2014

Essays on technology and international trade

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Essays on Technology and International Trade

A Dissertation

Submitted to the Graduate Faculty of the
Louisiana State University and
Agricultural and Mechanical College
in partial fulfillment of the
requirements for the degree of
Doctor of Philosophy

in

The Department of Economics

by
Xianliang Tian
M.S., Louisiana State University, 2011
May 2014

For Yu Xia and Zixuan

Acknowledgments

I am indebted to my advisor Prof. Bulent Unel for his constant guidance, support, and encouragement in writing this thesis. He has been a role model for me as a hardworking and enthusiastic researcher and teacher, and without him this work would not be completed.

I would like to thank my committee members Prof. Areendam Chanda, Prof. Doug Micmillin, and Prof. Fang Yang for their invaluable comments and suggestions which made this thesis richer. I am in particular grateful to Prof. Chanda and Prof. McMillin for generously sharing their time and advice throughout my graduate study.

Finally, I am indebted to my dear wife. Her love and understanding have always been the source of strength in my heart. Special thanks to my friends, who were willing to share my sorrows as well as joys. Their company made me feel at home. Particularly, I am thankful to Zhengjia, Xue, Dachao, Ting, and Guangli.

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Abstract

The three essays contained in this dissertation are about technology and international trade. The first essay examines optimal intellectual property rights (IPR) protection in developing countries, while the other two estimate product quality at the sectoral level for a panel of twelve manufacturing sectors in twenty OECD countries using a novel approach and relate import competition and R&D investment to the growth of sectoral product quality.

Chapter 2 is motivated by the work of Acemoglu and Zilibotti (2001), who argue that the technologies developed in the North are not appropriate for the needs of the South, due to a "technology-skill mismatch" problem. Chapter 2 tries to solve this problem by putting forward a sector-differentiated IPR protection for developing countries. Specifically, in autarky, the IPR protection in the low-skill intensive sector of the South should be greater than its high-skill intensive sector. However, the greater protection for the low-skill intensive sector is not necessary when free trade in the final good is allowed between the North and South. This implies that international trade can help the South solve the technology-skill mismatch problem.

In Chapter 3, I estimate product quality at the sector level for twenty OECD countries based on a gravity equation derived from a quality-heterogeneity model of trade. I find that the estimated quality levels vary substantially across countries and over time, and as in Hallak and Schott (2011), there is a positive correlation between countries' product quality and their per-capita income that is declining over time. Lastly, the quality gap between rich and poor countries is more pronounced in capital- and skill-intensive sectors.

Using quality estimates from Chapter 3, the fourth chapter investigates the contributions of import competition and R&D investment to the growth of sectoral product quality. I find that import competition leads to substantial quality upgrading, confirming the findings of Amiti and Khandelwal (2013). I also find that both R&D and human capital can facilitate quality upgrading by increasing the absorptive capacity of developing countries, corroborating the results of Fisher-Vanden and Terry (2009).

Chapter 1: Introduction

This dissertation consists of three essays on technology, international trade and economic development. The first paper investigates optimal intellectual property rights (IPR) protection for developing countries in the process of economic development, while the other two papers estimate sectoral product quality for a panel of twelve manufacturing sectors in twenty OECD countries using a firm-heterogeneity model of trade, and examine the contribution of import competition, domestic R&D investment, and human capital to the growth of product quality at the sectoral level.

In the literature, one explanation for low income per capita in less-developed-countries (LDC) is that the technologies they adopt from developed countries are not appropriate for their needs. For instance, Acemoglu and Zilibotti (2001) argue that when the poor, low-skill intensive South imitates the technologies developed in the rich, high-skill intensive North, the direction of innovation will depend on the relative supply of skills in North, and consequently the low-skill abundant South cannot fully benefit from the new technologies in North. This is a typical technology-skill mismatch problem. An interesting question in this framework to ask is - is it possible for the South to solve the technology-skill mismatch problem without changing its factor supplies?

To this end, Chapter 2 extends the Acemoglu and Zilibotti model by introducing a sector-specific IPR protection in South, and studies how such an extension can change the direction of innovations in North towards the needs of South. Unlike the Acemoglu and Zilibotti model, when innovators in North develop new technologies in my model, they also consider the needs of South because the IPR protection laws

set up by the Southern government allow the innovators in North to extract revenues from South. The crucial point in my analysis is the possibility of sector-specific IPR protection in South.

I show that in autarky the optimal IPR strategy for South requires stronger IPR protection for the low-skill intensive sector. The intuition behind this result is simple to follow: when the low-skill sector receives stronger IPR protection, innovators in North will be induced to invent more low-skill technologies since there is a greater market incentive. As a result, the technologies in North will better match the skill endowment of South. I then analyze the same problem when North and South can freely trade the output of the two sectors as in Acemoglu and Zilibotti (2001). I show that in this case stronger IPR protection in the low-skill sector of South is not necessary to change the direction of innovation in North. This implies that trade can help South overcome the technology-skill mismatch problem.

One outcome of technical progress is improved product quality. Consequently, product quality plays an important role in the study of international trade and economic growth. However, due to a lack of data on reliable estimates of product qualities, researchers usually use export prices as a proxy for product quality. As indicated by Hallak and Schott (2011), this practice is inadequate because several other factors (e.g., higher factor prices) can also lead to higher product prices. To bridge this gap, Chapter 3 estimates product quality at the sectoral level using data from a panel of twelve manufacturing sectors in twenty OECD countries during the period 1995-2006.

The estimation procedure is as follows. I first use an extension of Baldwin and Harrigan's quality-heterogeneity model of trade as a starting point for my analysis. This theoretical model leads to a gravity model similar to that in Helpman et

al. (2008). Finally, using the resulting gravity model, following Hallak and Schott (2011), I identify product quality as an unexplained part of export value when trade frictions, input costs, productivity, etc. are explicitly controlled.

My analysis yields several interesting results. First, I find that estimated quality levels vary substantially across countries and over time. Second, as in Hallak and Schott (2011), there is a positive correlation between countries' product quality and their per-capita income. However, because countries' product quality is converging at a higher rate than the convergence in national income, the correlation is weakening over time. Last but not least, the quality gap between rich and poor countries is more pronounced in capital- and skill-intensive sectors.

The study in Chapter 3 is different from two previous papers directly estimating product qualities. In one paper, Khandelwal (2010) evaluates the quality of imported goods in the U.S. using a nested Logit demand system, whereas in Chapter 3 I estimate product quality at the sectoral level for different countries. In the other, Hallak and Schott (2011) derive countries' product quality from information contained in their trade balances. They then estimate the U.S. trading partners' relative manufacturing quality from 1989 to 2003. My analysis differs from theirs in the following aspects. First, they estimate countries' manufacturing quality, whereas I estimate sectoral-level quality for two-digit manufacturing industries. Second, I extract product qualities using a gravity model derived from a firm-heterogeneity model of trade.

Using quality estimates from Chapter 3, Chapter 4 investigates the effects of import competition and domestic R&D investment on the upgrading of sectoral product quality.

This is the second paper after the work of Amiti and Khandelwal (2013) to empirically examine the impact of import competition on quality growth. Although we use

different methodologies and data sets, we arrive at the same conclusion - an increase in import competition will force firms to upgrade their product quality in order to cope with competition from abroad. Another finding is that new technologies spilled from developed countries facilitate quality upgrading in developing countries, which adds to the literature of technology spillover in economic development (see, e.g., Acharya and Keller (2008)).

Chapter 4 is the first attempt to empirically relate domestic R&D investment to the growth of sectoral product quality. I find that both R&D investment and human capital contribute to the growth of quality at a sectoral level by increasing the absorptive capacity of developing countries, which is consistent with the findings of Fisher-Vanden and Terry (2009).

Chapter 2: Optimal IPR Protection, Directed Imitation and Economic Development

2.1 Introduction

Economists have offered several explanations for the difficulties some countries encounter in adopting new technologies. One explanation for low income per capita in less-developed-countries (LDC) is that the technologies they adopt from advanced countries are not appropriate for their needs. Basu and Weil (1998), for example, emphasize the level of development in the technology adoption process, while Acemoglu and Zilibotti (2001) focus on the importance of the technology-skill mismatch arising from the relative supplies of skills in less developed countries.[1] More specifically, in the Acemoglu and Zilibotti model, technological innovation takes place in the rich, skill-intensive North while the poor, low-skill intensive South gets access to new technologies through *costless* imitation. Because innovators in the North can only extract revenues from the domestic market, the direction of innovation depends on the relative supply of skills in North, and thus the low-skill abundant South cannot fully benefit from the new technologies in North.

An interesting question in this framework to ask is whether it is possible for South to solve the technology-skill mismatch problem without changing its factor supplies. To this end, this paper extends the Acemoglu and Zilibotti model by introducing *sector-specific* intellectual property rights (IPR) protection in South, and studies how such an extension can change the direction of innovations in North towards

[1]There are several other explanations of why the new technologies are not adopted by LDCs. Prente and Prescott (1999), for example, analyze the effects of monopoly power on developing countries' technology adoption where a coalition of factor suppliers oppose the adoption of new and more efficient technologies.

the needs of South. In my model, unlike the Acemoglu and Zilibotti model, when innovators in North develop new technologies, they also consider the needs of South because the IPR protection laws set up by the Southern government allow innovators in North to extract revenues from South. The crucial point in my analysis is the possibility of sector-specific IPR protection in South.

I first analyze this problem withinin a closed economy framework, where there is no trade in goods. I show that in autarky the optimal IPR strategy for South requires a stronger IPR protection for the low-skill intensive sector. The intuition behind this result is simple to follow: when the low-skill intensive sector has stronger IPR protection, innovators in North can extract more rent from the low-skill abundant South. As a result, they can change the direction of their innovations towards South's needs. I then analyze the same problem when North and South freely trade the output of the two sectors as in Acemoglu and Zilibotti (2001). I show that in this case stronger IPR protection in the low-skill sector is not necessary to change the direction of innovation in North. This implies that trade can help South overcome the technology-skill mismatch.

The crucial assumption in my analysis is the existence of the sector-specific IPR protection. How reasonable is this assumption? There are indeed several papers that have documented that during the process of development the extent of IPR protection in different sectors can be quite different. Lo (2011), for example, finds that prior 1986 patent protection in Taiwan only covered manufactured products and manufacturing processes, while after patent reforms in 1986 it extended to chemical and pharmaceutical products. Kumar (2003) documents that Japan's patent protection had not covered pharmaceutical and chemical products until 1975, when its

technological capacity in these fields had grown strong enough.[2] The most influential work in this area is by Lerner (2002) who provides information on the patent systems for sixty countries with the highest GDPs in the world as of 1997. Each country is reported at 25-year intervals during the period 1850-1999. The information (which includes coverage, length, cost, limitations of patent protection, etc.) he documents suggests that industries covered by patent law and the patent length differ substantially across countries and over time.[3]

This paper is also related to a growing theoretical literature on optimal IPR in economic growth and development. Chu et al. (2011) develop a model where domestic innovation and imitation constitute two sources of economic growth. The optimal arrangement involves weak IPR in the early stages of development to encourage imitation and strong IPR protection later on to stimulate innovation. Chen and Puttitanun (2005) also notice a U-shaped IPR–development relationship. Kim, Lee and Park (2006) propose a model wherein the "appropriate type" of IPR should be different between the stages of development. However, these studies consider optimal IPR protection at a country level as opposed to a sectoral level as this paper does.

There are two notable exceptions in the above literature. First, Acemoglu and Akcigit (2006) develop a general equilibrium model in which optimal IPR protection that maximizes the growth rate involves greater protection for industries where technology leaders are far ahead of their followers, and weaker protection for those

[2] Kumar (2003) also shows that the Indian government enacted new Patent Acts in 1970 to promote domestic innovation by restricting patent protection in chemical and pharmaceuticals to processes only. The patent term was also greatly shortened in these fields.

[3] The necessity of treating different sectors differently when protecting IPR has increasingly drawn economists' attention. For example, Burk and Lemley (2009) argue that in the application of patent laws, the courts should apply different standards to different industries to best satisfy their needs because the innovation pattern and the way patents affect innovation are enormously different across industries.

where innovators are close to each other in technology. In their model, optimal IPR are based on the industry structure and technology gap within an industry, while in this paper it depends on the relative factor endowment of South. Second, in a recent paper, Chu (2009) studies the optimal patent breadth across sectors in a quality-ladder economic growth model. Using simulation analysis, he finds that the welfare improvement is substantial when transferring from an unvaried patent protection to a sector-differentiated one, even though the difference across sectors is only moderate. His optimal patent design, however, depends on the size and technology potential of the sector instead of the relative factor endowment in each sector. In addition, his model is a closed-economy analysis whereas this paper considers the case where the countries trade with each other.

The rest of the paper is organized as follows. Section 2.2 presents the basic model. Section 2.3 extends the model to international trade. Section 2.4 concludes.

2.2 Setup of The Model

Consider a world of two countries (North and South) with two sectors whose outputs are imperfect substitutes with each other. Each country has a fixed supply of skilled and unskilled labor. In the present setup, North represents a skill abundant, developed country that develops new technologies through R&D, and South represents a labor abundant, less developed country that imitates technologies developed in North. As in Acemoglu (2002), one sector uses skilled labor and a set of intermediate goods to produce output, whereas the other sector uses unskilled labor and another set of intermediate goods to produce output. The outputs of the two sectors are then combined to produce the final good. The final good is either consumed, invested, or used in innovation (in North) and imitation (in South). In this section, I study the closed-economy equilibrium, and for notational simplicity, I drop the country index whenever this does not cause any confusion.

2.2.1 Preferences

Consumers in both countries have identical preferences and their utilities are derived from consumption of the final good. The preferences of the representative agent are given by

$$U = \int_0^\infty e^{-\rho t} \ln C_t dt, \tag{1}$$

where $\rho > 0$ is the time-discount rate and C_t is the consumption at time t. The utility maximization yields the well-known Euler equation

$$\frac{\dot{C}_t}{C_t} = r_t - \rho, \tag{2}$$

where r_t is the interest rate at time t.

2.2.2 Production

As indicated above, final good Y is produced from the output of the two sectors according to the following CES production function:

$$Y = \left(Y_L^{\frac{\varepsilon-1}{\varepsilon}} + Y_H^{\frac{\varepsilon-1}{\varepsilon}} \right)^{\frac{\varepsilon}{\varepsilon-1}}, \tag{3}$$

where Y_L and Y_H denote the output of the low-skill and high-skill sectors, respectively, and ε is the elasticity of substitution between the output of these sectors. I assume that goods Y_L and Y_H are gross substitutes so that $\varepsilon > 1$.

Final good Y is produced in competitive markets, and thus the profit maximization yields

$$\frac{P_L}{P_H} = \left(\frac{Y_L}{Y_H} \right)^{-\frac{1}{\epsilon}}, \tag{4}$$

where P_L and P_H are the corresponding prices of the low-skill and high-skill sectors. P_Y denotes the price of the final good and the first-order conditions further ensure that

$$P_Y = \left(P_L^{1-\varepsilon} + P_H^{1-\varepsilon} \right)^{\frac{1}{1-\varepsilon}}. \tag{5}$$

In the subsequent analysis, I take the final good in North as a numeraire so that its price equals one, $P_Y^N = 1$.

Goods Y_L and Y_H are produced according to the following production functions

$$Y_L = L^{1-\beta} \int_0^{N_L} x_{Lv}^{\beta} dv, \qquad Y_H = H^{1-\beta} \int_0^{N_H} x_{Hv}^{\beta} dv, \tag{6}$$

where $\beta \in (0,1)$. Here x_{iv} denotes the amount of intermediate good v used in production of good Y_i and N_i represents the mass of intermediate goods used in sector $i = H, L$. I assume that these intermediate goods fully depreciate after their use, as in Acemoglu (2002).

These goods are also produced in competitive markets. Using the production functions in (6), profit maximization then implies that the demand for each intermediate good v is given

$$x_{Lv} = \left(\frac{\beta P_L}{p_{Lv}}\right)^{\frac{1}{1-\beta}} L, \qquad x_{Hv} = \left(\frac{\beta P_H}{p_{Hv}}\right)^{\frac{1}{1-\beta}} H, \tag{7}$$

where p_{iv} denotes the rental price of intermediate good v in sector $i = H, L$.

Intermediate goods are produced by a set of monopolists, each choosing to produce a different variety. All monopolists in both sectors face the same production technology: δ units of final good Y are required to produce one unit of each intermediate good. To simplify notation, without loss of generality, I assume that $\delta = \beta^2$. Each monopolist faces the isoelastic demand function given by equation (7), and profit maximization yields

$$p_{Lv} = p_{Hv} = \beta P_Y. \tag{8}$$

With these price functions, the corresponding profits are given by

$$\pi_{Lv} = \beta(1-\beta) \left[\frac{P_L}{P_Y}\right]^{\frac{1}{1-\beta}} P_Y L, \qquad \pi_{Hv} = \beta(1-\beta) \left[\frac{P_H}{P_Y}\right]^{\frac{1}{1-\beta}} P_Y H. \tag{9}$$

Thus, all intermediate goods producers in each sector make the same profit. In addition, using (7) and (8), the production functions in (6) yield

$$Y_L = \left[\frac{P_L}{P_Y}\right]^{\frac{\beta}{1-\beta}} N_L L, \qquad Y_H = \left[\frac{P_H}{P_Y}\right]^{\frac{\beta}{1-\beta}} N_H H. \tag{10}$$

From (4), (5), and (10), the relative price of output in each sector relates to the ratio of technology, N_L/N_H, as follows:

$$\frac{P_L}{P_Y} = \left[1 + \left(\frac{LN_L}{HN_H}\right)^{-\frac{(1-\beta)(\epsilon-1)}{(1-\beta)\epsilon+\beta}}\right]^{\frac{1}{\epsilon-1}}, \qquad \frac{P_H}{P_Y} = \left[1 + \left(\frac{LN_L}{HN_H}\right)^{\frac{(1-\beta)(\epsilon-1)}{(1-\beta)\epsilon+\beta}}\right]^{\frac{1}{\epsilon-1}} \tag{11}$$

2.2.3 Innovation and Imitation

New products are invented in the R&D sector of North while South copies these products with some costs. The product development process is similar to that in Rivera-Batiz and Romer (1991). The market for blueprints is competitive, and production of a new blueprint in any sector requires μ units of the final good in North, and thus

$$\dot{N}_L^N = R_L/\mu, \qquad \dot{N}_H^N = R_H/\mu, \tag{12}$$

where superscript N represents North, and R_i is the amount of the final good Y used in the process of product development in sector $i = H, L$. For the sake of notational simplicity, I set $\mu = \beta(1-\beta)$.

Once a new intermediate good is developed, the firm that produces this new good in sector i generates π_{it}^N profits in North in each period. In addition, South protects the intellectual property rights of Northern firms in the process of imitation. More specifically, the Southern government collects a faction κ_i of the profits of each monopolist in sector i and transfers them to inventors in North.[4] Denote with v_{it}

[4]Other than the payment of royalty fee, in the literature, there are other measures associated with the protection of IPR, for example, the regulation of band breadth for patents.

the value of a product in sector i, the no-arbitrage condition then is given by

$$\dot{\mathrm{v}}_{it} + \pi_{it}^N + \kappa_i \pi_{it}^S (P_Y^N / P_Y^S) = r_t \mathrm{v}_{it}, \tag{13}$$

where P_Y^N / P_Y^S is the purchasing power parity (PPP) between North and South.

South gets access to new technologies only through a costly imitation.[5] Imitation of a new product from North requires τ units of final good Y^S. Once the imitation costs are paid, South has an access to the world technology frontiers; as a result, $N_L^S = N_L^N \equiv N_L$ and $N_H^S = N_H^N \equiv N_H$.

2.2.4 Equilibrium Analysis

In this section, I consider only the steady-state (balanced growth path) equilibrium analysis where South imitates all available technologies in North. Since the R&D sector in North is perfectly competitive, the equilibrium value of an intermediate good must be equal to its development cost, i.e. $\mathrm{v}_{it} = \mu$. Thus, the value of any differentiated good is constant, and equation (13) becomes $\pi_i^N + \kappa_i \pi_i^S (P_Y^N / P_Y^S) = r\mu$. Substituting the profit functions from (9) into the latter and using $P_Y^N = 1$ and $\mu = \beta(1-\beta)$ implies

$$(P_L^N)^{\frac{1}{1-\beta}} L^N + \kappa_L \left(\frac{P_L^S}{P_Y^S} \right)^{\frac{1}{1-\beta}} L^S = (P_H^N)^{\frac{1}{1-\beta}} H^N + \kappa_H \left(\frac{P_H^S}{P_Y^S} \right)^{\frac{1}{1-\beta}} H^S = r. \tag{14}$$

Consider the first equality in (14). Since P_L^j / P_Y^j for $j = N, S$ decreases in N_L/N_H as indicated in the first equation in (11), the left-hand-side (LHS) of this equality is decreasing in N_L/N_H. On the other hand, P_H^j / P_Y^j is increasing in N_L/N_H, and thus, the right-hand-side (RHS) of the first equality is also increasing in N_L/N_H.

[5] According to UNESCO (2010), in 2007, developed countries carried out over 76 percent of R&D in the world. Although the role of innovation in explaining the catch-up phenomenon is analyzed in the literature, the innovation activity in developing countries is mostly adaptive, imitative, and incremental (Kim et al., 2006). In a recent paper, Madsen, Islam and Ang (2010) find that for OECD countries, R&D affects economic growth by innovation, while for developing countries its role in economic growth is mainly through imitation.

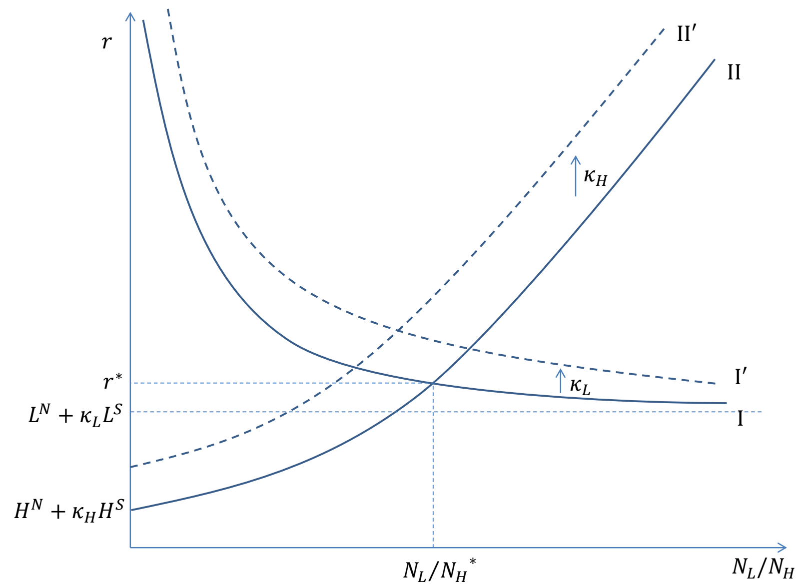

FIGURE 1: Closed-economy Equilibrium Interest Rate

These two curves uniquely intersect each other as depicted in Figure 1. Substituting the equilibrium value of N_L/N_H into (14) yields a unique equilibrium interest rate r. Since on the balanced growth path C, Y_L, and Y_H all grow at the same rate g, equation (2) then yields a unique growth rate for each economy.

