta-1)\frac{\dot{N}_t^*}{N_t^*}+\frac{\dot{M}_t^*}{M_t^*}\right]. \tag{C.3}$$

Since $N_t^{\beta-1}M_t=\left(\frac{A}{A^*}\right)^{\frac{1}{\alpha}}N_t^{*\beta-1}M_t^*$, the equation (C.3) is

$$(\beta-1)\frac{\dot{N}_t}{N_t}+\frac{\dot{M}_t}{M_t}=(\beta-1)\frac{\dot{N}_t^*}{N_t^*}+\frac{\dot{M}_t^*}{M_t^*}. \tag{C.4}$$

Rearranging the equation (C.4) yields the equation (3.16), which is as follows:

$$\begin{aligned}\frac{\dot{N}_t}{N_t} &= \frac{\dot{N}_t^*}{N_t^*}+\frac{1}{1-\beta}\left(\frac{\dot{M}_t}{M_t}-\frac{\dot{M}_t^*}{M_t^*}\right)\\ &= \frac{\dot{N}_t^*}{N_t^*}+\frac{\delta}{1-\beta}(N_t^{\beta}-N_t^{*\beta}).\end{aligned}$$