Note also that an increase in κ_L increases N_L/N_H, whereas an increase in κ_H decreases N_L/N_H as shown in Figure 1. In either case, the interest rate r, and thus the growth rate g increases. The intuition is simple: an increase in κ_i increases profits obtained from sales in South, which will increase incentives for inventors in North to develop more new products. The following proposition summarizes these results.

Proposition 1. *For a given κ_L and κ_H in closed-economy equilibrium, both countries grow at the same unique rate. In addition, the growth rate increases in κ_H and κ_L.*

When there is no IPR protection in South (i.e., $\kappa_L = \kappa_H = 0$), using (4), (9), (10), and (14) implies

$$\frac{N_L}{N_H} = \left(\frac{L^N}{H^N}\right)^{(1-\beta)(\epsilon-1)}. \tag{15}$$

Thus, as in Acemoglu and Zilibotti (2001), the direction of the technical change in North only depends on North's relative labor supply. Thus, if South does not implement any IPR protection, there will be a technology-skill mismatch in South and consequently the aggregate TFP and income per capita in South will be lower than in North (see Acemoglu, 2002 for more on this).

2.2.5 Optimal IPR Protection Policies in South

In this section, I investigate optimal IPR policies that can change the direction of technical progress so that South can benefit more from the innovations developed in North. To this end, I will first discuss the optimal (or ideal) N_L/N_H for South that maximizes the welfare in South. I restrict my analysis to the steady-state case.

Along the BGP, the consumption C_t^S, investment I_t^S, and output Y_t^S grow at rate g, which equals the growth rate of N_L and N_H. Using the utility function (1), the welfare of the representative agent at time t then becomes

$$U_t = \frac{\ln C_t^S}{\rho} + \frac{g}{\rho^2}.$$

Using (7), (8) and (10), one can show that the investment is given by $I_t = \beta Y_t^S$.[6] In addition, imitation of each new product requires South to pay τ units of the final good. Since $\dot{N}_{Lt} = gN_{Lt}$ and $\dot{N}_{Ht} = gN_{Ht}$, the cost of imitation at time t then is $\tau g N_t$, where $N_t = N_{Lt} + N_{Ht}$. Thus, $C_t^S = (1-\beta)Y_t^S - \tau g N_t$. Substituting these

[6]To see this, note that from (7), (8) and (10), the (real) investment in each country is calculated as $I = (p_{Lv}x_{Lv}N_L + p_{Hv}x_{Hv}N_H)/P_Y = \beta(P_LY_L + P_HY_H)/P_Y$. Due to perfect competition in the production of final goods, $\beta(P_LY_L + P_HY_H)/P_Y = \beta Y$. Thus, $I_t^j = \beta Y_t^j$ for $j = N, S$.

into the above utility function yields

$$U_t = \frac{\ln[(1-\beta)Y_t^S - \tau g N_t]}{\rho} + \frac{g}{\rho^2}. \tag{16}$$

For a given value of g and $N_t = N_{Lt} + N_{Ht}$, what is the optimal level for N_L/N_H that maximizes the welfare given by (16)? As shown in Appendix A, the optimal ratio of N_L/N_H is given by

$$\frac{N_L^S}{N_H^S} = \left(\frac{L^S}{H^S}\right)^{(1-\beta)(\epsilon-1)}. \tag{17}$$

A comparison of (15) and (17) reveals that, for South, the optimal ratio of technology is based on South's factor endowment, whereas the optimal ratio in North reflects North's relative factor endowment (assuming that North does not get any IPR payments from South).

Proposition 2. *Along the BGP, the optimal ratio of N_L/N_H for South is given by (17). That is, at the optimal solution, South prefers the relative number of products N_L/N_H to reflect its own relative factor endowment.*

Although South does not innovate, it can change the *direction* of technology innovation in North by designing an optimal intellectual property rights (IPR) protection system, and thus giving North's innovators a market incentive. How should South design its IPR system to achieve the optimal ratio N_L/N_H in (17)? More specifically, what values of κ_L and κ_H should South choose so that it can change the direction of technical innovation for its own benefit?

Given that $L^S/H^S > L^N/H^N$, a comparison of (15) and (17) then implies that $N_L^S/N_H^S > N_L^N/N_H^N$, i.e. the optimal ratio of technology in South is more low-skill oriented than that chosen by North. As can be easily seen from Figure 1, inducing

North to increase N_L/N_H requires South to increase κ_L and decrease κ_H. When South achieves the optimal technology ratio given by (17), it can be shown that $(P_L^S/P_Y^S)^{\frac{1}{1-\beta}} L^S = (P_H^S/P_Y^S)^{\frac{1}{1-\beta}} H^S$.[7] Then (14) can be arranged as

$$(\kappa_L - \kappa_H) \left(\frac{P_L^S}{P_Y^S} \right)^{\frac{1}{1-\beta}} L^S = (P_H^N)^{\frac{1}{1-\beta}} H^N - (P_L^N)^{\frac{1}{1-\beta}} L^N \tag{18}$$

At South's optimal ratio of technology, the RHS of (18) is positive.[8] It then follows that $\kappa_L > \kappa_H$. In other words, to achieve the optimal technology ratio, South's IPR protection in the low-skill sector should be stronger than that in the high-skill sector.

Before going further, it is important to emphasize that the implicit assumption in the above result is that South is sufficiently low-skill labor abundant so that the RHS of (18) is smaller than $(P_L^S/P_Y^S)^{1/(1-\beta)} L^S$. Otherwise, $\kappa_L - \kappa_H > 1$, which contradicts with $\kappa_i \in [0, 1]$ and $\kappa_L - \kappa_H \in (0, 1]$. In addition, equation (18) implies that as South gets more low-skill abundant (i.e., as L^S increases), the difference between κ_L and κ_H reduces.

Proposition 3. *To achieve the optimal ratio of technology, unskilled-labor abundant South should implement an IPR system in which the IPR protection in the low-skill sector is greater than that in the high-skill sector (i.e.,* $\kappa_L > \kappa_H$*).*

2.3 International Trade

In the previous section, I analyzed the closed-economy equilibrium for each country, and showed that when (unskilled) labor abundant South implements an IPR policy

[7]This is shown in Appendix A.

[8]Using (4) and (10), it can be shown that at the initial ratio of technology chosen by North, $N_L^N/N_H^N = (L^N/H^N)^{(1-\beta)(\epsilon-1)}$, $(P_H^N)^{\frac{1}{1-\beta}} H^N = (P_L^N)^{\frac{1}{1-\beta}} L^N$. Using (11) and $P_Y^N = 1$, P_H^N is an increasing function in N_L/N_H, while P_L^N is decreasing in N_L/N_H. Because $N_L^S/N_H^S > N_L^N/N_H^N$, it then follows that $(P_H^N)^{\frac{1}{1-\beta}} H^N > (P_L^N)^{\frac{1}{1-\beta}} L^N$ at South's optimal ratio of technology, N_L^S/N_H^S.

in which the unskilled labor intensive sector gets more protection, South can change the direction of technical change for its own benefits. In this section, I extend this model by allowing *free* trade in two sectors' outputs Y_L and Y_H between North and South, and investigate optimal IPR protection policies in South. I assume that trade is balanced. In addition, to avoid the situation where firms in South copy the products developed in North, and sell them back to North at lower prices, following much of the literature (e.g., Gancia and Bonfiglioli (2008)), I assume that there is no trade in intermediate goods.

Before going further, it is worth noting how opportunity to trade arises in the current setting. Using equations (4) and (10) implies that in autarky,

$$\frac{P_L^j}{P_H^j} = \left(\frac{N_L L^j}{N_H H^j}\right)^{-\frac{1-\beta}{(1-\beta)\epsilon+\beta}}, \qquad j = S, N.$$

Since South is labor intensive (i.e., $L^S/H^S > L^N/H^N$), it then follows that the relative price of good Y_L in autarky is cheaper in South (i.e., $P_L^S/P_H^S < P_L^N/P_H^N$). Thus, under the free-trade South exports the labor-intensive good Y_L and imports skill-intensive good Y_H.

Let P_i^W for $i = H, L$ denote the price of good i in the world market. Equation (5) then ensures that the price of the final good Y is also the same across countries, i.e. $P_Y^N = P_Y^S \equiv P_Y^W$. I continue to take the final good Y as numeraire so that $P_Y^W = 1$. Using equation (4) then implies that

$$\frac{P_L^W}{P_H^W} = \left(\frac{Y_L^N + Y_L^S}{Y_H^N + Y_H^S}\right)^{-\frac{1}{\epsilon}}, \tag{19}$$

where Y_i^j denotes the total output produced in sector $i = H, L$ in country $j = N, S$. Substituting output levels from (10) with $P_i^j = P_i^W$ into the above equation and

rearranging the terms yields

$$\frac{P_L^W}{P_H^W} = \left[\frac{N_L}{N_H}\left(\frac{L^S + L^N}{H^S + H^N}\right)\right]^{-\frac{1-\beta}{(1-\beta)\epsilon+\beta}}. \tag{20}$$

2.3.1 No IPR Protection in South under Free Trade

In this section, I study the implications of no IPR protection in South under free trade. Note that equation (14) still holds under free trade, except now P_i^j is replaced by P_i^W. When there is no IPR production, (14) implies

$$\frac{P_L^W}{P_H^W} = \left(\frac{L^N}{H^N}\right)^{\beta-1}, \tag{21}$$

note that this relative price is identical to the autarkic relative price in North. Thus, when South does not implement any IPR protection policies, after trade liberalization the relative world price of the labor-intensive good Y_L will be equal to the autarkic relative price of this good in North.

Substituting (21) into (20) implies

$$\frac{N_L}{N_H} = \left[\frac{H^S/H^N + 1}{L^S/L^N + 1}\right]\left(\frac{L^N}{H^N}\right)^{(1-\beta)(\epsilon-1)}. \tag{22}$$

Since South is labor abundant (i.e., $L^S/H^S > L^N/H^N$), the first term on the RHS is less than one. Thus, a comparison of (22) to (15) indicates that the relative number of intermediate goods N_L/N_H under the free trade is smaller than that in autarky. In other words, under free trade, when South does not implement any IPR protection policy, the direction of technical change in North will be more high-skill intensive than that in autarky.

Proposition 4. *If South implements no IPR protection, under free trade, the innovation in North will be more high-skill oriented than that in autarky.*

The intuition behind the above result is as follows. Given that the relative price does not change in North after opening to trade, North has to produce more high-skill products and export them to South to balance the import of low-skill goods from South, which requires the South to invent more high-skill intermediate goods. The result presented in Proposition 3 is similar to Gancia and Bonfiglioli (2008), who consider a North-South trade model where North *completely* specializes in production of skill-intensive goods, whereas South *completely* specializes in production of labor-intensive goods. In my model, however, there is no complete specialization.

2.3.2 Optimal IPR Protection under Free Trade

I now turn to study the optimal IPR protection policies in South under free trade. As in the closed-economy case, the optimal ratio of technology, N_L^S/N_H^S, in South is again determined by maximizing the welfare function (16). Substituting the solution back into (20) yields South's "desired" relative world price, P_L^W/P_H^W. The following lemma characterizes the desired relative world price for South (see Appendix B for the proof).

Lemma 1. *Under free trade, South's desired relative world price, P_L^W/P_H^W, satisfies the following relationship*

$$\left(\frac{L^S}{H^S}\right)^{\beta-1} < \frac{P_L^W}{P_H^W} < \left(\frac{L^S+L^N}{H^S+H^N}\right)^{\beta-1}.$$

Note that under free trade, the equilibrium condition (14) implies the following relationship

$$(P_L^W)^{\frac{1}{1-\beta}}L^N + \kappa_L(P_L^W)^{\frac{1}{1-\beta}}L^S = (P_H^W)^{\frac{1}{1-\beta}}H^N + \kappa_H(P_H^W)^{\frac{1}{1-\beta}}H^S. \tag{23}$$

Since $L^S/H^S > L^N/H^N$, it then follows that $(L^S+L^N)/(H^S+H^N) > L^N/H^N$. The above lemma then implies that $P_L^W/P_H^W < (L^N/H^N)^{\beta-1}$, i.e. $(P_L^W)^{\frac{1}{1-\beta}}L^N <$

$(P_H^W)^{\frac{1}{1-\beta}} H^N$. Equation (23) then yields

$$\kappa_L (P_L^W)^{\frac{1}{1-\beta}} L^S > \kappa_H (P_H^W)^{\frac{1}{1-\beta}} H^S. \tag{24}$$

Since $(P_L^W)^{\frac{1}{1-\beta}} L^S > (P_H^W)^{\frac{1}{1-\beta}} H^S$ (see Lemma 1), the inequality (24) always holds whenever $\kappa_L > \kappa_H$. In other words, $\kappa_L > \kappa_H$ is a sufficient (but not necessary) condition to make the inequality in (24) hold. Consequently, unlike the closed-economy case, under free trade, South's optimal IPR protection for the low-skill sector may not need to exceed that for its high-skill sector.

To understand under what conditions κ_H may exceed κ_L, Figure 2 represents the equilibrium condition (23). The steeper line represents the LHS of equation (23). The two curves intersect each other at point A where $\kappa_L = \kappa_H = \kappa^*$. When interest rate lower than r^*, it is necessary that $\kappa^* > \kappa_L > \kappa_H$ to keep the equilibrium condition (23). On the other hand, when interest rate is higher than r^* (and thus, the economy grows at a faster rate), it then follows that $\kappa^* < \kappa_L < \kappa_H$. Thus, when both sectors in South have weak IPR protections, the low-skill sector should receive relatively stronger IPR protection; whereas when both sectors have strong IPR protections, the IPR protection for the high-skill sector should be stronger.

The intuition is as follows. When South implements no IPR protection, the relative world price is the same as North's relative price in autarky, which is greater than South's desired relative world price. Then to induce North to invent more low-skill technologies and thus lower the relative world price, South first sets up IPR laws with stronger protection for its low-skill sector (such that $\kappa_L^2 > \kappa_H^2$ in Figure 2). Using (9), $(P_L^W)^{\frac{1}{1-\beta}} L^S > (P_H^W)^{\frac{1}{1-\beta}} H^S$ implies that the profit of intermediate-good producers in South's exporting, low-skill sector is greater than that in its high-skill sector. Then when the South strengthens its IPR protection, the market incentive for innovators in North's low-skill sector will increase faster if κ_L and κ_H increase at

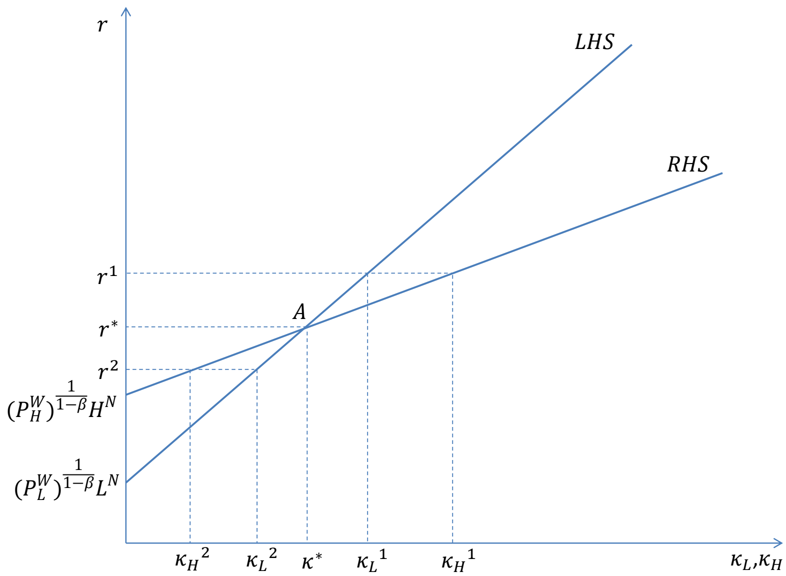

FIGURE 2: Optimal κ_L and κ_H under Free Trade

the same rate. Consequently, to balance the incentive for both types of innovators and fix the technology ratio N_L/N_H at the desired level, κ_H has to increase at a higher rate, which will eventually yield $\kappa_L < \kappa_H$ (such as κ_L^1 and κ_H^1 in Figure 2).

Proposition 5. *Under free trade, the optimal IPR protection policy in South does not necessarily require stronger IPR protection for the low-skill intensive sector. More precisely, when the IPR protections are weak in both sectors, South should have relatively stronger IPR protection in low-skill intensive sector (i.e., $\kappa_L > \kappa_H$); when the IPR protections are strong in both sectors, South should have relatively stronger IPR protection in the high-skill intensive sector (i.e., $\kappa_H > \kappa_L$).*

2.3.3 Further Discussion

The model presented in the previous sections has considered a world of two regions: North and South. North represents developed countries, whereas South represents

the less developed countries (LDCs). But developing countries differ in many dimensions such as factor endowments and size. Consequently, N_L/N_H for South as a whole may not be optimal for some LDCs in the South. In this section, I demonstrate that for some small-size LDCs whose relative supply of skilled labor is different from South's, it is still possible for them to improve their welfare by adopting only a subset of technologies developed in North.

To this end, following Barro and Sala-i-Martin (1997), I assume that the cost of imitation in sector $i = H, L$ in country j of South is given by $\tau(N_i^j/N_i^N)^\xi$ where $\xi > 0$ is an exogenous constant. Using (10) implies that under free-trade, the marginal contribution to GDP of adopting one new technology in each sector is given by $(P_L^W)^{\frac{1}{1-\beta}} L^j$ and $(P_H^W)^{\frac{1}{1-\beta}} H^j$.[9] Thus, along the BGP, LDCs in South should ensure that the imitation cost of the last adopted technology is no greater than its marginal contribution to GDP, which implies the following constraints [10]

$$\tau \left[\frac{N_L^j}{N_L^N} \right]^\xi \leq (P_L^W)^{\frac{1}{1-\beta}} L^j, \qquad \tau \left[\frac{N_H^j}{N_H^N} \right]^\xi \leq (P_H^W)^{\frac{1}{1-\beta}} H^j, \tag{25}$$

where $N_L^j \leqslant N_L^N$ and $N_H^j \leqslant N_H^N$. (25) indicates that small countries (with small L^j and H^j) are more likely to meet the constraint and adopt only a subset of the available technologies.

In addition, when adopting only part of North's technologies, LDCs with a relatively more low-skill (high-skill) intensive labor supply should adopt a bigger fraction of North's low-skill (high-skill) technologies. To prove this, consider a LDC with such a high-skill intensive labor structure that $(P_L^W)^{\frac{1}{1-\beta}} L^j < (P_H^W)^{\frac{1}{1-\beta}} H^j$. Suppose that

[9] I implicitly assume that the impact of adopting one new blueprint on the world price is negligible.

[10] Lin and Zhang (2006) also study the selection of technologies, but they do not discuss government policies to achieve the selection. Acemoglu, Aghion and Zilibotti (2006) analyze the importance of selection of high-ability managers and good firms when the economy is approaching the technology frontier, while this paper discusses selecting a subset of technologies from North.

the size of the country is so small that it meets some constraint in (25). If only the first constraint is met, then the country will adopt part of low-skill technologies in North, while it adopts all available high-skill technologies.[11] If the country is small enough in that both constraints are met, then dividing the left equation by the right one yields $N_L^j/N_H^j < N_L^N/N_H^N$. Only by adopting a bigger fraction of high-skill technologies in North could the country achieve this. Note that in doing so, the *adopted* technology ratio of the country is more close to its own optimal ratio of technology.

However, firms do not coordinate their actions to determine the *appropriate* number of technologies. It is possible that the present value of profits from selling intermediate goods can exceed the imitation cost, while the latter is greater than the marginal contribution of adopting a new technology to GDP. It then follows that firms will adopt the new technology, but it is not worthwhile for the economy. In this case, government can provide subsidies to induce firms to adopt the right numbers of technologies. More specifically,

$$S_i = \alpha\tau \left[\frac{N_i^j}{N_i^N}\right]^{\xi}, \qquad i = L, H,$$

where S_i is the subsidy for adopting one new technology in sector $i = L, H$, and $\alpha = [1 - \beta(1-\beta)(1-\kappa_i)/r]$.[12] So the subsidy is a fraction α of the technology adoption cost (or imitation cost).

To see how this policy works, suppose that $\tau\left[N_L^j/N_L^N\right]^{\xi} < (P_L^W)^{\frac{1}{1-\beta}} L^j$ so that adopting a new technology is desired by the government. Using (9) implies that $(1-\kappa_L)\pi_{Lv}/r > (1-\alpha)\tau\left[N_L^j/N_L^N\right]^{\xi}$, i.e. when subsidies are provided, for each firm the present value of profits (after paying the royalties) from selling intermediate

[11] It is impossible that the second constraint is met while the first is not, since $(P_L^W)^{\frac{1}{1-\beta}} L^j < (P_H^W)^{\frac{1}{1-\beta}} H^j$.

[12] If α turns to be negative, then the policy of interest is actually a tax upon the technology adoption.

goods is greater than the *net* technology adoption cost. Then firms adopt more technologies until $\tau\left[N_L^j/N_L^N\right]^{\xi} = (P_L^W)^{\frac{1}{1-\beta}}L^j$. At this point, it can be shown that $(1-\kappa_L)\pi_{Lv}/r = (1-\alpha)\tau\left[N_L^j/N_L^N\right]^{\xi}$. Obviously, adopting more technologies beyond that point is not desired either by the government or firms.

2.4 Conclusion

It is well-known that intellectual property rights protection can stimulate R&D activities and technological progress. However, the role of IPR protection in changing the "direction" of R&D and innovation is rarely analyzed. Built on Acemoglu (2002), this paper studies the optimal IPR protection policies in South, which can "induce" the direction of innovation in North towards South's needs, and thus increase South's income per capita.

The optimal IPR protection in South is a sector-specific one. In autarky, South's low-skill intensive sector should receive stronger IPR protection while protection for the high-skill intensive sector ought to be relatively weaker. Under free trade, however, the paper shows that the IPR protection in South's low-skill intensive sector does not necessarily exceed that in the high-skill sector. Specifically, when the IPR protection is relatively low in each sector, the low-skill sector in South should receive greater protection, whereas in the case that the IPR protection is relatively high in both sectors, the IPR protection for the high-skill sector should be more stressed. The paper also shows that when the countries in South are heterogeneous with respect to their factor endowments, the optimal ratio of technology for South as a whole may not be optimal for individual countries. Nevertheless, they can still improve their situations by adopting only subset of the available technologies.

In this paper, the invention is only supposed to happen in North, while South accesses to the new technologies by imitation. Although this assumption is mostly

consistent with observed data, the R&D activities in some developing countries, such as China and India, have recently been booming. Thus, extending the present model by allowing South to conduct its own R&D is an interesting avenue for future research.

Chapter 3: Estimating Sectoral Product Quality Under Quality Heterogeneity

3.1 Introduction

Product quality plays an important role in the study of international trade and economic growth.[13] Due to a lack of data on reliable estimates of product qualities, researchers usually use export prices as a proxy of product quality. However, as indicated by Hallak and Schott (2011), this practice is inadequate because several other factors (e.g. higher factor prices) can also lead to higher product price.

In this paper, I estimate product quality at the sectoral level using data from a panel of twelve manufacturing sectors in twenty OECD countries between 1995 and 2006. I use an extension of Baldwin and Harrigan's (2011) "quality heterogeneous-firms trade" model as a starting point for my analysis; this theoretical model leads to a gravity model similar to that in Helpman et al. (2008). Using the resulting gravity model, following Hallak and Schott (2011), I identify product quality as an unexplained part of export value when trade frictions, input costs, productivity, etc. are explicitly controlled. To consistently estimate the gravity model, I follow the two-stage approach of Helpman et al. (2008). Specifically, in the first stage, I estimate a Probit equation for selection into trade partners, and in the second stage, I estimate the resulting gravity model using predicted components from the first stage. The main advantage of their approach is that it corrects the bias caused by selection into trade, when the zero trade phenomenon is not negligible among country pairs.[14]

[13] Linder (1961) is the first to have conjectured that consumers in rich countries spend a larger portion of their income on high quality products; the strong demand by consumers, in turn, induces these countries to develop a comparative advantage in high quality products. Consequently, product quality plays a key role in determining trade flows among high-income countries. The relationship between product quality and trade is then theoretically exploited by Flam and Helpman (1987), Fajgelbaum et al. (2011) and Gervais (2012), among others, and recent empirical studies have indeed documented the strong positive relationship between per capita income and product quality (see, e.g., Schott (2004), Hummels and Klenow (2005), Hallak (2006) and Choi et al. (2009)).

[14] This is a typical sample selection problem which was first stated by Heckman (1979).

My analysis yields several interesting results. First, I find that estimated quality levels vary substantially across countries and over time. For instance, in 2006, Italy, France and Spain took the first three places in the rank of *overall* product quality, whereas Slovenia, Finland and Slovak Republic were the countries with the least overall product quality. As to the change of quality, Czech Republic and Greece underwent the greatest rise in their overall product quality, from 17th and 18th in 1995, respectively, rising to 11th and 12th in 2006. On the other hand, the biggest fall of ranking in the overall product quality happened in Austria, with its rank of 7th plummeting to 15th in 2006.

Second, as in Hallak and Schott (2011), there is a positive correlation between product quality and per-capita income. However, because countries' product quality is converging at a higher rate than the convergence in national income, the correlation is weakening over time. Last but not least, the quality gap between rich and poor countries is more pronounced in capital- and skill-intensive sectors.

This paper is related to a large literature on firm heterogeneity and international trade.[15] On the theoretical side, my model is a multi-sector extension of Baldwin and Harrigan's (2011) model where consumers care about quality, and higher quality goods are more expensive to produce. As in Melitz's (2003) model, trade involves both fixed and variable costs. Existence of fixed foreign-market entry costs partitions firms into exporters and non-exporters, and only firms producing high quality products can export. The latter prediction implies that it is possible that no firms in a sector of a given country find it profitable to export. Consequently, the model predicts zero trade flows between some country pairs, which is consistent with data.

[15]See, e.g., Melitz and Redding (2012) for a comprehensive review of this literature.

Ignoring these country pairs during estimation will lead to a serious selection bias problem.

On the empirical side, my paper is more closely related to Helpman et al. (2008) and Hallak and Schott (2011). Helpman et al. (2008) develop a firm-heterogeneity model of international trade where firms vary in their productivity, and due to fixed and variable costs of exporting, only more productive firms export as in the Melitz model. Consistent with data, their model predicts zero trade flows in either direction between some country pairs. In addition, their model leads to a gravity equation that they consistently estimate using a two-stage estimation procedure. My paper complements their seminal work in several important ways. First, in their model firms are heterogeneous with respect to their productivity, whereas in my model firms are heterogeneous with respect to their product quality as well as productivity. Second, their analysis is at the country level and they estimate the gravity equation using trade data from 1986; whereas my analysis is at the sectoral level and I estimate the gravity equation for each sector in each year over the period 1995–2006. Finally, unlike their model, I explicitly take into account the heteroscedasticity in trade volumes using the FGLS method in estimation. This correction is important, as Flam and Nordstrom (2011) demonstrate when estimating a gravity model; the problem caused by heteroscedasticity in trade data can be even more severe than the biases caused by selection into trade and firms' heterogeneity.

In an influential study, Hallak and Schott (2011) derive countries' product quality from information contained in their trade balances. They then estimate the U.S. trading partners' relative manufacturing quality from 1989 to 2003 and find that unit value ratios cannot be a good proxy for relative quality differences and convergence in countries' quality is more rapid than convergence of their income. My

analysis differs from their work in two important ways. First, they estimate countries' manufacturing quality, whereas I estimate sectoral-level quality for two-digit manufacturing industries. Second, I extract product qualities using a gravity model which is derived from a firm-heterogeneity model of trade.

This paper is also related to a strand of literature that evaluates the growth of quality. For instance, Bils and Klenow (2001) quantify annual growth of quality of goods in US using estimated "quality Engel curves." Bils (2004) derives quality growth of durables from CPI data by studying consumers' behavior when they shift from old products to new substitutes. However, they do not provide estimates of product quality for different countries and sectors across years. My analysis differs from these papers by directly estimating product quality. In another related study, Khandelwal (2010) evaluates the quality of imported goods in the U.S. using a nested logit demand system. In this paper, I estimate product quality at the sectoral level for different countries.

The rest of this paper is organized as follows. Section 3.2 presents the theoretical model that motivates my empirical analysis. Section 3.3 derives a gravity equation and discusses issues necessary to consistently estimate the gravity equation. Section 3.4 describes the data used in the analysis. In Section 3.5, I estimate the gravity model and extract countries' sectoral quality indexes. Section 3.6 presents additional results for robustness checks and section 3.7 concludes.

3.2 Theoretical Framework

In this section, I present the basic elements of the model regarding consumer preferences, production, and firm entry decisions to export markets. I consider a world of J countries (indexed by i or j) and S sectors (indexed by s). Each sector (industry) is populated by a continuum of heterogeneous firms, each producing a

single variety of differentiated product. Capital and labor are the only factors of production. When incorporating product quality into preferences and production, I closely follow the model of Baldwin and Harrigan (2011).

3.2.1 Preferences

The preferences of a representative agent in country i are described by the following two-tier utility function where the upper tier is Cobb-Douglas and the lower tier is Constant Elasticity Substitution (CES),

$$U_i = \prod_s Q_{is}^{\eta_{is}}, \qquad Q_{is} = \left[\int_{v \in \mathcal{V}_{is}} [\lambda_{is}(v) q_{is}(v)]^{\alpha_s} \, dv \right]^{\frac{1}{\alpha_s}}, \tag{26}$$

where $\eta_{is} \in (0,1)$ with $\sum_s \eta_{is} = 1$, and $\alpha_s \in (0,1)$. The variable $\mathcal{V}_{is}$ represents the set of available varieties in sector s of country i, $q(v)$ is the quantity consumed of variety v, and $\lambda(v)$ is the quality of variety v. The elasticity of substitution between varieties in sector s is given by $\varepsilon_s = 1/(1-\alpha_s)$, which is the same across countries.

Consumers spending an amount E_i maximize their instantaneous utility by allocating $E_{is} = \eta_{is} E_i$ amounts on goods produced in sector s. It is well-known that with the CES aggregator, the optimal quantity $q(v)$ is then given by

$$q_{is}(v) = \frac{E_{is} \lambda_{is}(v)^{\varepsilon_s - 1} p_{is}(v)^{-\varepsilon_s}}{P_{is}^{1-\varepsilon_s}}, \tag{27}$$

where P_{is} is the quality-adjusted aggregate price index associated with the consumption index Q_{is} (i.e., $P_{is} Q_{is} = E_{is}$), and it is given by

$$P_{is} = \left[\int_{v \in \mathcal{V}_{is}} \left(\frac{p_{is}(v)}{\lambda_{is}(v)} \right)^{1-\varepsilon_s} dv \right]^{\frac{1}{1-\varepsilon_s}}. \tag{28}$$

3.2.2 Production and Trade

Differentiated products are produced by a continuum of monopolists, each producing a particular variety. Capital and labor are the factors of production and their

intensity of use varies across sectors. More specifically, the cost of producing one unit of product with quality λ is given by[16]

$$C_{is}(\lambda) = \lambda^a c_{is}/A_{is}, \qquad c_{is} = r_i^{\beta_s} w_i^{1-\beta_s}, \tag{29}$$

where $a \in (0,1)$ is a constant parameter, A_{is} represents sector-level productivity; r_i and w_i are rental price of capital and wage rate, respectively, in country i; and $\beta_s \in (0,1)$ represents the share of capital in production. Consistent with many empirical studies, according to (29), marginal cost of production increases with product quality (Verhoogen, 2008; Baldwin and Harrigan, 2011), and decreases with sectoral productivity A_{is}.

Following Helpman et al. (2008), I assume that production involves no fixed overhead cost. However, firms wishing to export to country j face a fixed exporting cost $c_{is}f_{ij}$, where c_{is} is given by (29). In addition, each exporting firm also faces variable trade costs, which take the standard iceberg form: τ_{ijs} units of good must be shipped from country i in order for 1 unit to arrive at country j. Fixed exporting cost $c_{is}f_{ij}$ ensures that only a fraction of firms will participate in trade.

Each firm faces a demand curve described in (27), and maximizing profits in each market yields the following optimal prices in domestic and foreign markets:

$$p_{is}(\lambda) = \frac{\lambda^a c_{is}}{\alpha_s A_{is}}, \qquad p_{ijs}(\lambda) = \frac{\tau_{ijs}\lambda^a c_{is}}{\alpha_s A_{is}}, \tag{30}$$

where p_{ijs} represents the price of good in foreign market j, and c_{is} is given by (29). The demand function (27) and the above pricing rules imply that profits obtained

[16]Specification (29) is similar to that in Dinopoulos and Unel (2011) and Dinopoulos and Unel (2013).

from the sales in domestic and foreign market j are given by

$$\pi_{is}(\lambda) = \frac{E_{is}\lambda^{(\varepsilon_s-1)(1-a)}}{\varepsilon_s}\left[\frac{c_{is}}{\alpha_s A_{is} P_{is}}\right]^{1-\varepsilon_s}, \tag{31a}$$

$$\pi_{ijs}(\lambda) = \frac{E_{js}\lambda^{(\varepsilon_s-1)(1-a)}}{\varepsilon_s}\left[\frac{\tau_{ijs} c_{is}}{\alpha_s A_{is} P_{js}}\right]^{1-\varepsilon_s} - c_{is} f_{ij}. \tag{31b}$$

A firm with product quality λ from country i exports to country j if $\pi_{ijs}(\lambda) \geqslant 0$. Existence of the fixed cost $c_{is} f_{ij}$ ensures that there exists a quality cutoff level λ^*_{ijs} such that only firms with $\lambda \geqslant \lambda^*_{ijs}$ export to country j.

I now address bilateral trade volume. To compute trade volumes, it is necessary to first specify the distribution of quality levels. I assume that $\lambda \sim \lambda_{is}\nu$, where λ_{is} is an exogenous constant and ν is a random variable drawn from a Pareto distribution, truncated over the support $[\nu_{sL}, 1]$. Specifically, the cumulative distribution function (c.d.f.) of ν is given by

$$G_s(\nu) = \frac{\nu^{k_s} - \nu_{sL}^{k_s}}{1 - \nu_{sL}^{k_s}}, \tag{32}$$

where k_s is the shape parameter of the distribution. I assume that $k_s > \varepsilon_s - 1$ so that the integrals converge. In addition, I assume that the c.d.f. is sector-specific and *time-invariant*. According to this formulation, λ_{is} is the maximum quality level that a product within sector s can have. Obviously, for each quality cutoff λ^*_{ijs} there exists a unique ν^*_{ijs} such that all firms with $\nu \geqslant \nu^*_{ijs}$ export. With the above distribution function, define

$$V_{ijs} = \begin{cases} \int_{\nu^*_{ijs}}^{1} \nu^{(1-a)(\varepsilon_s-1)} dG_s(\nu) & \text{if } \nu^*_{ijs} \leqslant 1 \\ 0 & \text{otherwise} \end{cases}. \tag{33}$$

Using the demand function (27) and pricing rule in (30) implies that the (f.o.b) value of country i's export in sector s to country j is given by

$$p_{is}(\lambda) q_{ijs}(\lambda) = \left[\frac{c_{is}}{\alpha_s A_{is} P_{js}}\right]^{1-\varepsilon_s} \tau_{ijs}^{-\varepsilon_s} E_{js} \lambda^{(\varepsilon_s-1)(1-a)}, \tag{34}$$

and integrating (34) across all exporting firms in sector s implies that the value of country i's export to country j in sector s is

$$EX_{ijs} = \left[\frac{c_{is}}{\alpha_s A_{is} P_{js}}\right]^{1-\varepsilon_s} \tau_{ijs}^{-\varepsilon_s} \lambda_{is}^{(1-a)(\varepsilon_s-1)} E_{js} N_{is} V_{ijs},$$

where N_{is} is the mass of products produced in sector s of country i and V_{ijs} is given by (33). Using the distribution function (32), EX_{ijs} becomes

$$EX_{ijs} = H_s N_{is} E_{js} \left[\frac{c_{is}}{\alpha_s A_{is} P_{js}}\right]^{1-\varepsilon_s} \tau_{ijs}^{-\varepsilon_s} \lambda_{is}^{(1-a)(\varepsilon_s-1)} \left[1 - (\nu_{ijs}^*)^{(1-a)(\varepsilon_s-1)+k_s}\right], \quad (35)$$

where $H_s = k_s / [((1-a)(\varepsilon_s - 1) + k_s)(1 - \nu_{sL}^{k_s})] > 0$ is a sector-specific constant.

3.3 Empirical Specification

In this section, I describe in detail how to consistently estimate equation (35). Specifically, I will use the two-step approach of Helpman et al. (2008), then introduce the method for evaluating countries' sectoral product quality.

3.3.1 Parameter Estimation

Taking the logarithm on both sides of (35), the export volume from country i to j in sector s can be expressed as

$$\ln(EX_{ijs}) = \theta_0 + \theta_i + \theta_j - \varepsilon_s \ln \tau_{ijs} + \psi_{ijs}, \quad (36)$$

where $\theta_0 = lnH_s + (\varepsilon_s - 1)ln\alpha_s$ is a constant term; $\theta_i = (1-\varepsilon_s)(\ln c_{is} - \ln A_{is}) + (\varepsilon_s - 1)(1-a)\ln \lambda_{is} + \ln N_{is}$ is a fixed effect for the exporting country; $\theta_j = (\varepsilon_s - 1)\ln P_{js} + \ln E_{js}$ is a fixed effect for the importing country; and $\psi_{ijs} = \ln[1 - (\nu_{ijs}^*)^{(1-a)(\varepsilon_s-1)+k_s}]$. In specification (36), τ_{ijs} refers to variable trade costs, and following the vast literature on estimating gravity models, I assume that $\varepsilon_s \ln \tau_{ijs} = \sum_{n=1}^{N} \gamma_n \ln D_{ijs}^n + \sum_{m=1}^{M} \iota_m B_{ijs}^m - u_{ijs}$, where $\{D_{ijs}^n\}$ is a set of continuous trade impediments between country i and j, such as distance and tariff. $\{B_{ijs}^m\}$ is a set of

dichotomous trade barriers, including common border, common language, common legal origin, the same colonial history, etc. Substituting this into (36) yields

$$\ln(EX_{ijs}) = \theta_0 + \theta_i + \theta_j - \sum_{n=1}^{N} \gamma_n \ln D_{ijs}^n - \sum_{m=1}^{M} \iota_m B_{ijs}^m + \psi_{ijs} + u_{ijs}, \tag{37}$$

where $u_{ijs} \sim N(0, \sigma_u^2)$.

Given that only positive export data are used in estimating (37), the consistent estimation of (37) requires correction of the sample selection bias. In addition, the variable ψ_{ijs} is not directly observable. The rest of this subsection introduces a two-step procedure to consistently estimate (37), following Helpman et al. (2008).

Step One: A Consistent Estimator of ψ_{ijs}

Note that when a positive export volume from country i to j in sector s is observed, it must be the case that the firm with the highest quality in the sector can make a profit from exporting to country j. As a result, the operating profits of this firm obtained from the sales in country j must be greater than the fixed cost of exporting. Using (31b) implies

$$\mathbf{Z}_{ijs} \equiv \frac{\frac{E_{js}\lambda_{is}^{(\varepsilon_s-1)(1-a)}}{\varepsilon_s}\left[\frac{\tau_{ijs}c_{is}}{\alpha_s A_{is} P_{js}}\right]^{1-\varepsilon_s}}{c_{is} f_{ij}} > 1. \tag{38}$$

As in Helpman et al. (2008), I specify the fixed exporting cost (in logs) between country i and j as a linear function of a set of *exclusion* variables, $\mathbf{F}_{ij}$, i.e., $\ln f_{ij} = \delta_0 + \delta \mathbf{F}_{ij} - \upsilon_{ij}$. Taking the logarithm of both sides of (38) yields

$$\mathbf{z}_{ijs} = \chi_0 + \chi_i + \chi_j - \sum_{n=1}^{N} \alpha_s \gamma_n \ln D_{ij}^n - \sum_{m=1}^{M} \alpha_s \iota_m B_{ij}^m - \delta \mathbf{F}_{ij} + \overline{\upsilon}_{ijs}, \tag{39}$$

where $\mathbf{z}_{ijs} \equiv \ln(\mathbf{Z}_{ijs})$, and $\overline{\upsilon}_{ijs} \equiv \alpha_s u_{ijs} + \upsilon_{ij}$. In this specification, $\chi_0 = -\ln \varepsilon_s + (\varepsilon_s - 1)\ln \alpha_s - \delta_0$ is a constant term, $\chi_i = (\varepsilon_s - 1)(1-a)\ln \lambda_{is} - \varepsilon_s \ln c_{is} + (\varepsilon_s - 1)\ln A_{is}$

is a fixed effect for the exporting country, $\chi_j = (\varepsilon_s - 1)\ln P_{js} + \ln E_{js}$ is a fixed effect for the importing country, and $\overline{v}_{ijs} \sim N(0, \sigma_v^2)$.

According to (38), when there is a positive recorded trade volume from country i to j in sector s, $\mathbf{Z}_{ijs} > 1$, implying that $\mathbf{z}_{ijs} \equiv \ln(\mathbf{Z}_{ijs}) > 0$. Thus, based on the participation in trade between country i and j in sector s, (39) can be estimated using a Probit model that specifies the probability of country i exporting j as a function of observable variables. After estimating this Probit model, let $\widehat{Pr}_{ijs}$ be the predicted probability of country i exporting to j in sector s, then the latent variable $\mathbf{z}_{ijs}$ is predicted as $\widehat{\mathbf{z}}_{ijs} \equiv \sigma_v \Phi^{-1}(\widehat{Pr}_{ijs})$, where $\Phi(\cdot)$ is the c.d.f. of the standard normal distribution. I can also calculate the expectation of white noise u_{ijs}, conditional on country i exporting to j in the sector. Let E_{ijs} denote a dummy that equals one if country i exports to j in sector s, and zero otherwise. Normal distributions of u_{ijs} and $\overline{v}_{ijs}$ imply that $\mathbb{E}[u_{ijs}|E_{ijs} = 1] = \rho\sigma_u u^*_{ijs}$, where ρ is the correlation coefficient between u_{ijs} and $\overline{v}_{ijs}$, $u^*_{ijs} \equiv \phi(\Phi^{-1}(\widehat{Pr}_{ijs}))/\widehat{Pr}_{ijs}$, and $\phi(.)$ is the p.d.f. of the standard normal distribution (see Appendix D for the proof).

Using the definition of cutoff quality ν^* and equation (38) implies that $\mathbf{Z}_{ijs} = (\nu^*)^{(1-\varepsilon_s)(1-a)}$.[17] Then because $\mathbf{z}_{ijs} = \ln \mathbf{Z}_{ijs}$ and $\psi_{ijs} = \ln[1 - (\nu^*_{ijs})^{(1-a)(\varepsilon_s - 1)+k_s}]$, the variable ψ_{ijs} can be expressed as follows

$$\begin{aligned}\psi_{ijs} &= \ln\left[1 - (\nu^*)^{(\varepsilon_s-1)(1-a)+k_s}\right] \\ &= \ln\left\{1 - \exp\left[\left(\frac{1}{1-a}\right)\left(\frac{1}{1-\varepsilon_s}\right)((\varepsilon_s - 1)(1-a) + k_s)\,\mathbf{z}_{ijs}\right]\right\}. \quad (40)\end{aligned}$$

Following Helpman et al. (2008), I approximate the RHS of (40) by a polynomial of the third order. In Appendix D, I show that $\mathbb{E}[\psi_{ijs}|E_{ijs} = 1] = f_0 + \sum_{p=1}^{3} f_p \widehat{\mathbf{z}}^p_{ijs} + \sum_{q=0}^{2} g_q \widehat{\mathbf{z}}^q_{ijs} u^*_{ijs}$, where f_p and g_q are coefficients.[18]

[17]Recall that ν^* is the cut-off quality such that $\pi_{ijs}(\nu^*) = 0$, where $\pi_{ijs}(.)$ is given by (31b). Using (38), the zero-profit condition $\pi_{ijs}(\nu^*) = 0$ yields $\mathbf{Z}_{ijs} = (\nu^*)^{(1-\varepsilon_s)(1-a)}$.

[18]Helpman et al. (2008) use a polynomial of $E[\mathbf{z}_{ijs}|E_{ijs} = 1]$ to approximate $E[\psi_{ijs}|E_{ijs} = 1]$, which is theoretically inappropriate since the expectations operator cannot directly enter the power function due to Jensen's inequality.

Step Two: Estimating (37) using positive trade data

Employing these specifications, I can now consistently estimate (37) using only positive trade data with the following specification:

$$\begin{aligned}
\ln(EX_{ijs}) &= \theta_0 + \theta_i + \theta_j - \sum_{n=1}^{N} \gamma_n \ln D_{ijs}^n - \sum_{m=1}^{M} \iota_m B_{ijs}^m \\
&\quad + \mathbb{E}\left[\psi_{ijs} | E_{ijs} = 1\right] + \mathbb{E}\left[u_{ijs} | E_{ijs} = 1\right] + e_{ijs} \\
&= \varrho_0 + \theta_i + \theta_j - \sum_{n=1}^{N} \gamma_n lnD_{ijs}^n - \sum_{m=1}^{M} \iota_m B_{ijs}^m \\
&\quad + \sum_{p=1}^{3} f_p \widehat{\mathbf{z}}_{ijs}^p + \sum_{q=0}^{2} g_q \widehat{\mathbf{z}}_{ijs}^q u_{ijs}^* + e_{ijs}, \qquad (41)
\end{aligned}$$

where $\varrho_0 = \theta_0 + f_0$, and e_{ijs} is the error term satisfying $\mathbb{E}\left[e_{ijs} | E_{ijs} = 1\right] = 0$.[19] As indicated before, the advantage of this specification is that it simultaneously accounts for selection biases in trade and firms' heterogeneity.

3.3.2 Product Quality Evaluation

To improve the efficiency of estimation, I estimate (41) using FGLS method, taking into account the heteroscedasticity of the error term. Using $\theta_i = (1 - \varepsilon_s)(\ln c_{is} - \ln A_{is}) + (\varepsilon_s - 1)(1 - a) \ln \lambda_{is} + \ln N_{is}$, after estimation, (41) can be written as

$$\begin{aligned}
\ln(EX_{ijs}) &= \widehat{\varrho}_0 + (1 - \varepsilon_s)(\ln \widehat{c}_{is} - ln\widehat{A}_{is}) + (\varepsilon_s - 1)(1 - a) \ln \lambda_{is} + ln\widehat{N}_{is} + \widehat{\theta}_j \\
&\quad - \sum_{n=1}^{N} \widehat{\gamma}_n \ln D_{ij}^n - \sum_{m=1}^{M} \widehat{\iota}_m B_{ij}^m + \sum_{p=1}^{3} \widehat{f}_p \widehat{\mathbf{z}}_{ijs}^p + \sum_{q=0}^{2} \widehat{g}_q \widehat{\mathbf{z}}_{ijs}^q u_{ijs}^* + \widehat{e}_{ijs} \\
&\equiv (\varepsilon_s - 1)(1 - a) \ln \lambda_{is} + (1 - \varepsilon_s) \ln(\widehat{c}_{is} / \widehat{A}_{is}) + \ln \widehat{N}_{is} + \widehat{\xi} \mathbf{\Xi} + \widehat{e}_{ijs}, \qquad (42)
\end{aligned}$$

where $\mathbf{\Xi}$ includes all other variables (excluding the dummy for the exporting country), and $\widehat{\xi}$ represents the vector of the corresponding estimated coefficients. The variable $\widehat{c}_{is}$ is directly calculated using data on wages and interest rates, and $\widehat{A}_{is}$ is

[19] $Var[e_{ijs} | E_{ijs} = 1]$ need not be the same across countries, since trade volume data are quite heteroscedastic.

approximated by the Solow residual. A comparison of the fixed effect of the exporting country in (36) with that in (39) implies that $\ln \widehat{N}_{is} = \widehat{\theta}_i - \widehat{\chi}_i - \ln \widehat{c}_{is}$. However, ε_s cannot be estimated in this paper, so I use estimates from other studies.

From (42), $\ln \lambda_{is}$ can be expressed as follows:

$$\ln \lambda_{is} = \frac{1}{(\varepsilon_s - 1)(1-a)} \left[\ln(EX_{ijs}) - (1-\varepsilon_s) \ln(\widehat{c}_{is}/\widehat{A}_{is}) - \ln \widehat{N}_{is} - \widehat{\xi}\boldsymbol{\Xi} - \widehat{e}_{ijs} \right].$$

Since $\mathbb{E}[\widehat{e}_{ijs}|E_{ijs} = 1] = 0$, I estimate the logarithm of sectoral product quality as[20]

$$\ln \widehat{\lambda}_{is} = \frac{1}{(\varepsilon_s - 1)} \left[\ln(EX_{ijs}) - (1-\varepsilon_s) \ln(\widehat{c}_{is}/\widehat{A}_{is}) - \ln \widehat{N}_{is} - \widehat{\xi}\boldsymbol{\Xi} \right]. \tag{43}$$

Suppose that country i exports products in sector s to J countries, then I have J estimates of $\ln \widehat{\lambda}_{ijs},\ j = 1, ..., J$. Denote $\widehat{Var}(e_{ijs})$ the estimated variance of e_{ijs}, I use a weighted average of $\ln \widehat{\lambda}_{ijs}$ as the final estimate of $\ln \lambda_{is}$, where the weight is $1/\widehat{Var}(e_{ijs})$.[21] Specifically, I regress J estimates on a constant using weighted OLS (with the weight equaling to $1/\sqrt{\widehat{Var}(e_{ijs})}$), then use the estimated constant as the final estimate of sectoral product quality (in logs).

3.4 Data

This section provides an overview of the data employed in my analysis. Appendix C provides details about data sources and the construction of variables. I use several data sources to construct country– and industry–level data.

The data on value added, investment, labor, compensation of labor, price indexes, and R&D come from the Structural Analysis (STAN) database, OECD (2008a).

[20] Since $1/(1-a)$ is positive and constant across sectors, countries, and years, it has no role when comparing product quality across countries or over time. Thus, I disregard this (unobserved) coefficient when estimating the logarithm of sectoral quality.

[21] Asymptotically, $\ln \widehat{N}_{is}$ and $\widehat{\xi}$ all go to the true value, thus the variance of $\ln \widehat{\lambda}_{ijs}$ goes to $[(1-\alpha_s)/\alpha_s]^2 Var(e_{ijs})$. I thus give more weight to estimators which are more accurately estimated when using $1/\widehat{Var}(e_{ijs})$ as the weight. The logic is the same as that behind GLS estimation, and consequently the ultimate quality estimator is more efficient.

Following Unel (2008), I use worker-hours as labor input and the data on annual working hours per worker are from the labor force statistics, OECD (2012). Upon constructing labor, capital, and output data, I construct sectoral-level Total Factor Productivity (TFP) using the standard TFP-level accounting approach. Data on sectoral-level elasticity of substitution are from Imbs and Mejean (2009) (See Table 1).

Export data come from the UN Comtrade database via the World Integrated Trade Solution (WITs), developed by the World Bank.[22] Trade barrier variables are drawn from various sources: bilateral tariff data are from the Trade Analysis and Information System (TRAINS) database, whereas data on bilateral distance, common border, common language, colonial relationship, common legal origin, common currency, and free trade agreements (FTAs) are all from the CEPII database. I combine the data from Helpman et al. (2008) and World Bank to construct the landlocked dummy. GDP and GDP per capita data are from the World Development Indicators (WDI) database. The religion data come from Helpman et al. (2008); and data on economic freedom are obtained from the Heritage Foundation.

Constrained by the availability of data, I construct a panel data set on twelve manufacturing industries in twenty countries between 1995 and 2006. The countries are Austria (AUT), Canada (CAN), the Czech Republic (CZE), Germany (DEU), Denmark (DNK), Spain (ESP), Finland (FIN), France (FRA), the United Kingdom (GBR), Greece (GRC), Hungary (HUN), Italy (ITA), the Netherlands (NLD),

[22] Comtrade declares that import data may be recorded with higher precision due to the tariff consideration. However, not all countries in the world report their import data to the UN. In the early portion of 1995-2006, the number of countries reporting import data is rather limited, suggesting that some countries in my analysis might export to all other countries. In this case, neither the fixed effects of these countries nor their product quality can be estimated in the extensive analysis. Consequently, I use export data instead of import data even though the latter were recorded more precisely.

TABLE 1: Sectoral Elasticity of Substitution

Sector (ISIC Rev.3)	**Elasticity of Substitution**
Food (15)	4.23
Textile (17T19)	6.12
Wood (20)	3.96
Paper (21T22)	4.49
Chemicals (24)	5.08
Rubber (25)	4.58
Non-metallic Mineral (26)	5.87
Basic Metals (27)	5.7
Fabricated Metal (28)	3.81
Machinery (29)	5.11
Electrical (30T33)	6.63
Transport Equipment (34T35)	4.8

Note: The table is calculated from the estimates of Imbs and Mejean (2009). The elasticities of substitution for 3-digit ISIC Rev.3 industries are averaged to the 2-digit level, which are then averaged to the sectoral level if the sector consists of two or more 2-digit industries.

Norway (NOR), New Zealand (NZL), Portugal (PRT), Slovakia (SVK), Slovenia (SVN), Sweden (SWE), and the United States (USA). The twelve manufacturing sectors are at the two-digit ISIC level: food products and beverage (ISIC 15); textile products, leather and footwear (ISIC 17T19); wood and products of wood and cork (ISIC 20); pulp, paper, paper products, printing and publishing (ISIC 21T22); chemicals and chemical products (ISIC 24); rubber and plastics products (ISIC 25); other non-metallic mineral products (ISIC 26); basic metals (ISIC 27); fabricated metal products, except machinery and equipment (ISIC 28); machinery and equipment (ISIC 29); electrical and optical equipment (ISIC 30T33); and transport equipment (ISIC 34T35).

3.5 Results

3.5.1 Parameter Estimation

To consistently estimate the gravity model requires exclusion variables which affect selection into trade while having no impact on the intensive margin. Helpman et al.

(2008) construct an exclusion variable based on the cost as well as the amount of time and procedures to set up a business in both countries. However, the data is only for 1986 and not suitable for this study covering many years. There is another variable, *Religion* in their paper, reflecting the extent of similarity between religions of both countries. It works well as an exclusion variable in their country-level study, but is not as effective in this sector-level research. As a preliminary check, I estimate (39) and (41) including *Religion* as a regressor, but not correcting for biases of sample selection and firms' heterogeneity when regressing (41).[23] As shown in Table 2, *Religion* is not a good exclusion variable for six sectors: Paper, Chemical, Rubber, Fabricated metal, Machinery, and Transport equipment.

I then construct a new exclusion variable, *Economic Freedom*, from the Index of Economic Freedom created by the Heritage Foundation. The Index of Economic Freedom is comprehensive in that it covers government regulation, availability of finance, labor cost, etc., which are supposed to directly relate to the fixed costs of maintaining a trade relationship in a foreign country, instead of variable trade costs. Table 3 shows that *Economic Freedom* outperforms the *Religion* of Helpman et al. (2008), and only in two sectors (Textile and Transport equipment) does it fail as an exclusion variable. In addition, I find that Colonial Relationship Post 1945 is an eligible exclusion variable for several sectors, as shown in Table 4. Consequently, each sector in this study has at least one exclusion variable in the extensive analysis.[24]

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[23]FGLS method is used when regressing (41), and the logarithm of standard error of the error term is assumed to be a linear function of GDP and GDP per capita of both countries as well as the distance between them (all in logs).

[24]Helpman et al. (2008) also find that Common Language is another valid exclusion variable in their country-level study. Additionally, they find the coefficient of Common Border has opposite signs in the extensive and intensive analyses, which provides an extra source of identification. Those results, however, are not found in this sector-level study.

Finally, I use Religion and Economic Freedom as exclusion variables for the following sectors: Food, Wood, Non-metallic mineral, Basic metals, and Electrical. I choose Economic Freedom and Colonial Relationship Post 1945 for sectors of Paper, Fabricated metal and Machinery. The remaining sectors having only one exclusion variable are as follows: Religion for Textile; Economic Freedom for the sectors of Rubber and Chemicals; and Colonial Relationship Post 1945 for Transport equipment.

Table 5 shows the main results when regressing (39). Some gravity variables have the expected impact on selection into trade across all sectors, such as common language, distance between countries, and the dummy indicating if they belong to the same regional trade agreement (RTA); whereas other variables affect different sectors differently. For instance, sharing a common border is found to only facilitate trade in the sectors of Textile, Wood, and Non-metallic mineral. In a country-level study, Helpman et al. (2008) report negative effects of being an island or landlocked on the incidence of trade. In this paper, however, being an island is found to be beneficial for trade in the sector of Wood, which makes sense since transportation costs can be greatly reduced. Besides, international trade in sectors of Textile and Machinery is more likely to occur between landlocked countries.

I estimate (41) using the FGLS method, explicitly taking into account the heteroscedasticity in trade volume.[25] Although there is no theory explaining heteroscedasticity in trade volume, I assume that the variance of export value is a function

[25]Santos Silva and Tenreyro (2009) claim that the model of Helpman et al. (2008) is too restrictive in that it does not allow for the heteroscedasticity of trade data. They then suggest a Poisson Pseudo Maximum Likelihood method which accommodates heteroscedasticity in both the likelihood of trade and trade volume. In this paper, I adapt the model of Helpman et al. (2008) to accommodate heteroscedasticity in trade volume by assuming that $Var[e_{ijs}|E_{ijs} = 1]$ varies across countries.

TABLE 2: Exclusion Restriction Test for Variable, *Religion*

	Extensive Analysis			Intensive Analysis		
Sector	1995	2000	2006	1995	2000	2006
Food	0.566	0.691	0.665	-0.211	0.174	0.152
	(0.134)***	(0.125)***	(0.121)***	(0.153)	(0.153)	(0.143)
Textiles	0.441	0.317	0.448	-0.18	0.147	-0.0917
	(0.131)***	(0.13)**	(0.13)***	(0.175)	(0.168)	(0.156)
Wood	0.395	0.58	0.33	-0.167	0.0397	-0.0343
	(0.151)***	(0.148)***	(0.131)**	(0.238)	(0.218)	(0.196)
Paper	0.561	0.436	0.701	0.516	0.393	0.343
	(0.164)***	(0.159)***	(0.15)***	(0.171)***	(0.176)**	(0.163)**
Chemicals	0.846	0.714	0.683	0.487	0.454	0.197
	(0.145)***	(0.139)***	(0.13)***	(0.144)***	(0.151)***	(0.148)
Rubber	0.561	0.595	0.613	0.435	0.491	0.204
	(0.145)***	(0.134)***	(0.134)***	(0.149)***	(0.153)***	(0.142)
Non-metallic	0.701	0.895	0.704	0.0816	0.268	0.2
Minerals	(0.137)***	(0.134)***	(0.131)***	(0.175)	(0.174)	(0.166)
Basic metals	0.729	0.214	0.475	0.0768	0.164	0.483
	(0.136)***	(0.129)*	(0.123)***	(0.203)	(0.219)	(0.284)*
Fabricated	0.79	0.557	0.472	0.071	0.404	0.227
Metal	(0.162)***	(0.159)***	(0.138)***	(0.155)	(0.138)***	(0.135)*
Machinery	0.431	0.69	0.519	0.337	0.5	0.302
	(0.187)**	(0.167)***	(0.16)***	(0.118)***	(0.133)***	(0.125)**
Electrical	0.467	0.936	0.894	0.0385	0.0679	0.091
	(0.172)***	(0.172)***	(0.151)***	(0.155)	(0.161)	(0.153)
Transport	0.279	0.474	0.209	0.256	0.472	0.176
Equipment	(0.164)*	(0.16)***	(0.145)	(0.223)	(0.214)**	(0.197)

Note: This table reports the coefficient of *Religion* when regressing equation (39) and (41) for 1995, 2000 and 2006. Equation (39) uses the Probit model whereas (41) uses the FGLS method. Robust standard errors are included in the parentheses. ***, **, and * refer to 1%, 5%, and 10% significant level, respectively.

TABLE 3: Exclusion Restriction Test for Variable, *Economic Freedom*

	Extensive Analysis			Intensive Analysis		
Sector	1995	2000	2006	1995	2000	2006
Food	0.267	0.183	0.303	-0.029	-0.243	-0.201
	(0.114)**	(0.1)*	(0.099)***	(0.235)	(0.18)	(0.166)
Textiles	0.058	0.352	0.12	-0.62	-0.409	-0.213
	(0.125)	(0.11)***	(0.116)	(0.204)***	(0.207)**	(0.171)
Wood	0.445	0.291	0.125	0.0078	-0.117	0.0713
	(0.129)***	(0.115)**	(0.104)	(0.351)	(0.278)	(0.25)
Paper	0.764	0.624	0.541	0.454	-0.202	0.163
	(0.139)***	(0.117)***	(0.111)***	(0.242)*	(0.238)	(0.194)
Chemicals	0.547	0.806	0.649	0.295	0.092	0.273
	(0.123)***	(0.113)***	(0.112)***	(0.166)*	(0.153)	(0.151)*
Rubber	0.528	0.321	0.213	0.165	-0.065	0.03
	(0.125)***	(0.112)***	(0.113)*	(0.17)	(0.175)	(0.146)
Non-metallic	0.493	0.368	0.454	0.073	0.265	0.276
Minerals	(0.121)***	(0.111)***	(0.109)***	(0.221)	(0.211)	(0.17)
Basic metals	0.249	0.411	0.393	-0.459	-0.33	0.21
	(0.114)**	(0.1)***	(0.099)***	(0.25)*	(0.224)	(0.184)
Fabricated	0.317	0.514	0.733	0.211	-0.252	0.064
Metal	(0.136)**	(0.125)***	(0.115)***	(0.212)	(0.214)	(0.164)
Machinery	0.617	0.733	0.435	-0.079	-0.181	0.097
	(0.152)***	(0.136)***	(0.128)***	(0.186)	(0.178)	(0.135)
Electrical	0.382	0.38	0.39	0.341	0.023	0.059
	(0.155)**	(0.138)***	(0.13)***	(0.189)*	(0.184)	(0.166)
Transport	0.33	0.467	0.472	0.737	0.131	-0.018
Equipment	(0.135)**	(0.127)***	(0.123)***	(0.268)***	(0.228)	(0.238)

Note: This table reports the coefficient of *Economic Freedom* when regressing equation (39) and (41) for 1995, 2000 and 2006. Equation (39) uses the Probit model whereas (41) uses the FGLS method. Robust standard errors are included in the parentheses. ***, **, and * refer to 1%, 5%, and 10% significant level, respectively.

TABLE 4: Exclusion Restriction Test for Variable, *Colonial Relationship Post 1945*

	Extensive Analysis			Intensive Analysis		
Sector	1995	2000	2006	1995	2000	2006
Paper	1.289	1.698	1.467	-0.074	0.178	0.247
	(0.44)***	(0.507)***	(0.444)***	(0.349)	(0.309)	(0.25)
Fabricated	1.038	1.331	0.906	0.259	-0.021	0.1
Metal	(0.403)***	(0.388)***	(0.373)**	(0.303)	(0.24)	(0.295)
Machinery	1.407	0.845	0.576	-0.036	-0.096	0.386
	(0.478)***	(0.448)**	(0.432)	(0.281)	(0.229)	(0.262)
Transport	1.319	1.502	1.338	0.026	-0.31	0.0297
Equipment	(0.386)***	(0.35)***	(0.363)***	(0.409)	(0.32)	(0.405)

Note: This table reports the coefficient of *Colonial Relationship Post 1945* when regressing equation (39) and (41) for 1995, 2000 and 2006. Equation (39) uses the Probit model whereas (41) uses the FGLS method. Robust standard errors are included in the parentheses. ***, **, and * refer to 1%, 5%, and 10% significant level, respectively.

of GDP of exporting and importing countries (in logs), based on the evidence provided by Flam and Nordstrom (2011). In addition, I assume that the variance depends on the GDP per capita of both countries and the distance between them (all in logs). Table 6 shows that the variance of export value negatively relates to GDP and GDP per capita of both countries in most cases, consistent with the finding of Flam and Nordstrom (2011). Besides, it also positively correlates with the distance between them. Those variables explain a significant portion of the variance with R-square over 0.27 in most sectors.

Table 7 reports the results when estimating (41). Since generated regressors are used in (41), I repeatedly re-sample countries with replacement and report bootstrapped standard errors. As expected, sharing a common border and legal origin both have positive effects on trade volume in all sectors, whereas distance adversely affects the trade between countries. However, the negative impact of tariffs is only found in the sectors of Wood, Rubber, Fabricated metal, Machinery and Electrical.

Different from the findings of Helpman et al. (2008), being an island is found to be beneficial to trade in some sectors, while sharing a common currency negatively correlates with trade volume in nearly half of the sectors.[26] Note that the coefficient of u^*_{ijs} is precisely estimated in most cases. When the coefficient is not significant, as for the Paper sector, the coefficient of $\widehat{\mathbf{z}}^2_{ijs}$ is accurately estimated.[27] Consequently, in this sector-level study, the biases caused by selection into trade and (or) firms' heterogeneity are important in all cases, which is compatible with other country-level research (e.g., Helpman et al. (2008) and Flam and Nordstrom (2011)).[28]

3.5.2 Product Quality

Having estimated parameters, I use the approach described in Section 3.3.2 to evaluate countries' product quality sector by sector and year by year. To facilitate comparison across countries, I first calculate the *overall* quality index by averaging sectors' product quality for each country, weighted by the share of each sector in value added of total manufacturing.[29] Following Hallak and Schott (2011), I subtract the calculated overall quality by the annual mean of all countries. Table 8 lists the *demeaned* quality of 19 OECD countries (excluding New Zealand) and their rankings for selected years. The last column also lists the change of demeaned overall quality and its rank between 1995 and 2006.

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[26] Flam and Nordstrom (2011) also find a negative effect of currency union on the intensive margin of trade. They claim that this is due to the sample of countries they choose.

[27] $\widehat{\mathbf{z}}_{ijs}$, $\widehat{\mathbf{z}}_{ijs}u^*_{ijs}$ and $\widehat{\mathbf{z}}^2_{ijs}u^*_{ijs}$ are dropped from the specification because they are highly correlated with either $\widehat{\mathbf{z}}^2_{ijs}$ or u^*_{ijs} (with correlation coefficient greater than 0.9). In cases where $\widehat{\mathbf{z}}^3_{ijs}$ highly correlates with $\widehat{\mathbf{z}}^2_{ijs}$ or u^*_{ijs}, it is also dropped.

[28] However, when the coefficient of u^*_{ijs} is significant, I cannot tell if it is because of selection into trade or firms' heterogeneity. This is because $E[\psi_{ijs}|E_{ijs}=1]$ and $E[u_{ijs}|E_{ijs}=1]$ in (41) all have u^*_{ijs} included.

[29] Constrained by data availability for some countries, the product quality of several sectors cannot be estimated, which limits the comparability of calculated overall quality across countries. The situation is especially serious for New Zealand, who has complete data for only 3 sectors (Food, Textile, and Non-metallic mineral). Therefore, I drop New Zealand and calculate the overall quality index for the other 19 countries. As a robustness check, I also construct the overall quality index using only sectoral quality estimates available to all the 19 countries. However, the ranking of the countries' overall quality is quite similar to that in Table 8.

TABLE 5: The Results of Analyzing the Extensive Margin

	Food	Textile	Wood	Paper	Chemicals	Rubber
Contiguity	0.458	1.888	0.936	0.00083	0.259	0.548
	(0.3)	(0.38)***	(0.307)***	(0.26)	(0.39)	(0.355)
Common Language	0.474	0.433	0.513	0.75	0.525	0.571
	(0.096)***	(0.101)***	(0.099)***	(0.106)***	(0.108)***	(0.105)***
Common Colonizer	0.418	0.239	0.366	0.631	0.178	1.046
Post 1945	(0.137)***	(0.163)	(0.161)**	(0.185)***	(0.171)	(0.181)***
Colonial Relationship	0.932	1.329	0.496	1.589	0.698	0.321
Post 1945	(0.7)	(0.508)***	(0.342)	(0.486)***	(0.661)	(0.47)
Colonial Relationship	0.317	0.46	0.436	0.456	1.456	0.49
Ever	(0.59)	(0.38)	(0.276)	(0.274)*	(0.554)***	(0.37)
Common Legal	0.19	0.327	0.118	0.206	0.124	0.175
Origin	(0.067)***	(0.072)***	(0.069)*	(0.075)***	(0.077)	(0.078)**
Distance (in logs)	-1.168	-1.196	-1.104	-1.444	-1.292	-1.212
	(0.07)***	(0.08)***	(0.065)***	(0.079)***	(0.083)***	(0.078)***
Island	-0.07	-0.14	0.569	-0.614	0.139	0.183
	(0.24)	(0.25)	(0.213)***	(0.286)**	(0.27)	(0.233)
Landlocked	0.226	0.491	0.112	-0.107	0.246	0.25
	(0.229)	(0.231)**	(0.274)	(0.286)	(0.221)	(0.23)
Common Currency	1.142	2.45	0.206	0.934	0.941	0.689
	(0.284)***	(0.392)***	(0.325)	(0.423)**	(0.452)**	(0.407)*
Regional Trade	0.483	0.613	0.319	0.233	0.432	0.566
Agreement	(0.109)***	(0.114)***	(0.105)***	(0.112)**	(0.118)***	(0.144)***
Religion	0.651	0.448	0.315			
	(0.128)***	(0.13)***	(0.135)**			
Economic Freedom	0.303		0.125	0.57	0.637	0.291
	(0.099)***		(0.104)	(0.108)***	(0.106)***	(0.109)***
Observations	7385	7825	7421	7414	7096	7530

TABLE 5. (Continued)

	Non-metallic mineral	Basic metals	Fabricated metal	Machinery	Electrical	Transport equipment
Contiguity	1.277	0.46	0.072	0.502	0.219	0.433
	(0.486)***	(0.28)	(0.29)	(0.311)	(0.381)	(0.253)*
Common Language	0.659	0.566	0.601	0.774	0.765	0.488
	(0.108)***	(0.106)***	(0.112)***	(0.122)***	(0.126)***	(0.108)***
Common Colonizer	0.694	0.606	0.44	-0.138	0.102	0.413
Post 1945	(0.17)***	(0.156)***	(0.184)**	(0.212)	(0.238)	(0.189)**
Colonial Rela.	0.789	0.3	1.042	0.88	1.851	1.338
Post 1945	(0.485)	(0.48)	(0.407)***	(0.462)*	(0.534)***	(0.363)***
Colonial Rela.	0.0059	0.621	0.19	0.638	-0.025	0.25
Ever	(0.364)	(0.381)	(0.29)	(0.323)**	(0.26)	(0.23)
Common Legal	0.098	0.203	0.238	0.073	0.082	0.257
Origin	(0.073)	(0.071)***	(0.081)***	(0.093)	(0.088)	(0.073)***
Distance (in logs)	-1.082	-1.041	-1.382	-1.388	-1.225	-1.106
	(0.073)***	(0.072)***	(0.08)***	(0.088)***	(0.093)***	(0.071)***
Island	0.265	0.077	-0.061	-0.028	-0.067	0.101
	(0.27)	(0.28)	(0.26)	(0.31)	(0.309)	(0.301)
Landlocked	0.339	0.18	-0.12	0.575	-0.069	0.211
	(0.226)	(0.21)	(0.26)	(0.239)**	(0.25)	(0.275)
Common Currency	1.193	0.769	0.761	-0.33	0.835	0.422
	(0.409)***	(0.279)***	(0.34)**	(0.42)	(0.69)	(0.303)
Regional Trade	0.488	0.665	0.31	0.564	0.213	0.302
Agreement	(0.114)***	(0.107)***	(0.11)***	(0.132)***	(0.126)*	(0.11)***
Religion	0.703	0.448			0.893	
	(0.137)***	(0.13)***			(0.157)***	
Economic Freedom	0.454	0.393	0.749	0.437	0.39	
	(0.109)***	(0.099)***	(0.111)***	(0.127)***	(0.13)***	
Observations	6857	7385	7090	7200	7069	7541

Note: This table reports the results when regressing equation (39). The Probit model is used, and the data are for 2006. Robust standard errors are included in parentheses. ***, **, and * refer to 1%, 5%, and 10% significant level, respectively.

TABLE 6: The Determination of Heteroscedasticity of Exports

	GDP (Importer)	GDP Per Capita (Importer)	GDP (Exporter)	GDP Per Capita (Exporter)	Distance	R^2
Food	-0.0001	-0.123	-0.154	-0.025	0.0975	0.31
	(0.033)	(0.038)***	(0.028)***	(0.034)	(0.0484)**	
Textile	0.0923	-0.163	-0.167	0.011	0.076	0.28
	(0.042)**	(0.043)***	(0.03)***	(0.032)	(0.048)	
Wood	0.097	-0.186	-0.12	0.052	0.245	0.3
	(0.036)***	(0.051)***	(0.033)***	(0.042)	(0.053)***	
Paper	0.09	-0.156	-0.04	-0.136	0.201	0.27
	(0.053)*	(0.072)**	(0.045)	(0.059)**	(0.071)***	
Chemicals	-0.068	-0.0013	-0.158	-0.016	0.077	0.29
	(0.032)**	(0.043)	(0.028)***	(0.037)	(0.045)*	
Rubber	-0.062	0.086	-0.118	-0.07	0.151	0.29
	(0.036)*	(0.05)*	(0.034)***	(0.038)*	(0.047)***	
Non-metallic	-0.069	-0.054	-0.145	0.044	0.177	0.26
Mineral	(0.041)*	(0.048)	(0.033)***	(0.04)	(0.043)***	
Basic Metals	-0.072	0.159	-0.205	-0.065	0.205	0.32
	(0.034)**	(0.049)***	(0.053)***	(0.035)*	(0.052)***	
Fabricated	0.0093	-0.213	-0.08	-0.018	0.154	0.28
Metal	(0.047)	(0.054)***	(0.042)**	(0.054)	(0.057)***	
Machinery	-0.118	-0.005	-0.14	-0.068	0.137	0.23
	(0.054)**	(0.055)	(0.044)***	(0.052)	(0.056)**	
Electrical	-0.122	-0.008	-0.114	-0.07	0.159	0.27
	(0.042)***	(0.056)	(0.033)***	(0.043)	(0.054)***	
Transport	0.001	-0.142	-0.018	-0.149	0.045	0.29
Equipment	(0.047)	(0.051)***	(0.038)	(0.043)***	(0.052)	

Note: Equation (41) is first regressed. Then the logarithm of the square of estimated error term is regressed on a constant, the GDP and GDP per capita of both countries as well as the distance between them (all in logs). The data are for 2006. Robust standard errors are in parentheses. ***, **, and * refer to 1%, 5%, and 10% significant level, respectively.

TABLE 7: The Results of Analyzing the Intensive Margin

	Food	Textile	Wood	Paper	Chemicals	Rubber
Tariff	1.31e-05	0.00017	-0.0714	-0.0088	-0.01	-0.031
	(0.00014)	(0.0057)	(0.019)***	(0.014)	(0.012)	(0.011)***
Contiguity	0.749	0.407	0.596	0.451	0.337	0.54
	(0.114)***	(0.122)**	(0.132)***	(0.11)***	(0.107)***	(0.106)***
Common Language	0.23	0.189	0.119	0.151	0.273	0.121
	(0.097)**	(0.097)**	(0.123)	(0.113)	(0.098)***	(0.094)
Common Colonizer	0.0033	-2.1	0.377	0.097	0.163	-0.117
Post 1945	(0.728)	(0.659)***	(0.733)	(0.976)	(0.618)	(0.65)
Colonial Relationship	0.426	0.553	0.041		-0.23	0.387
Post 1945	(0.27)	(0.283)*	(0.3)		(0.228)	(0.264)
Colonial Relationship	0.306	0.112	0.477	0.369	0.097	0.018
Ever	(0.127)**	(0.122)	(0.16)***	(0.113)***	(0.118)	(0.107)
Common Legal	0.25	0.219	0.259	0.411	0.311	0.356
Origin	(0.065)***	(0.066)***	(0.093)***	(0.075)***	(0.066)***	(0.059)***
Distance (in logs)	-0.929	-1.14	-1.198	-0.995	-0.964	-1.1
	(0.056)***	(0.064)***	(0.084)***	(0.065)***	(0.055)***	(0.057)***
Island	0.287	0.039	0.508	1.066	0.415	0.21
	(0.215)	(0.26)	(0.388)	(0.242)***	(0.226)*	(0.17)
Landlocked	0.532	0.172	0.246	-0.246	0.203	0.02
	(0.221)**	(0.169)	(0.23)	(0.198)	(0.18)	(0.18)
Common Currency	0.204	-0.099	-0.301	-0.081	0.03	-0.226
	(0.104)*	(0.109)	(0.135)	(0.108)	(0.105)	(0.096)**
Regional Trade	0.31	0.095	-0.383	0.596	0.398	0.365
Agreement	(0.098)***	(0.131)	(0.157)**	(0.12)***	(0.106)***	(0.11)***
$\widehat{\mathbf{z}}^2_{ijs}$	0.102	0.131	0.139	0.082	0.148	0.28
	(0.039)***	(0.013)***	(0.018)***	(0.014)***	(0.039)***	(0.061)***
$\widehat{\mathbf{z}}^3_{ijs}$	-0.004				-0.008	-0.048
	(0.012)				(0.011)	(0.017)**
u^*_{ijs}	0.427	0.705	0.618	0.205	0.681	0.576
	(0.091)***	(0.128)***	(0.127)***	(0.125)	(0.122)***	(0.157)***
Observations	1635	1660	1425	1293	1587	1556

TABLE 7. (Continued)

	Non-metallic mineral	Basic metals	Fabricated metal	Machinery	Electrical	Transport equipment
Tariff	-0.007	-0.0087	-0.024	-0.029	-0.036	-0.0055
	(0.014)	(0.02)	(0.013)*	(0.014)**	(0.011)***	(0.007)
Contiguity	0.577	0.513	0.533	0.39	0.208	0.478
	(0.109)***	(0.126)***	(0.103)***	(0.1)***	(0.121)*	(0.144)***
Common Language	0.197	-0.128	0.068	0.285	0.264	0.131
	(0.104)*	(0.131)	(0.087)	(0.09)***	(0.108)**	(0.131)
Common Colonizer	-0.617	0.674	-0.47	0.528	-0.64	1.43
Post 1945	(0.629)	(0.564)	(0.66)	(0.446)	(0.65)	(0.353)***
Colonial Relationship	0.126	-0.018			0.438	
Post 1945	(0.297)	(0.341)			(0.334)	
Colonial Relationship	0.129	0.358	0.164	0.137	-0.072	-0.069
Ever	(0.114)	(0.167)**	(0.095)*	(0.097)	(0.11)	(0.159)
Common Legal	0.273	0.229	0.328	0.197	0.249	0.252
Origin	(0.065)***	(0.093)**	(0.059)***	(0.054)***	(0.067)**	(0.084)***
Distance (in logs)	-1.14	-1.03	-1.03	-0.839	-0.964	-0.781
	(0.062)***	(0.071)***	(0.053)***	(0.051)***	(0.06)***	(0.092)***
Island	0.73	0.867	0.512	0.544	0.166	0.426
	(0.37)**	(0.277)	(0.257)**	(0.173)***	(0.241)	(0.234)
Landlocked	-0.021	0.057	0.077	-0.059	-0.392	-0.149
	(0.167)	(0.227)	(0.147)	(0.13)	(0.155)**	(0.191)
Common Currency	-0.135	0.0007	-0.253	-0.208	-0.279	-0.298
	(0.107)	(0.14)	(0.088)***	(0.081)**	(0.1)***	(0.124)**
Regional Trade	0.075	0.47	0.099	0.264	0.197	0.573
Agreement	(0.131)	(0.136)***	(0.113)	(0.095)**	(0.115)*	(0.145)***
$\widehat{\mathbf{z}}^2_{ijs}$	0.092	0.354	0.178	0.098	0.119	0.117
	(0.056)*	(0.092)***	(0.03)***	(0.01)***	(0.013)***	(0.016)***
$\widehat{\mathbf{z}}^3_{ijs}$	0.01	-0.051	-0.02			
	(0.016)	(0.026)**	(0.009)**			
u^*_{ijs}	0.519	0.257	0.452	0.717	0.797	0.753
	(0.151)***	(0.226)	(0.107)***	(0.128)***	(0.127)***	(0.141)***
Observations	1538	1550	1348	1379	1445	1275

Note: This table reports the results of regressing equation (41), using FGLS method. $\widehat{\mathbf{z}}_{ijs}$, $\widehat{\mathbf{z}}_{ijs}u^*_{ijs}$ and $\widehat{\mathbf{z}}^2_{ijs}u^*_{ijs}$ are dropped since they are highly correlated with $\widehat{\mathbf{z}}^2_{ijs}$ or u^*_{ijs} (with correlation coefficient greater than 0.9). When $\widehat{\mathbf{z}}^3_{ijs}$ is highly correlated with $\widehat{\mathbf{z}}^2_{ijs}$ or u^*_{ijs}, it is also dropped from the specification. The data are for 2006. Bootstrapped standard errors are in parentheses. ***, **, and * refer to 1%, 5%, and 10% significant level, respectively.

It is interesting to find that the estimated quality levels vary substantially across countries and over time. In 2006 for instance, Italy, France, and Spain took the first three places in the rank of *overall* product quality, whereas Slovenia, Finland, and the Slovak Republic were the countries with the lowest overall product quality. As to the change of quality, the Czech Republic and Greece underwent the greatest rise in their overall product quality, from 17th and 18th in 1995, respectively, to 11th and 12th in 2006. On the other hand, the biggest fall in overall product quality ranking happened in Austria, with its 1995 rank of 7th plummeting to 15th in 2006.

Note that even within a country, product quality for different sectors differs a lot, and undergoes different changes. Take the U.S. as an example: as shown in Table 9, its quality rank in Textile decreased from 4th to 7th during 1995-2006, whereas its rank in Transport Equipment climbed 3 places during the period.[30]

The change in demeaned quality in Table 8 indicates product quality convergence over time, first reported by Hallak and Schott (2011). The average demeaned quality of countries with overall quality greater than the annual mean decreased from 0.378 to 0.298 during 1995-2006, whereas the average for other countries with below-mean overall quality increases from -0.378 to -0.364 during the period. I also divide the 19 OECD countries into two equal-size groups (high-income/low-income) according to their GDP per capita in 1995 (the median country is dropped). Figure 3 depicts the evolution of the average of demeaned overall quality within each group. It is clear that there is a convergence in overall quality between the high and low income groups.

[30] Surprisingly, the U.S.'s product quality in Electrical ranks only 16th in 2006. However, this may be due to the problem in the U.S.'s value added deflator in that sector. The deflator decreases from 2.817 in 1995 to only 0.508 in 2006, suggesting that it has been "quality-adjusted" (Unel, 2008). Consequently, the real value added and sectoral TFP will be over-estimated, whereas the product quality in the sector will be under-estimated since TFP acts as a subtracter when estimating product quality. Sweden also confronts the same problem – its value added deflator in Electrical decreases from 2.625 to 0.428 during 1995-2006. As a result, its product quality in that sector ranks only 18th in 2006.

TABLE 8: The Product Quality and its Rank of 19 OECD Countries

Demeaned Quality								
Country	1995	1997	1999	2001	2003	2005	2006	Change
Germany	0.983	0.639	0.676	0.695	0.608	0.415	0.278	-0.705
France	0.697	0.513	0.495	0.463	0.460	0.448	0.458	-0.239
Netherlands	0.475	0.367	0.386	0.350	0.395	0.253	0.244	-0.232
Spain	0.367	0.369	0.396	0.337	0.363	0.411	0.390	0.023
Italy	0.364	0.559	0.643	0.569	0.647	0.782	0.774	0.410
United States	0.346	0.327	0.419	0.853	0.478	0.258	0.125	-0.221
Austria	0.317	0.026	-0.023	-0.133	-0.227	-0.312	-0.411	-0.728
Denmark	0.158	0.054	0.108	0.072	0.140	0.172	0.161	0.003
United Kingdom	0.062	0.077	0.271	0.399	0.280	0.311	0.239	0.177
Sweden	-0.145	0.054	-0.054	0.053	-0.077	-0.191	-0.354	-0.209
Norway	-0.147	0.037	0.055	-0.057	-0.074	-0.037	0.068	0.214
Canada	-0.171	-0.136	-0.205	-0.066	-0.133	0.000	0.054	0.225
Finland	-0.186	-0.237	-0.369	-0.338	-0.470	-0.420	-0.604	-0.417
Slovenia	-0.296	-0.624	-0.528	-0.526	-0.705	-0.460	-0.501	-0.204
Portugal	-0.425	-0.474	-0.366	-0.290	-0.275	-0.250	-0.167	0.258
Hungary	-0.440	-0.590	-0.580	-0.437	-0.440	-0.299	-0.429	0.011
Czech Republic	-0.460	-0.488	-0.353	-0.216	-0.092	-0.012	-0.092	0.368
Greece	-0.550	-0.295	-0.332	-0.656	-0.343	-0.319	-0.109	0.441
Slovak Republic	-0.962	-0.481	-0.749	-0.618	-0.492	-0.658	-0.615	0.347
Rank								
Country	1995	1997	1999	2001	2003	2005	2006	Change
Germany	1	1	1	2	2	3	4	-3
France	2	3	3	4	4	2	2	0
Netherlands	3	5	6	6	5	7	5	-2
Spain	4	4	5	7	6	4	3	1
Italy	5	2	2	3	1	1	1	4
United States	6	6	4	1	3	6	8	-2
Austria	7	11	10	12	13	15	15	-8
Denmark	8	8	8	8	8	8	7	1
United Kingdom	9	7	7	5	7	5	6	3
Sweden	10	9	11	9	10	12	14	-4
Norway	11	10	9	10	9	11	9	2
Canada	12	12	12	11	12	9	10	2
Finland	13	13	16	15	17	17	18	-5
Slovenia	14	19	17	17	19	18	17	-3
Portugal	15	15	15	14	14	13	13	2
Hungary	16	18	18	16	16	14	16	0
Czech Republic	17	17	14	13	11	10	11	6
Greece	18	14	13	19	15	16	12	6
Slovak Republic	19	16	19	18	18	19	19	0

Note: Sectoral product quality (in logs) is first averaged for each country, weighted by the share of each sector in the value added of total manufacturing; then subtracted by the annual mean of all countries' overall product quality. The countries are listed according to their ranks of overall quality in 1995. The last column is the change of demeaned quality and its rank during 1995-2006.

TABLE 9: The Ranking of Sectoral Quality

A. Textile

Country	1995	2000	2006	Change
Austria	1	5	11	-10
Canada	15	17	5	10
Czech Rep.	10	12	14	-4
Germany	2	2	12	-10
Denmark	14	19	13	1
Spain	6	9	4	2
Finland	18	15	19	-1
France	7	8	9	-2
United Kindom	13	6	8	5
Greece	5	4	2	3
Hungary	19	14	10	9
Italy	9	7	1	8
Netherlands	8	11	15	-7
Norway	17	13	20	-3
New Zealand	11	10	6	5
Portugal	3	3	3	0
Slovakia	20	20	16	4
Slovenia	12	16	18	-6
Sweden	16	18	17	-1
USA	4	1	7	-3

B. Chemicals

Country	1995	2000	2006	Change
Austria	3	13	17	-14
Canada	9	7	2	7
Czech Rep.	15	15	12	3
Germany	1	4	11	-10
Denmark	4	12	9	-5
Spain	7	6	3	4
Finland	11	9	13	-2
United Kindom	6	2	4	2
Greece	14	14	5	9
Hungary	13	8	10	3
Italy	5	3	1	4
Netherlands	2	5	7	-5
Portugal	16	11	8	8
Slovakia	17	17	14	3
Slovenia	10	16	16	-6
Sweden	12	10	15	-3
USA	8	1	6	2

C. Machinery

Country	1995	2000	2006	Change
Austria	4	13	17	-13
Canada	19	16	8	11
Czech Rep.	17	15	11	6
Germany	1	2	2	-1
Denmark	10	7	6	4
Spain	6	11	7	-1
Finland	13	12	14	-1
France	2	5	5	-3
United Kindom	9	3	4	5
Greece	18	14	19	-1
Hungary	16	19	18	-2
Italy	3	4	1	2
Netherlands	7	10	10	-3
Norway	15	8	13	2
Portugal	12	17	9	3
Slovakia	8	6	16	-8
Slovenia	11	18	15	-4
Sweden	14	9	12	2
USA	5	1	3	2

D. Transport Equipment

Country	1995	2000	2006	Change
Austria	7	10	16	-9
Canada	15	12	10	5
Czech Rep.	12	15	13	-1
Germany	2	1	3	-1
Denmark	13	11	9	4
Spain	6	6	4	2
Finland	9	8	6	3
France	1	3	2	-1
United Kindom	11	5	8	3
Greece	18	19	19	-1
Hungary	17	18	17	0
Italy	4	4	1	3
Netherlands	5	7	7	-2
Norway	16	13	12	4
Portugal	3	14	15	-12
Slovakia	19	16	11	8
Slovenia	14	17	18	-4
Sweden	10	9	14	-4
USA	8	2	5	3

Note: This table lists countries' ranking of four sectors' product quality for three years. The last column is the alteration of the ranking from 1995 to 2006.

Figure 4 graphs the change of average demeaned quality in each group for 4 sectors. The convergence of quality in the sector of Chemicals and Transport Equipment is clear-cut. Product quality of Textile in the low-income group even surpassed the high-income group in the second half of the period. To formally investigate the quality convergence intra-sector, I regress the standard deviation of sectoral product quality (in logs) at each year on a constant and time trend. As Table 10 shows, more than half the sectors display the convergence in product quality.

Hallak and Schott (2011) also find that convergence in overall product quality is at a higher rate than convergence in GDP per capita. To see if that happens in this study, I calculate that the difference in the average of per-capita GDP (in logs) between the two groups narrowed from 1.034 to 0.756 during 1995-2006, while the gap in average overall quality almost vanished during the period (from 0.465 to 0.0035 during 1995-2006), confirming the finding of Hallak and Schott (2011).

Another finding of Hallak and Schott (2011) is that countries' overall product quality positively correlates with their per-capita income. However, the correlation is weakening over time due to the different rates of convergence in overall quality and per-capita GDP. I also check the relevance of this result to my study, and calculate the coefficient of correlation between countries' overall product quality and their GDP per capita. The results confirm that the positive correlation is declining over time.[31]

To examine if the correlation between product quality and per-capita GDP differs across sectors, I redo the analysis above using sectoral quality estimates. The results in Table 11 demonstrate the positive correlation in most cases. However, the extent of

[31] For example, the correlation coefficient between countries' overall product quality and their GDP per capita is 0.732, 0.668 and 0.392 at year 1995, 2000 and 2006, respectively. The average of the correlation coefficients across years is 0.616.

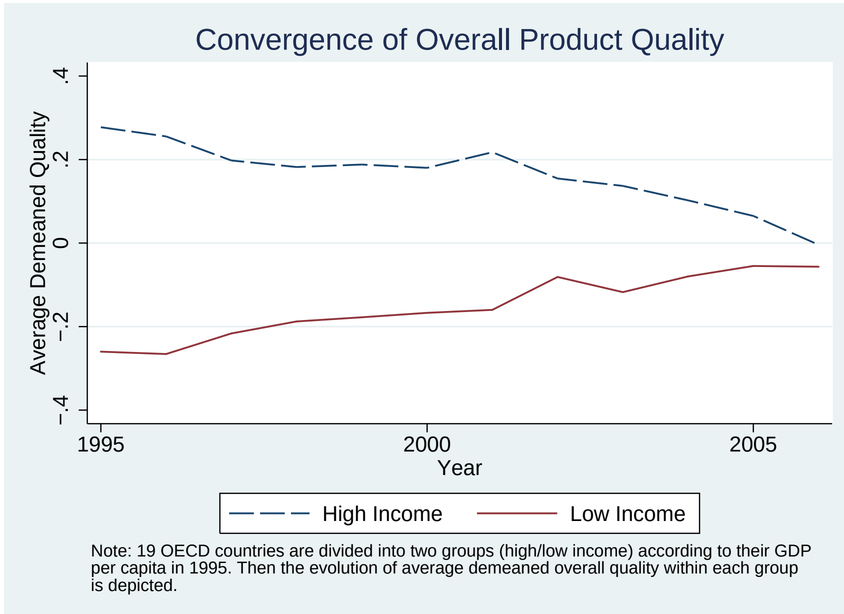

FIGURE 3: The Change of Average Demeaned Overall Quality in 1995

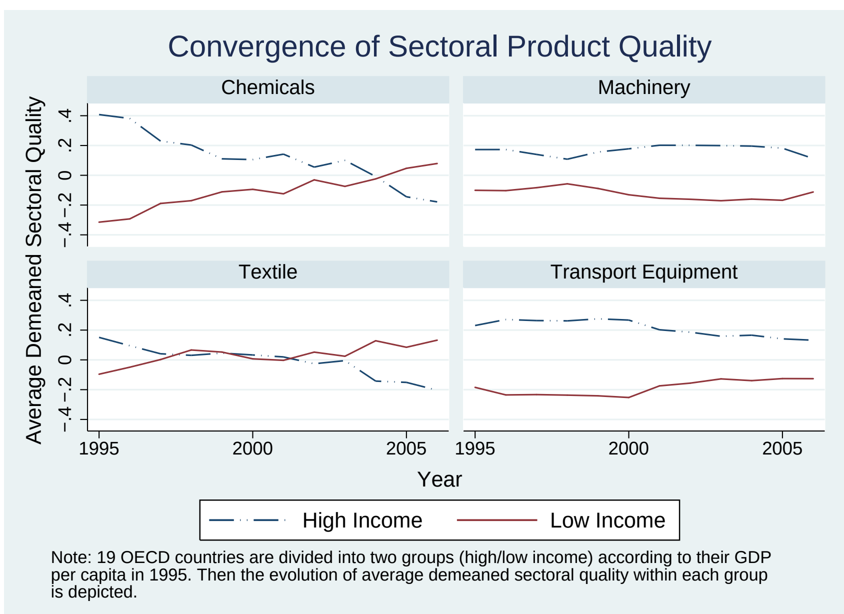

FIGURE 4: The Change of Average Demeaned Sectoral Quality in 1995

TABLE 10: Convergence of Sectoral Product Quality Over Years

Sector	Coefficient	Standard Error
Food	-0.0093	0.0028***
Textile	-0.012	0.0027***
Wood	0.0066	0.0041
Paper	-0.026	0.0036***
Chemical	-0.022	0.0055***
Rubber	-0.0033	0.0031
Non-metallic mineral	-0.0063	0.0019***
Basic metal	0.014	0.0069*
Fabricated metal	0.0059	0.0042
Machinery	0.0057	0.0031*
Electrical	-0.013	0.0034***
Transport equipment	-0.015	0.0018***

Note: This table regresses the standard deviation of sectoral product quality (in logs) at each year on a constant and time trend. The coefficient of the time trend is reported. *, ** and *** represent 10%, 5% and 1% significant level, respectively.

correlation differs enormously across sectors. For instance, in 2000 the strongest correlation occurs in Transport equipment, whereas the weakest occurs in Non-metallic mineral.[32]

Last but not least, although rich countries tend to have higher product quality than poor countries, the quality gap between them is more pronounced in capital- and skill-intensive sectors. To formally investigate how sectoral product quality relates to sectors' characteristics, I regress sectoral quality estimates (in logs) on measurements of investment-, skill-, and R&D-intensity of the sector, and their interactions with countries' GDP per capita (in logs). Investment- and R&D-intensity are defined as total fixed capital formation and R&D expenditure as a fraction of sec-

[32] Fadinger and Fleiss (2011) find that sectoral productivity also positively correlates with countries' income per capita, and in the mid nineties, the strongest correlation was in Metal products and the weakest in the sector of Food.

TABLE 11: Correlation Between Sectoral Product Quality and Per-capita GDP

Sector	1995	2000	2006	Average
Food	0.688	0.581	0.347	0.506
Textile	0.398	0.302	-0.225	0.145
Wood	0.525	0.502	0.231	0.432
Paper	0.482	0.561	0.362	0.501
Chemical	0.778	0.558	0.142	0.516
Rubber	0.504	0.598	0.292	0.512
Non-metallic mineral	-0.065	0.139	0.026	0.105
Basic metal	0.56	0.52	0.377	0.48
Fabricated metal	0.498	0.534	0.383	0.515
Machinery	0.38	0.509	0.442	0.466
Electrical	0.403	0.527	0.076	0.382
Transport equipment	0.637	0.643	0.385	0.547

Note: This table shows the correlation coefficient between countries' sectoral product quality and GDP per capita (both in logs) for three years. The last column is the average of correlation coefficients across years.

toral value added, respectively. Skill-intensity is the ratio of non-production workers to total employment.[33] All these statistics are measured using the U.S.'s industrial data and averaged across 1995-2006. To prevent potential endogeneity, I also control for countries' openness and human capital which may affect sectoral product quality and GDP per capita simultaneously.

As Table 12 shows, the coefficient of the interaction between investment-intensity and GDP per capita is positive and significant, confirming the positive correlation between sectoral quality and GDP per capita. Furthermore, it indicates that the difference in product quality between rich and poor countries is more pronounced in capital-intensive sectors. Similar results are also found for statistics of skill- and

[33]Skill intensity is first calculated using the 6-digit 1997 NAICS US's industry data from Beck et al. (2013). The results are then aggregated into 2-digit ISIC Rev3. level using the concordance table from Statistics Canada. When aggregating, employment in the industry is taken as the weight. Finally, the skill intensity for each ISIC Rev3. industry is averaged across 1995-2006.

TABLE 12: How Sectoral Product Quality Relates to Sector Characteristics

	ln(Quality)	*ln(Quality)*	*ln(Quality)*	*ln(Quality)*
Investment Intensity	-0.247			-0.172
	(0.042)***			(0.06)***
Investment Intensity	0.015			0.012
*ln(GDP Per Capita)	(0.004)***			(0.006)**
Skill Intensity		-8.269		-4.74
		(1.34)***		(2.097)**
Skill Intensity		0.527		0.429
*ln(GDP Per Capita)		(0.134)***		(0.21)**
R&D Intensity			-0.084	0.016
			(0.018)***	(0.03)
R&D Intensity			0.004	-0.003
*ln(GDP Per Capita)			(0.001)**	(0.003)
R-Square	0.4	0.37	0.4	0.42
Observations	2640	2640	2640	2640

Note: Control variables include a set of country and year dummies; countries' import penetration rate, export share in production and the percentage of secondary school completion in the population aged 15 and over. Standard errors clustered at country*year are in parentheses. ***,** and * represent 1%, 5% and 10% significant level, respectively.

R&D-intensity; however, the coefficient of the interaction term for R&D-intensity turns insignificant in Table 12 when I include all these sectoral characteristics in the analysis.[34]

3.6 Robustness

In Section 3.5.2, I notice that the value added deflator for the Electrical sector in the U.S. and Sweden might have been quality-adjusted. Consequently, the TFP of this sector will be over-estimated in these countries, whereas their product quality in Electrical will be under-estimated. To see if countries' estimated overall quality and its ranking are sensitive to this potential bias, I re-present Table 8 with the Electrical sector dropped.

[34] Beside clustered standard errors, I also employed robust and bootstrapped standard errors in the estimation, and the estimated standard errors are quite similar to those in Table 12.

As Table 13 shows, for most countries the rank of overall quality and its change over time are quite similar to those in Table 8. However, for some countries, they are decidedly different. For instance, the rank of Finland in rises from 18th to 12th when the Electrical sector is dropped, while the Netherland's rank in decreases from 5th to 8th. As to changes in ranking over time, during 1995-2006, the rank of Austria falls 13 places with Electrical dropped, compared to losing only 8 places in Table 8. Because the U.S.'s product quality in Electrical is potentially under-estimated, its overall quality in 2006 rises from 8th to 5th with Electrical dropped. Meanwhile, from 1995 to 2006, the U.S. gains 2 places in overall quality instead of losing 2 spots as in Table 8.

3.7 Conclusion

This paper estimates countries' sectoral product quality in a gravity model. The estimation framework controls for the biases caused by selection into trade and firms' heterogeneity, in light of Helpman et al. (2008). I also explicitly take into account the heteroscedasticity of trade volume to estimate coefficients more efficiently. This paper can be seen as a companion to Khandelwal (2010), who estimates product quality at product level using a nested logit demand model. I assume that firms are heterogeneous in quality, which makes it different from the work of Hallak and Schott (2011), who assume uniform quality within the sector.

The estimated product quality confirms some findings of Hallak and Schott (2011). For instance, product quality is positively correlated with countries' income per capita, and converging over time at a higher rate than the convergence in national income. I also find that the quality gap between rich and poor countries is more pronounced in capital- and skill- intensive sectors.

TABLE 13: Robustness Check (Product Quality and its Rank of 19 Countries)

Demeaned Quality								
Country	1995	1997	1999	2001	2003	2005	2006	Change
Germany	1.071	0.724	0.748	0.722	0.672	0.462	0.344	-0.727
France	0.739	0.614	0.558	0.469	0.520	0.501	0.536	-0.203
Netherlands	0.504	0.354	0.350	0.289	0.304	0.143	0.147	-0.356
Austria	0.426	0.124	0.042	-0.118	-0.222	-0.347	-0.433	-0.859
Italy	0.387	0.583	0.623	0.537	0.620	0.775	0.786	0.399
Spain	0.358	0.335	0.317	0.255	0.272	0.304	0.306	-0.051
United States	0.265	0.324	0.405	0.856	0.522	0.319	0.275	0.011
Denmark	0.209	0.082	0.119	0.093	0.170	0.167	0.243	0.034
United Kingdom	0.110	0.115	0.304	0.379	0.250	0.284	0.236	0.127
Finland	-0.095	-0.049	-0.003	-0.089	-0.051	-0.031	-0.163	-0.068
Norway	-0.129	0.069	0.060	-0.140	-0.154	-0.115	0.032	0.161
Canada	-0.201	-0.190	-0.272	-0.172	-0.258	-0.124	-0.056	0.145
Sweden	-0.268	0.017	-0.066	-0.055	-0.099	-0.105	-0.238	0.031
Slovenia	-0.281	-0.627	-0.579	-0.574	-0.759	-0.504	-0.512	-0.231
Czech Republic	-0.469	-0.472	-0.323	-0.228	-0.081	-0.005	-0.072	0.397
Portugal	-0.483	-0.549	-0.465	-0.377	-0.355	-0.345	-0.241	0.241
Hungary	-0.531	-0.593	-0.473	-0.418	-0.359	-0.161	-0.333	0.198
Greece	-0.603	-0.396	-0.471	-0.742	-0.426	-0.454	-0.224	0.379
Slovak Republic	-1.005	-0.463	-0.873	-0.688	-0.564	-0.764	-0.634	0.372
Rank								
Country	1995	1997	1999	2001	2003	2005	2006	Change
Germany	1	1	1	2	1	3	3	-2
France	2	2	3	4	4	2	2	0
Netherlands	3	4	5	6	5	8	8	-5
Austria	4	7	10	11	13	16	17	-13
Italy	5	3	2	3	2	1	1	4
Spain	6	5	6	7	6	5	4	2
United States	7	6	4	1	3	4	5	2
Denmark	8	9	8	8	8	7	6	2
United Kingdom	9	8	7	5	7	6	7	2
Finland	10	12	11	10	9	10	12	-2
Norway	11	10	9	12	12	12	9	2
Canada	12	13	13	13	14	13	10	2
Sweden	13	11	12	9	11	11	14	-1
Slovenia	14	19	18	17	19	18	18	-4
Czech Republic	15	16	14	14	10	9	11	4
Portugal	16	17	15	15	15	15	15	1
Hungary	17	18	17	16	16	14	16	1
Greece	18	14	16	19	17	17	13	5
Slovak Republic	19	15	19	18	18	19	19	0

Note: Sectoral product quality (in logs) is first averaged for each country, weighted by the share of each sector in the value added of total manufacturing; then subtracted by the annual mean of all countries' overall product quality. When calculating the overall quality indexes, electrical and optical equipment sector is excluded since its quality might be under estimated for some countries. The countries are listed according to their ranks of overall quality in 1995. The last column is the change of demeaned quality and its rank during 1995-2006.

Of course, this study is subject to several limitations. First, due to data availability, I only estimate the product quality for 20 OECD countries. It will be interesting to extend the analysis to more countries (especially developing ones), with access to additional data in the future. Second, I assume a CES utility function in the model, which yields constant markups across firms. A model allowing different markups for firms with different quality will be intriguing and better compatible with the facts. Third, if more gravity variables are possible, the estimated quality may be less noisy and more useful.

Chapter 4: Import Competition, R&D and Quality Growth

4.1 Introduction

One outcome of economic growth is an increase of productivity. As new technologies are invented, we are able to produce more goods and services for a given amount of inputs which results in a higher income per capita and living standard. On the other hand, generally speaking, during the process of economic growth, we are producing products of higher quality for several reasons. First, people would like to consume more and higher quality goods as they become wealthier (see, for example, Linder (1961) and Fajgelbaum et al. (2011)). Second, firms might want to upgrade their product quality as a strategy to cope with market competition (See, for example, Grossman and Helpman (1991)).[35]

Empirically, there is a large literature investigating the evolution of productivity at the country and sectoral levels, as well as the driving forces behind it.[36] However, because of the difficulties associated with measuring product quality, empirical research evaluating the growth of quality is inadequate and investigation about what drives the upgrading of quality is quite rare.

This paper contributes to the literature by empirically examining the effects of import competition and domestic R&D on the growth of product quality using the sector-level quality estimates in Chapter 3. As in Hallak and Schott (2011), I define

[35]Product quality can also be improved as a byproduct of workers' investment in human capital (see, for example, Stokey (1991)).

[36]Empirical analysis of productivity growth includes Baumol (1986) and Fare et al. (1994), among others. As to the reasons behind the change of productivity, some other literature studies the effects of trade liberalization on productivity, such as Bustos (2011), Bloom et al. (2011), and Acharya and Keller (2008), among others. There is another strand of literature studying the effects of R&D on productivity growth, including Griliches (1994) and Griffith et al (2004), among others.

"quality" as any tangible or intangible non-price properties of a good which are desired by consumers. Suppose that Goods A and B are of the same type and price, but Good A has a larger market share than Good B. I assert that Good A has a higher product quality than Good B.[37]

I find import competition significantly contributes to the growth of product quality, confirming the results of Amiti and Khandelwal (2013). In addition, I find that research and development (R&D) and human capital have positive effects on quality upgrading only through increasing the absorptive capacity of quality-lagged countries.

This paper relates to a strand of literature evaluating the growth of quality. For instance, Bils and Klenow (2001) quantify the annual growth of quality of goods in U.S. using the estimated "quality Engel curves." In another paper, Bils (2004) derives quality growth of durables from CPI data by studying consumers' behavior when they shift from old products to new substitutes. This study differs from theirs in that I calculate the growth of quality directly by using the estimates of product quality for different countries and sectors across years.

My analysis also relates to the literature that investigates the impact of trade on quality upgrading. Eswaran and Kotwal (2007), Verhoogen (2008), and Fan et al. (2013) develop models showing that trade liberalization induces firms to upgrade their product quality.[38] However, these studies suffer from a lack of data on reliable estimates of product qualities. An exception is Amiti and Khandelwal (2013),

[37]Under this broad definition of quality, the higher quality embedded in Good A may be due to technical reasons: for example, Good A is more durable or has more functions than Good B. In other cases, the larger market share and thus "quality" of Good A might be simply due to a more successful marketing strategy that shifts consumers' preference toward Good A.

[38]In a similar way, Bustos (2011), Bloom et al. (2011), and Unel (2013) among many others have demonstrated that trade liberalization enables firms to upgrade their technologies.

who investigate firms' quality upgrading upon an exogenous import tax cut using product-level quality indexes. In this paper, I analyze the effect of an increase in import penetration on quality growth using sectoral-level quality estimates from a gravity equation. Although we use different methodologies and data sets, we arrive at the same conclusion - import competition contributes to quality upgrading of firms.

Finally, this paper contributes to the large theoretical literature on Research and Development (R&D) and quality upgrading in economic growth. Indeed, the role of R&D on quality upgrading is the hallmark of quality-ladder endogenous growth models.[39] To the best of my knowledge, this is the first paper to extract quality indexes and relate them to R&D investment and human capital.

4.2 Related Literature

Theoretical literature in international trade often asserts that trade liberalization can help improve the product quality of the country. For example, Eswaran and Kotwal (2007) argue that free trade can improve welfare in developing countries by increasing the quality of goods they produce. In another influential paper, Verhoogen (2008) models quality upgrading as a reaction of more productive firms to an exogenous currency devaluation. More recently, Fan et al. (2013) sets up a model with heterogeneous firms where firms' product quality is endogenous. When there is a decrease in tariffs, firms respond by choosing higher quality if they are heterogenous in quality. In an attempt to explain the increase in skill-premium shortly after trade liberalization, Eslava et al. (2012) build a model where firms invest in quality upgrading technologies when they face import competition.

However, due to a lack of quality estimates, empirical evidence about how trade liberalization affects quality upgrading is inadequate. Amiti and Khandelwal (2013)

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[39] The literature on this subject is vast. See Aghion and Howitt (2006) for a comprehensive review of this literature.

first provide evidence that import competition increases the rate at which product quality is upgraded.[40] This paper is the second to present evidence that import competition contributes to quality upgrading. Although we use quality estimates from different models, the conclusion is the same - import competition contributes to quality upgrading.

As to the relationship between R&D and quality growth, Flam and Helpman (1987) theoretically explore how R&D and technological progress in South stimulate the upgrading of product quality in North. In Arnold and Kornprobst (2008), sectoral R&D investment directly increases the highest quality level in the sector. Lambertini and Orsini (2010) also model the upgrading of product quality as the result of domestic R&D investment.

Empirically, Faruq (2010) analyzes the quality of goods imported by the US and finds that goods from countries with more intensive R&D investment tend to be of higher quality. Johansson (2007) also documents that Swedish regions with easier access to R&D resources have a comparative advantage in producing quality goods. In another study using micro-data of a panel of Chinese steel producers, Fisher-Vanden and Terry (2009) find that technologies acquired from foreign countries have to be combined with domestic R&D to improve the product quality of those firms.

However, to the best of my knowledge, there is no literature empirically testing the role of domestic R&D investment in the upgrading of sectoral product quality. This paper attempts to bridge that gap since I have quality estimates sector by sector and year by year.

[40] In a related paper, David (2011) analyzes the improvement of product quality for a panel of Spanish manufacturing firms when they confront an exogenous increase in market competition.

The rest of this paper is organized as follows. Section 4.2 describes the data used in the analysis. Section 4.3 specifies the empirical models for the analysis. Section 4.4 presents the empirical results, and Section 4.5 checks robustness. Section 4.6 concludes.

4.3 Data

4.3.1 Data Sources

This section provides an overview of the data employed in my analysis. Appendix C provides details about data sources and the construction of variables. I use several data sources to construct country- and industry-level data.

The data on value added, import penetration, R&D intensity, and the ratio of export to output at the sectoral level come from the Structural Analysis (STAN) database, OECD (2008a). I use the business enterprise R&D expenditure data from OECD (2012) for sectoral R&D investment. The sectoral value added and R&D investment data are all transformed into 2000 U.S. dollars. A human capital measurement at the sectoral level wouldl be more appropriate for this study; however, I cannot find such comparable data covering those countries and sectors of interest. I thus use the percentage of secondary school completion in the population ages 15 and above to represent human capital at the country level, which is drawn from Barro and Lee (2013). Finally, I take the quality estimates from Chapter 3 as the proxy for countries' product quality (in logs) at sector level during 1995-2006.

Constrained by the availability of data, I construct a panel data set on twelve manufacturing industries in twenty countries between 1995 and 2006. The countries are Austria (AUT), Canada (CAN), the Czech Republic (CZE), Germany (DEU), Denmark (DNK), Spain (ESP), Finland (FIN), France (FRA), the United Kingdom (GBR), Greece (GRC), Hungary (HUN), Italy (ITA), the Netherlands (NLD), Nor-

way (NOR), New Zealand (NZL), Portugal (PRT), Slovakia (SVK), Slovenia (SVN), Sweden (SWE), and the United States (USA). The twelve manufacturing sectors are at the two-digit ISIC level: food products and beverage (ISIC 15); textile products, leather and footwear (ISIC 17T19); wood and products of wood and cork (ISIC 20); pulp, paper, paper products, printing and publishing (ISIC 21T22); chemicals and chemical products (ISIC 24); rubber and plastics products (ISIC 25); other non-metallic mineral products (ISIC 26); basic metals (ISIC 27); fabricated metal products, except machinery and equipment (ISIC 28); machinery and equipment (ISIC 29); electrical and optical equipment (ISIC 30T33); and transport equipment (ISIC 34T35).

4.3.2 Descriptive Statistics

Table 14 presents descriptive statistics for the manufacturing sectors of 20 OECD countries. Excepting countries' overall quality index in 1995, all other variables are averaged across 1995-2006. Columns 2-3 measure the openness of the manufacturing of these countries, where the Netherlands, Denmark and Slovakia have the highest openness.[41] R&D intensity in Column 4 is defined as the ratio of total business research and development expenditure to the manufacturing value added. The data on human capital are from Barro and Lee (2013), which is measured by the percentage of secondary school completion in the population aged 15 and above. Not surprisingly, Sweden, France, and the U.S. devote the greatest fraction of output into R&D; however it is interesting that Czech Republic and Slovenia have the highest average human capital level.

[41]Export/Production is the share of export value in sectoral production. Import penetration is defined as the import value divided by the sum of production and net import.

TABLE 14: Statistics for Countries, Averages During 1995-2006

Country	$\frac{EX}{Y}$	Import penetration	$\frac{R\&D}{Y}$	Human capital	Share of Y in sample	Share of R&D in sample	Quality (1995)	Growth of quality (demeaned)
Austria	62.3	62.6	6.1	39.2	1.2	1.2	0.32	-6.6
Canada	51.0	51.4	4.2	30.6	4.1	2.9	-0.17	2.0
Czech Republic	49.4	50.1	2.2	55.7	0.5	0.4	-0.46	3.3
Denmark	66.8	65.8	7.1	22.6	0.7	0.5	0.16	0.0
Finland	47.2	37.1	8.0	19.6	0.9	1.1	-0.19	-3.8
France	38.9	37.8	8.7	32.9	6.4	6.7	0.70	-2.2
Germany	45.1	37.8	7.4	38.9	13.1	16.7	0.98	-6.4
Greece	20.4	42.8	1.0	30.0	0.4	0.1	-0.55	4.0
Hungary	57.6	59.0	1.4	42.1	0.3	0.2	-0.44	0.1
Italy	31.3	27.3	2.2	28.0	6.8	2.8	0.36	3.7
Netherlands	82.8	81.3	5.9	37.0	1.7	1.8	0.48	-2.1
New Zealand	38.2	42.4	1.3	19.1	0.3	0.1	n/a	n/a
Norway	40.8	48.8	4.6	35.3	0.5	0.3	-0.15	1.9
Portugal	37.0	44.7	0.7	11.7	0.6	0.1	-0.42	2.3
Slovak Republic	65.9	65.2	0.7	30.1	0.2	0.0	-0.96	3.2
Slovenia	60.8	62.2	3.0	52.8	0.2	0.1	-0.30	-1.9
Spain	28.2	32.8	2.2	19.5	3.2	1.4	0.37	0.2
Sweden	52.3	45.6	12.8	47.6	1.6	2.4	-0.15	-1.9
United Kingdom	39.2	44.2	6.1	46.6	7.5	n/a	0.06	1.6
United States	15.7	21.9	8.6	34.8	49.8	61.0	0.35	-2.0

Note: All statistics are in percentages except Quality(1995). Human capital is the percentage of secondary school completion in the population aged 15 and above. Quality(1995) is countries' overall quality index in 1995. Because New Zealand's overall quality is not comparable with other countries', its level and growth are not listed.

The share of Y in sample in Table 14 is the manufacturing value added of each country as a fraction of total value added of all countries in the sample. Similarly, the share of R&D in the sample is the proportion of business R&D expenditure of each country in total R&D expenditure of the sample. They show that U.S., Germany, and France produced most of the outputs and conducted most of R&D activities in the sample. The last column presents countries' average growth rate of demeaned overall quality during 1995-2006. Compared with countries' overall quality index (demeaned) in 1995, it indicates overall quality convergence across countries. For example, Germany had the highest quality in 1995 but underwent nearly the biggest decrease in relative quality during the period.

Table 15 presents the descriptive statistics for the twelve sectors. The export ratio in production, import penetration, and R&D intensity in Columns 2-4 are first averaged across countries at each year, and then averaged across years. They show that on average, Electrical, Textile, and Transport equipment are the sectors with the greatest openness, while Electrical, Chemical, and Transport equipment are most intensively engaged in R&D activities.

To measure the share of Y and R&D in sample in Table 15, I first calculate each sector's share of value added and R&D expenditure in the whole manufacturing of the country, and then average the shares across countries at each year. Finally, I average the shares of each sector across years to get the statistics in Columns 5-6. Thus, on average, Food, Electrical, and Paper are the largest sectors in terms of their shares of value added in the country, whereas most R&D activities are conducted in sectors of Chemicals, Transport equipment, and Machinery. The last column of Table 15 lists the average growth rate of the standard deviation of quality (in logs)

TABLE 15: Statistics for Sectors, Averages During 1995-2006, (%)

Sector	$\frac{EX}{Y}$	Import penetration	$\frac{R\&D}{Y}$	Share of Y in sample	Share of R&D in sample	Std(ln Quality) growth
Food	21.3	21.6	0.7	12.1	3.9	-1.0
Textile	68.1	72.9	1.1	5.9	1.6	-1.4
Wood	29.2	24.1	0.4	3.1	0.5	1.6
Paper	27.2	24.6	0.7	10.8	1.3	-5.3
Chemical	57.9	63.9	11.1	9.2	23.3	-3.8
Rubber	41.6	45.7	2.5	4.2	3.2	-1.5
Non-metallic mineral	23.7	24.0	1.1	4.9	1.4	-0.8
Basic metals	55.4	57.7	1.8	4.5	2.2	2.2
Fabricated metal	23.5	25.1	0.9	8.4	2.1	1.0
Machinery	60.2	62.6	4.7	9.4	9.9	0.9
Electrical	76.1	82.9	15.4	11.2	6.8	-1.5
Transport equipment	64.5	69.8	8.9	9.1	11.4	-2.9

Note: To measure Std(ln Quality) growth, I first calculate the standard deviation of quality within sector at each year, then I calculate the growth rate of the standard deviation year by year, which is finally averaged across years.

within the sector at each year. It shows that for most sectors there exists a convergence in product quality across countries, which is discussed in Chapter 3.

4.4 Empirical Specification

4.4.1 Import Competition and Quality Growth

Although much theoretical research concludes that trade liberalization contributes to firms' quality upgrading, Amiti and Khandelwal (2013) are the first to empirically show that import competition increases the rate at which product quality is upgraded.[42] To see if their results are replicated in this study, in Figure 5, I graph the change of import penetration in the whole manufacturing as well as overall product quality from 1995 to 2006 for four countries (the Czech Republic, Hungary, Slovakia, and Slovenia). It is evident that after 2002, when they became eligible to join the European Union, both their import penetration and overall product quality grow at a higher speed than before.[43]

To formally test if import competition increases countries' product quality in this study, I set up the specification as follows:

$$\begin{aligned} \Delta_n ln(Quality)_{ist} &= \beta_1 \Delta_n Import\ Pene_{ist} + \beta_2 \Delta_n Import\ Pene_{ist} * Upper_{is,t-n} \\ &+ \beta_3 Demeaned\ Quality_{is,t-n} + \kappa X_{is} + \alpha_i + \alpha_{zt} + \epsilon_{ist}, \qquad (44) \end{aligned}$$

where Δ_n is the difference between a variable and its n-period-lagged value. $Import\ Pene_{ist}$ is the rate of import penetration in sector s of country i at year t. $Upper_{ist}$ is a dummy indicating whether the product quality of the sector lies in the upper half at year t. X_{is} is a set of other control variables, including $H_{i,t-n}$, $R\&D_{is,t-n}$ and

[42] In another paper, David (2011) analyzes the improvement of product quality for a panel of Spanish manufacturing firms when they confront an exogenous increase in market competition.

[43] Although the Czech Republic, Hungary, Slovakia, and Slovenia were officially admitted to the EU in 2004, they were actually eligible to join the EU in 2002 by the Copenhagen European Council. I therefore prefer 2002 as the reference year in Figure 5, considering that upon that expectation, firms' behavior may have changed since 2002.

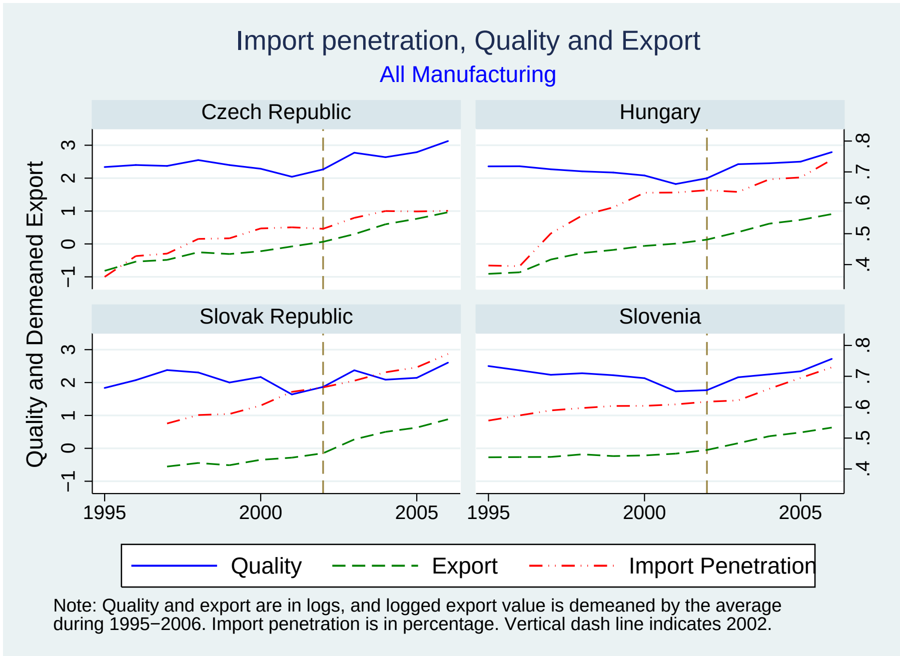

FIGURE 5: The Change of Quality for Four Countries When Accepted to EU

$R\&D\ inten_{is,t-n}$. H_{it} is the percentage of secondary school completion in the population aged 15 and over. $R\&D_{ist}$ and $R\&D\ inten_{ist}$ are enterprise R&D expenditure and sectoral R&D intensity, respectively.

In this specification, I expect β_1 to be positive if an increase in import penetration has a positive impact on the growth of product quality.[44] Empirical research (see, e.g., Acharya and Keller (2008)) suggests that more advanced technologies will spill over to less developed countries and thus increase their productivity when they import from developed countries. I hypothesize that this result is also true for quality upgrading and expect β_2 to be negative if quality-lagged countries have an extra source of quality growth via the "technology spillover effect". β_3 captures the quality convergence effect, and should be negative.

[44] Note that there is another theoretical possibility - higher product quality may deter the competition from abroad and thus decrease the import penetration. If this is true, however, the estimated β_1 will be even under estimated.

α_i is the country fixed effect. In order to control for in-period exogenous shocks to countries which cannot be captured by α_i, I include H_{it}, $R\&D_{ist}$ and $R\&D\ inten_{ist}$ in the specification.[45] Finally, since in this paper product quality is estimated separately sector by sector and year by year, the estimated quality indexes might have absorbed sector-specific shocks each year. I thus include a sector*year fixed effect, α_{zt}, in the specification.

4.4.2 Domestic R&D and Quality Upgrading

This subsection specifies the empirical model to test the role of domestic R&D in sectoral quality upgrading.

I assume that product quality is a function of knowledge stock, G, i.e., $\lambda = f(G)$. Taking the logarithm of both sides and differentiating with respect to time, the growth of quality is found to relate to the change of G, which equals to R&D expenditure, R.[46] That is, $\Delta ln(Quality) = \rho e_{\lambda y} R/Y$, where $\rho \equiv dY/dG$ is the return rate of R&D to output, $e_{\lambda y} \equiv (d\lambda/dY)Y/\lambda$ is the elasticity of product quality with respect to the output, and R/Y is the intensity of R&D investment. I then get the following specification:

$$\Delta ln(Quality)_{ist} \quad = \quad \phi \left(\frac{R}{Y}\right)_{is,t-1} + \gamma X_{is,t-1} + \varepsilon_{ist}, \tag{45}$$

where $\phi \equiv \rho e_{\lambda y}$, and X_{ist} is a set of other control variables.

Before regression, three additional components are added to the basic specification above. First, Stokey (1991) argues that human capital is an important determinant of product quality. I thus add a proxy for human capital in (45) to test

[45] It seems better to include country*year fixed effect in the specification instead of adding H_{it}, $R\&D_{ist}$ and $R\&D\ inten_{ist}$. However, this will cause a parameter proliferation problem if the size of data is not sufficiently large.

[46] Following Griffith et al. (2004), I assume that compared to R&D investment, the depreciation of knowledge stock is negligible.

its role in quality upgrading. Second, Griffith et al. (2004) find that technologies transferred from advanced countries can promote the TFP growth of less developed ones. I also incorporate a "technology spillover effect" into (45), hypothesizing that technologies spilled from the quality frontiers facilitate quality upgrading in quality-lagged countries and make an extra source of quality growth that is compatible with the quality convergence phenomenon.[47] Third, suggested by the empirical work of Fisher-Vanden and Terry (2009), I introduce "absorptive capacity" to the basic specification, assuming that technologies transferred have to be complemented by domestic R&D and human capital to be effective in quality upgrading. Consequently, the augmented specification takes the following form:

$$\begin{aligned} \Delta ln(Quality)_{ist} &= \alpha_t + \alpha_{is} + \phi_1 \left(\frac{R}{Y}\right)_{is,t-1} + \phi_2 H_{i,t-1} \\ &+ \delta_1 Lower_{is,t-1} + \delta_2 \left(\frac{R}{Y}\right)_{is,t-1} * Lower_{is,t-1} * \lambda^{DM}_{is,t-1} \\ &+ \delta_3 H_{i,t-1} * Lower_{is,t-1} * \lambda^{DM}_{is,t-1} + \gamma X_{is,t-1} + \varepsilon_{ist}, \qquad (46) \end{aligned}$$

where H_{it} is the percentage of secondary school completion in the population aged 15 and over (Barro and Lee, forthcoming); $Lower_{ist}$ is a dummy indicating whether the quality of sector s in country i is below the annual mean at year t; λ^{DM}_{ist} is the demeaned product quality (in logs); $X_{is,t-1}$ is a set of other control variables including import penetration and the fraction of export in sectoral output; and α_t and α_{is} are year and country*sector fixed effects, respectively.

In (46), ϕ_1 and ϕ_2 capture the direct effects of R&D and human capital on quality upgrading. δ_1 reflects the technology spillover effect, and should be positive. The two interaction terms capture the absorptive capacity of quality-lagged countries, which

[47]Beside technology transfer, the import of high-quality intermediate goods from advanced countries also benefits the quality upgrading of quality-lagged countries, which also drives quality convergence.

is supposed to correlate positively with domestic R&D expenditures and human capital. Because countries with quality estimates less than the annual mean will have negative demeaned quality indexes, λ_{ist}^{DM}, I expect δ_2 and δ_3 to be negative if absorptive capacity facilitates quality upgrading.

4.5 Results

4.5.1 Import Competition and Quality Growth

Table 16 reports the results when regressing (44). The second column presents the results when regressors are only the increase in sectoral import penetration and the lagged product quality (demeaned) at sector level. The estimated β_1 is 0.0038 and statistically different from zero, which means that for a one-percent increase in the rate of import penetration, sectoral product quality will increase by 0.38%. The coefficient of lagged demeaned quality is significantly negative, reflecting the convergence in product quality. In Column 3, an interaction term is added into the regression to capture different effects for countries with different quality. The estimated β_2 is negative and significant at the 10% level, implying that for the same increase in import competition, the growth of product quality for quality-leading countries will be less than quality-lagged countries. This can be interpreted by the fact that developing countries can benefit from the spilled technologies and high-quality intermediate goods when they import from developed countries, and thus have extra sources of quality upgrading.[48] There is a literature (e.g., Acharya and Keller (2008)) showing that the new technologies spilled from developed countries via import contribute to productivity growth in developing countries. This study complements that literature by demonstrating that the "spillover effect" also facilitates quality upgrading in quality lagged countries.

[48] Another possibility is that for the same amount of increase in import penetration, firms in quality-leading countries will face less competition pressure since their product quality is greater than that of incomers. Thus, it is less pressing to upgrade their product quality.

Theoretically, if omitted variables correlate with the change of import penetration and quality growth simultaneously, the estimated coefficients in Column 3 will be biased. One ideal approach to deal with this problem is to find a valid instrument for the increase in import penetration; however, I can't find such instruments in this study. Instead, I add all possible omitted variables into the regression to solve this problem. The results in Column 4 are quite similar to Column 3 except that the impact of import competition on quality upgrading has been increased by nearly 50%.

Columns 5-6 report the results when I consider quality growth over 3-year intervals. Generally, the results are similar to those for 1-year intervals in Columns 2-3. When more control variables are added, the estimated β_1 in Column 6 is again about 40% greater than that in Column 5. However, it is important to bear in mind that on the one hand, an increase in import competition will force firms to upgrade their product quality to compete against new comers from abroad. On the other hand, quality growth also has a role in changing import competition - higher product quality will deter the entrance of competitors from abroad, and thus lower the increase of import penetration. Thus, if I interpret the estimated β_1 in Table 16 as the effect of import competition upon quality upgrading, they will be under-estimated. Nevertheless, one can think of the estimated β_1 as the lower bound of that impact.

There is a significant literature empirically analyzing the relationship between export and productivity. For instance, Bernard (2004) demonstrates that the sectoral export level in the U.S. positively correlates with the productivity of the sector. However, empirical research about the relationship between export and product quality is limited. The theoretical model in this paper predicts that for a given sector, the higher the sectoral product quality, the lower the cut-off quality, ν^*, will be,

TABLE 16: Openness and Product Quality

	$\Delta_1 ln(Quality)$	$\Delta_1 ln(Quality)$	$\Delta_1 ln(Quality)$	$\Delta_3 ln(Quality)$	$\Delta_3 ln(Quality)$	$Ln(Quality)$
$\Delta_1 Import$	0.0038	0.0055	0.0082			
$Penetration$	(0.001)***	(0.001)***	(0.0017)***			
Interaction(-1)		-0.003	-0.006			
		(0.001)*	(0.002)***			
$\Delta_3 Import$				0.0042	0.0059	
$Penetration$				(0.0014)***	(0.0019)***	
Interaction(-3)				-0.0026	-0.0037	
				(0.0015)*	(0.0021)*	
Demeaned	-0.152	-0.148	-0.12			
Quality(-1)	(0.016)***	(0.016)***	(0.02)***			
Demeaned				-0.35	-0.3	
Quality(-3)				(0.029)***	(0.037)***	
Export/Production						0.0026
						(0.0005)***
Other Control Variables	No	No	Yes	No	Yes	Yes
Sector*Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2418	2418	1667	1974	1347	1815
R-square	0.78	0.78	0.79	0.8	0.82	0.85

Note: Δ_n means the difference between a variable and its n-period-lagged value. Interaction(-n) is defined as $\Delta_n Import\ Penetration_{ist} * Upper_{is,t-n}$, where $Upper_{ist}$ is a dummy indicating if the product quality of country i in sector s is above the mean of all countries' at year t. Other control variables include the percentage of secondary school completion in the population aged 15 and over (Barro and Lee, 2013); business enterprise R&D expenditure in each industry (OECD, 2012); and sectoral R&D intensity (OECD, 2011). Robust standard errors are in parentheses. ***,** and * represent 1%, 5% and 10% significant level, respectively.

implying that a larger fraction of firms in the sector will engage in export. The last column in Table 16 tests this prediction empirically, and it confirms that for a given sector, countries with higher sectoral quality usually export a larger portion of production.

4.5.2 R&D and Quality Growth

Table 17 reports the results when I empirically estimate (46). The second column analyzes the effect of sectoral R&D investment on the growth of product quality at the sectoral level where control variables include only the rate of import penetration and the fraction of export in sectoral output. The estimated coefficient of lagged sectoral R&D intensity is 0.42 with a standard error of 0.19, implying that if one more percent of sectoral outputs are used in R&D investment, the product quality at sector level will be increased by over 0.4 percent.

In Column 3, I add a dummy indicating whether the estimated quality of the country is below the average of all quality estimates at that year. Its estimated coefficient is positive and statistically different from zero, meaning that the "technology spillover effect" in the literature (see, e.g., Griffith et al. (2004)) also facilitates the quality upgrading in developing countries. It is also compatible with the quality convergence phenomenon observed in Chapter 3.

Column 4 adds an interaction term into the regression to reflect "the absorptive capacity" of developing countries (see, e.g., Griffith et al. (2004) and Fisher-Vanden and Terry (2009)). The basic idea is that technologies spilled from developed countries have to be combined with R&D investment to effectively facilitate TFP or quality growth. I assume that countries with lower sectoral product quality will potentially receive more new technologies spilled from developed countries. Then $Quality\_Demeaned_{ist}$ in the interaction term negatively correlates with the spilled

technologies, and the interaction term itself will negatively relate to counties' absorptive capacity as well. The estimated coefficient of the interaction term is negative and significant, implying that R&D investment contributes to developing countries' quality upgrading via increasing their absorptive capacity.

However, the coefficient of lagged R&D intensity in Column 4 turns insignificant when the interaction term is added in the regression. This is because with the interaction term, the identification of that coefficient will depend on countries whose sectoral product quality is greater than the annual mean. Those countries with relatively high product quality in the sample are the most developed, whose sectoral R&D intensity and quality growth are both close to each other. Thus, with limited variation in dependent and independent variables, the coefficient of lagged R&D intensity will not be successfully identified.

Column 5 investigates the contribution of human capital upon quality growth. It shows that countries' human capital level significantly facilitates the upgrading of sectoral product quality. Meanwhile, the effect of spilled technologies on developing countries' quality upgrading is confirmed again. Human capital is also found to facilitate the quality upgrading in quality-lagged countries via increasing their absorptive capacity. Column 6 puts R&D intensity and human capital in the regression simultaneously, and the coefficients of them are insignificant. However, their positive role in quality upgrading via the absorptive capacity is again confirmed, and the estimated coefficients of the interaction terms are very close to the estimates in Column 4 and 5.

Finally, in a study of productivity, Fadinger and Fleiss (2011) find that sectoral R&D investment positively correlates with the TFP at sector level. The last

TABLE 17: R&D and Product Quality

	$\Delta ln(Quality)$	$\Delta ln(Quality)$	$\Delta ln(Quality)$	$\Delta ln(Quality)$	$\Delta ln(Quality)$	$ln(Quality)$
$R_{is,t-1}/Y_{is,t-1}$	0.424	0.475	0.058		0.285	1.089
	(0.189)**	(0.188)**	(0.191)		(0.202)	(0.206)***
$Lower_{is,t-1}$		0.149	0.104	0.072	0.067	
		(0.025)***	(0.025)***	(0.025)***	(0.026)***	
$Inter\_R\&D$			-2.089		-1.199	
			(0.294)***		(0.417)***	
$H_{i,t-1}$				0.0042	0.0043	
				(0.002)***	(0.0029)	
$Inter\_H$				-0.01	-0.0085	
				(0.001)***	(0.0021)***	
Country*Sector FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2190	2190	2190	2418	2166	2376

Note: $Lower_{ist}$ is a dummy indicating if the product quality of country i in sector s is below the mean of all countries' at year t. H_{it} is the percentage of secondary school completion in the population aged 15 and over (Barro and Lee, 2013). $Inter\_R\&D$ is defined as $R_{is,t-1}/Y_{is,t-1} * Lower_{is,t-1} * Quality\_Demeaned_{is,t-1}$ for sector s of country i at year t. $Inter\_H$ is defined as $H_{i,t-1} * Lower_{is,t-1} * Quality\_Demeaned_{is,t-1}$ for sector s of country i at year t. Robust standard errors are in parentheses. ***,** and * represent 1%, 5% and 10% significant level, respectively.

column of Table 17 shows that a positive correlation also exists between sectoral R&D and the product quality of the sector.

4.6 Robustness

This section provides some robustness check for the analysis in Section 4.5. Table 18 examines the relationship between import competition and the growth of product quality over 5-year intervals. Again, import competition is found to facilitate the quality upgrading at the sectoral level. When additional control variables are included, the estimated β_1 in Column 4 is over 50% higher than the coefficient in Column 3, which is similar to the findings in Table 16 with 1- and 3-year lags. However, the magnitude of the effect is about 64% of that with 3-year lag, which is again 72% of the effect with 1-year lag, implying that the positive impact of import competition on quality upgrading is more substantial over short periods. One possible explanation is that over long-run, firms may resort to alternative strategies rather than upgrading their product quality to cope with the competition from abroad. The spilled technologies from quality frontiers are also found to facilitate the quality growth in developing countries in Column 4.

In Chapter 3, I notice that the value added deflator for the Electrical sector in the U.S. and Sweden might have been quality-adjusted. Consequently, the TFP of this sector will be over-estimated in these countries, whereas their product quality will be under-estimated. To see if the results in Table 16 and 17 are sensitive to this potential bias, I re-analyze the effects of import competition and domestic R&D investment upon the growth of sectoral product quality with the data of Electrical dropped.

Table 19 reports the results when regressing (44) with the Electrical sector omitted. It is interesting to notice that the estimated β_1 in each column of Table 19 is very close to those in Table 16. The convergence effects, i.e. the coefficients of

TABLE 18: Openness and Product Quality With 5-year Lag

	$\Delta_5 ln(Quality)$	$\Delta_5 ln(Quality)$	$\Delta_5 ln(Quality)$
$\Delta_5 Import$	0.0015	0.0025	0.0038
$Penetration$	(0.0006)**	(0.001)**	(0.0014)***
Interaction(-5)		-0.0013	-0.0028
		(0.001)	(0.001)*
Demeaned	-0.525	-0.518	-0.472
Quality(-5)	(0.038)***	(0.038)***	(0.045)***
Other Control Variables	No	No	Yes
Sector*Year FE	Yes	Yes	Yes
Country FE	Yes	Yes	Yes
Observations	1530	1530	1038

Note: Δ_5 means the difference between a variable and its 5-period-lagged value. Interaction(-5) is defined as $\Delta_5 Import\ Penetration_{ist} * Upper_{is,t-5}$, where $Upper_{ist}$ is a dummy indicating if the product quality of country i in sector s is above the mean of all countries' at year t. Other control variables include the percentage of secondary school completion in the population aged 15 and over; business enterprise R&D expenditure in each industry; and sectoral R&D intensity. Robust standard errors are in parentheses. ***,** and * represent 1%, 5% and 10% significant level, respectively.

lagged demeaned quality in Table 19, are also very similar to the estimates in Table 16. However, the coefficients of the interaction terms in Table 19 turn insignificant when the sector of Electrical is deleted from the sample. This implies that the sector of Electrical is one of the places where most of the technology spillover is taking place. This makes sense since according to Table 15, the sector of Electrical has the greatest openness (measured by Export/Production and Import penetration) and R&D intensity.

Table 20 analyzes the contribution of domestic R&D investment upon the upgrading of sectoral product quality when the Electrical sector is dropped from the sample. It is surprising that most of the estimated coefficients in Table 20 are very close to those in Table 17 with the full sample. This means that the demonstrated effects of R&D investment and human capital upon sectoral quality growth via the absorptive capacity are not caused by potential under-estimation of product quality in the sector of Electrical.

TABLE 19: Robustness Check (Openness and Product Quality)

	$\Delta_1 ln(Quality)$	$\Delta_1 ln(Quality)$	$\Delta_1 ln(Quality)$	$\Delta_3 ln(Quality)$	$\Delta_3 ln(Quality)$	$Ln(Quality)$
$\Delta_1 Import$	0.0058	0.0055	0.0089			
$Penetration$	(0.0014)***	(0.0017)***	(0.0019)***			
Interaction(-1)		0.0009	-0.0019			
		(0.0027)	(0.0032)			
$\Delta_3 Import$				0.0037	0.0056	
$Penetration$				(0.0015)**	(0.002)***	
Interaction(-3)				-0.0009	-0.0032	
				(0.0026)	(0.003)	
Demeaned	-0.155	-0.156	-0.124			
Quality(-1)	(0.017)***	(0.017)***	(0.021)***			
Demeaned				-0.35	-0.29	
Quality(-3)				(0.031)***	(0.039)***	
Export/Production						0.0041
						(0.0009)***
Other Control Variables	No	No	Yes	No	Yes	Yes
Sector*Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2211	2211	1529	1805	1237	1663
R-square	0.79	0.79	0.79	0.81	0.83	0.84

Note: Δ_n means the difference between a variable and its n-period-lagged value. Interaction(-n) is defined as $\Delta_n Import\ Penetration_{ist} * Upper_{is,t-n}$, where $Upper_{ist}$ is a dummy indicating if the product quality of country i in sector s is above the mean of all countries' at year t. Other control variables include the percentage of secondary school completion in the population aged 15 and over; business enterprise R&D expenditure in each industry; and sectoral R&D intensity. Data for the sector of Electrical are dropped. Robust standard errors are in parentheses. ***,** and * represent 1%, 5% and 10% significant level, respectively.

4.7 Conclusion

This paper investigates the effects of import competition and domestic R&D investment on the upgrading of sectoral product quality using the sectoral level quality estimates from Chapter 3.

This is the second paper empirically examining the impact of import competition on quality growth.[49] Although we use different methodologies and data sets, we arrive at the same conclusion - an increase in import competition will force firms to upgrade their product quality to cope with competition from abroad. Another finding is that new technologies spilled from developed countries facilitate quality upgrading in developing countries, which adds to the literature of technology spillover in economic development (see, e.g., Acharya and Keller (2008)).

This paper also empirically relates domestic R&D investment to the growth of sectoral product quality. I find that both R&D investment and human capital contribute to the growth of quality at sector level via increasing the absorptive capacity of developing countries. This result is consistent with the findings of Griffith et al. (2004) and Fisher-Vanden and Terry (2009).

[49] The first one is by Amiti and Khandelwal (2013).

TABLE 20: Robustness Check (R&D and Product Quality)

	$\Delta ln(Quality)$	$\Delta ln(Quality)$	$\Delta ln(Quality)$	$\Delta ln(Quality)$	$\Delta ln(Quality)$	$ln(Quality)$
$R_{is,t-1}/Y_{is,t-1}$	0.444	0.5	0.086		0.332	1.038
	(0.196)**	(0.195)**	(0.199)		(0.211)	(0.211)***
$Lower_{is,t-1}$		0.162	0.115	0.076	0.075	
		(0.026)***	(0.026)***	(0.026)***	(0.028)***	
$Inter\_R\&D$			-2.09		-1.09	
			(0.3)***		(0.425)***	
$H_{i,t-1}$				0.0042	0.0045	
				(0.002)**	(0.0031)	
$Inter\_H$				-0.011	-0.0096	
				(0.0015)***	(0.0023)***	
Country*Sector FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2000	2000	2000	2211	1978	2170

Note: $Lower_{ist}$ is a dummy indicating if the product quality of country i in sector s is below the mean of all countries' at year t. H_{it} is the percentage of secondary school completion in the population aged 15 and over. $Inter\_R\&D$ is defined as $R_{is,t-1}/Y_{is,t-1} * Lower_{is,t-1} * Quality\_Demeaned_{is,t-1}$ for sector s of country i at year t. $Inter\_H$ is defined as $H_{i,t-1} * Lower_{is,t-1} * Quality\_Demeaned_{is,t-1}$ for sector s of country i at year t. Data for the sector of Electrical are dropped. Robust standard errors are in parentheses. ***,** and * represent 1%, 5% and 10% significant level, respectively.

Chapter 5: Conclusion

This dissertation includes three papers discussing technology, international trade, and economic development. The first paper examines optimal intellectual property rights (IPR) protection for developing countries attempting to change the direction of technical progress to suit their needs. The other two papers present a new approach to estimate countries' product quality at the sectoral level and investigate the contributions of import competition and domestic R&D investment to the upgrading of product quality.

The first paper is motivated by the work of Acemoglu and Zilibotti (2001), where technical innovation only happens in North, while South imitates the technologies for a small cost. However, the newly-developed technologies are solely based on the skill endowment in North and not appropriate for the needs of South, since the latter is more low-skill labor abundant. Acemoglu and Zilibotti (2001) did not provide a solution for this typical technology-skill mismatch problem, and Chapter 2 of this dissertation tries to fill this gap by putting forward a sector-differentiated IPR protection for developing countries.

The intuition is quite straightforward to follow. When South sets up IPR laws to protect innovators in North, the innovation there will consider the needs of South, since there is a market incentive. The crucial point of this paper is that the IPR protection in South may be sector-differentiated. In autarky, the low-skill intensive sector in South should receive more IPR protection. Then, innovators in North will be induced to invent more low-skill technologies when they can extract more rent from the low-skill intensive sector of South. Consequently, innovation in North will

better match the skill endowment in South, and South's income per capita will increase. More interestingly, I show that under free trade of final goods between North and South, IPR protection in the low-skill intensive sector of South does not necessarily exceed its high-skill sector, which implies that international trade can help South overcome the technology-skill mismatch problem.

Technical progress leads to higher product quality, and product quality is an important variable in the study of international trade and economic growth. However, people usually use the prices of exported goods as a proxy for their quality due to the lack of reasonable quality estimates. This approach is not without its drawbacks, and Chapter 3 adds to the literature by directly estimating the product quality at the sector level for twelve manufacturing sectors in twenty OECD countries.

The estimation begins with a quality-heterogeneity model of trade which is an extension of the work by Baldwin and Harrigan (2011). I then derive a gravity equation from the theoretical model. Finally, as Hallak and Schott (2011) do, I identify product quality as an unexplained part of export value when trade frictions, input costs, productivity, etc. are controlled.

I find that the estimated quality levels vary substantially across countries and over time. Another finding is that as in Hallak and Schott (2011), there is a positive correlation between countries' product quality and their per-capita income. However, because countries' product quality is converging at a higher speed than the convergence in national income, the correlation is weakening over time. Lastly, the quality gap between rich and poor countries is more pronounced in capital- and skill-intensive sectors.

Chapter 4 in this dissertation examines the contributions of import competition and R&D investment to the growth of sectoral product quality using the qual-

ity estimates from Chapter 3. I find that import competition significantly leads to the upgrading of product quality, confirming the findings of Amiti and Khandelwal (2013). I also find that new technologies spilled from developed countries will facilitate quality upgrading in developing countries.

Regarding the role of domestic R&D investment in upgrading sectoral product quality, I find that both R&D investment and human capital contribute to the growth of quality at the sectoral level by increasing the absorptive capacity of developing countries, confirming the findings of Fisher-Vanden and Terry (2009).

References

Acemoglu, Daron, "Directed Technical Change," *The Review of Economic Studies*, 2002, *69*, 781–809.

Acemoglu, Daron, Philippe Aghion, and Fabrizio Zilibotti, "Distance to Frontier, Selection and Economic Growth," *Journal of the European Economic Association*, 2006, *4*, 37–74.

Acemoglu, Daron and Ufuk Akcigit, "State-Dependent Intellectual Property Rights Policy," 2006. NBER Working Paper 12775.

Acemoglu, Daron and Fabrizio Zilibotti, "Productivity Differences," *Quarterly Journal of Economics*, 2001, *116*, 563–606.

Acharya, Ram, and Wolfgang Keller, "Estimating the Productivity Selection and Technology Spillover Effects of Imports," *NBER Working Paper: 14079*, 2008.

Aghion, Philippe, and Peter Howitt, "Growth with Quality-Improving Innovations: An Integrated Framework." In Aghion, P. and Durlauf, S. N. Durlauf (eds) *Handbook of Economic Growth*, 2006, Volume 1A: 67–110.

Amiti, Mary, and Amit K. Khandelwal, "Import Competition and Quality Upgrading," *The Review of Economics and Statistics*, 2013, *95(2)*, 476-490.

Arnold, Lutz G., and Wolfgang Kornprobst, "Comparative Statics and Dynamics of The Romer R&D Growth Model With Quality Upgrading," *Macroeconomic Dynamic*, 2008, *12(5)*, 702-716.

Atkinson, Anthony B. and Joseph E. Stiglitz, "A New View of Technological Change," *The Economic Journal*, 1969, *79*, 573–578.

Baldwin, Richard, James Harrigan, "Zeros, Quality, and Space: Trade Theory and Trade Evidence," *American Economic Journal: Microeconomics*, 2011, *3*, 60-88.

Barro, Robert, and Jong-Wha Lee, "A New Data Set of Educational Attainment in the World, 1950-2010," *Journal of Development Economics*, 2013, *104*, 184-198.

Barro, R. J. and X. Sala-i-Martin, "Technological Diffusion, Convergence, and Growth," *Journal of Economic Growth*, 1997, *2(1)*, 1–26.

Basu, Susanto and David N. Weil, "Appropriate Technology and Growth," *Quarterly Journal of Economics*, 1998, *116*, 1025–154.

Baumol, William, "Productivity Growth, Convergence, and Welfare: What the Long-run Data Show," *The American Economic Review*, 1986, *76(5)*, 1072–1085.

Becker, Randy, Wayne Gray, and Jordan Marvakov, "NBER-CES Manufacturing Industry Database," *National Bureau of Economic Research and Census Bureau's Center for Economic Studies*, 2013.

Bernard, Andrew B, "Exporting and Productivity in the USA," *Oxford Review of Economic Policy*, 2004, *20(3)*, 343–357.

Bils, Mark, "Measuring the Growth from Better and Better Goods," *NBER Working Paper: 10606*, 2004.

Bils, Mark, and Peter J. Klenow, "Quantifying Quality Growth," *American Economic Review*, 2001, *91(4)*, 1006–1030.

Bloom, Nicholas, Mirko Draca, and John Van Reenen, "Trade Induced Technical Change? The Impact of Chinese Imports on Innovation, IT and Productivity," *NBER Working Paper: 16717*, 2011.

Broda, Christian, and David E. Weinstein, "Globalization and the Gains from Variety," *Quarterly Journal of Economics*, 2006, *121(2)*, 541–585.

Burk, D. and M. Lemley, "Is Patent Law Technology-specific?" *Berkeley Technology Law Journal*, 2002, *17*, 1155–1206.

Burk, D. and M. Lemley, "The Patent Crisis and How the Courts can Solve it," University of Chicago Press, 2009.

Bustos, Paula, "Trade Liberalization, Exports, and Technology Upgrading: Evidence on the Impact of MERCOSUR on Argentinian Firms," *American Economic Review*, 2011, *101(1)*, 304–40.

Caselli, Francesco, and James Feyrer, "The Marginal Product of Capital," *Quarterly Journal of Economics*, 2007, *122(2)*, 535–568.

Chen, Yongmin and Thitima Puttitanun, "Intellectual Property Rights and Innovation in Developing Countries," *Journal of Development Economics*, 2005, *78*, 474–493.

Choi, Yo Chul, David Hummels, and Chong Xiang, "Explaining Import Quality: the Role of the Income Distribution," *Journal of International Economics*, 2009, *77*, 265–276.

Chu, Angus C., "The Welfare Cost of One-size-fit-all Patent Protection," 2009. Available at http://mpra.ub.uni-muenchen.de/21401/.

Chu, Angus C., Guido Cozzi and Silvia Galli , "Innovating Like China: A Theory of Stage-Dependent Intellectual Property Rights," 2011. Available at http://www.talavera.rv.ua/dur/pdfs/WP2011-14.pdf.

David, Joel M., "Competition, Innovation, and the Sources of Product Quality and Productivity Growth," 2011. Available at http://www.intertic.org/Conference/David.pdf.

De Sousa, Jose, "The Currency Union Effect on Trade is Decreasing Over Time," *Economics Letters*, 2012, *117(3)*, 917–920.

Dhrymes, Phoebus, "Moments of Truncated (Normal) Distributions," 2005. Available at http:// www.columbia.edu/∼pjd1/mypapers/mycurrentpapers /dummytruncated.pdf.

Dinopoulos, Elias, and Bulent Unel, "Quality Heterogeneity and Global Economic Growth," *European Economic Review*, 2011, *55*, 595–612.

Dinopoulos, Elias, and Bulent Unel, "A Simple Model of Quality Heterogeneity and International Trade," *Journal of Economic Dynamic and Control*, 2013, *37*, 68–83.

Eslava, Marcela, Ana Cecilia Fieler, and Daniel Xu, "Trade, Competition and Quality-upgrading: A Theory with Evidence From Colombia," 2012. Available at http://econ.columbia.edu/files/econ/content/eslava_fieler_xu.pdf.

Eswaran, Mukesh, and Ashok Kotwal, "Quality-enhancing Trade Liberalization," *Journal of Development Economics*, 2007, *83*, 549–561.

Evenson, Robert E. and Larry E. Westphal, "Technology Change and Technology Strategy," *Handbook of Development Economics*, *Vol 3*, 1995.

Fadinger, Harald, and Pablo Fleiss, "Trade and Sectoral Productivity," *The Economic Journal*, 2011, *121*, 958–989.

Fajgelbaum, P., G. Grossman, and E. Helpman, "Income Distribution, Product Quality, and International Trade," *Journal of Political Economics*, 2011, *119(4)*, 721–765.

Fan, Haichao, Yao Amber Li, and Stephen R. Yeaple, "Trade Liberalization, Quality and Export Prices," 2013. Available at http://www.chinasummerinstitute.org/wp-content/uploads/Yao-Amber-Li.pdf.

Fare, Rolf, Shawna Grosskopf, Mary Norris, and Zhongyang Zhang, "Productivity Growth, Technical Progress, and Efficiency Change in Industrialized Countries," *The American Economic Review*, 1994,*84(1)*, 66–83.

Faruq, Hasan, "Impact of Technology and Physical Capital on Export Quality," *The Journal of Developing Areas*, 2010, *44(1)*, 167–185.

Feenstra, Robert C., Robert E. Lipsey, Haiyan Deng, Alyson C. Ma, and Hengyong Mo, "World Trade Flows: 1962-2000," *NBER Working Paper: 11040*, 2005.

Fisher-Vanden, Karen, and Rebecca Terry, "Is Technology Acquisition Enough to Improve China's Product Quality? Evidence From Firm-level Panel Data," *Economic of Innovation and New Technology*, 2009, *18(1)*, 21–38.

Flam, H., and E. Helpman, "Vertical Product Differentiation and North-South Trade," *American Economic Review*, 1987, *77*, 810–822.

Flam, H., and Hakan Nordstrom, "Gravity Estimation of the Intensive and Extensive Margins of Trade: An Alternative Procedure with Alternative Data," *CESifo Working Paper Seris No. 3387*, 2011.

Gancia, Gino and Alessandra Bonfiglioli, "North-South Trade and Directed Technical Change," *Journal of International Economics*, 2008, *76*, 276–295.

Gancia, Gino and Fabrizio Zilibotti, "Technological Change and Wealth of Nations," *Annual Review of Economics*, 2009, *1*, 93–120.

Gervais, Antoine, "Product Quality, Firm Heterogeneity and Trade Liberalization," 2012. Available at SSRN: http://ssrn.com/abstract=2137156.

Griffith, Rachel, Stephen Redding, and John Van Reenen, "Mapping The Two Faces of R&D: Productivity Growth in a Panel of OECD Industries," *The Review of Economics and Statistics*, 2004, *86(4)*, 883–895.

Griliches, Zvi, "Productivity, R&D, and the Data Constraint," *The American Economic Review*, 1994, *84(1)*, 1–23.

Grossman, Gene M., and Elhanan Helpman, "Quality Ladders in the Theory of Growth," *Review of Economic Studies*, 1991, *58(1)*, 43–61.

Hallak, J., "Product Quality and the Direction of Trade," *Journal of International Economics*, 2006, *68(1)*, 238–265.

Hallak, J., and Peter K. Schott, "Estimating Cross-Country Differences in Product Quality," *The Quarterly Journal of Economics*, 2011, *126(1)*, 417–474.

Harrigan, James, "Technology, Factor Supplies, and International Specialization: Estimating the Neoclassical Model," *American Economic Review*, 1997, *87*, 475–494.

Heckman, James J., "Sample Selection Bias as a Specification Error," *Econometrica*, 1979, *47(1)*, 153–161.

Helpman, Elhanan, Marc Melitz, and Yona Rubinstein, "Estimating Trade Flows: Trading Partners and Trading Volumes," *The Quarterly Journal of Economics*, 2008, *123(2)*, 441–487.

Hummels, David, "Toward a Geography of Trade Costs," *GTAP Working Paper No.17*, 1999.

Hummels, D., and P. Klenow, "The Variety and Quality of a Nation's Exports," *American Economic Review*, 2005, *95(2)*, 704–723.

Imbs, J., and I. Mejean, "Elasticity Optimism," *HEC Lausanne, unpublished mimeo*, 2009.

Johansson, Sara, "R&D Accessibility and Comparative Advantages in Quality Differentiated Goods," *CESIS Working Paper Series, Paper No. 107*, 2007.

Khandelwal, Amit, "The Long and Short (of) Quality Ladders," *Review of Economic Studies*, 2010, *77(4)*, 1450–1476.

Kim, Yee Kyoung, Keun Lee and Walter G. Park, "Appropriate Intellectual Property Protection and Economic Growth in Countries at Different Levels of Development," 2006. Available at http://www.american.edu/cas/faculty/-wgpark/upload/Intellectual-Property-Rights.pdf.

Kumar, Nagesh, "Intellectual Property Rights, Technology and Economic Development: Experiences of Asian Countries," *Economic and Political Weekly*, 2003, *38*, 209–226.

Lambertini, Luca, and Raimondello Orsini, "R&D for Quality Improvement and Network Externalities," *Networks and Spatial Economics*, 2010, *10*, 113-124.

Lanjouw, Jean O. and Josh Lerner, "The Enforcement of Intellectual Property Rights: A Survey of The Empirical Literature," 1997. NBER Working Paper 6296.

Lerner, Josh, "150 Years of Patent Protection," *American Economic Review*, 2002, *92*, 221–225.

Lin, Justin and Pengfei Zhang, "Appropriate Technology, Technological Selection and Economic Growth in Developing Countries," *China Economic Quarterly*, 2006.

Linder, Staffan Burenstam, "An Essay on Trade and Transformation," Stockholm: Almqvist and Wiksell, 1961.

Lo, Shih-tse, "Strengthening Intellectual Property Rights: Experience from the 1986 Taiwanese Patent Reforms," *International Journal of Industrial Organization*, 2011, *29*, 524–536.

Madsen, Jakob, Md Rabiul Islam and James Ang "Catching Up to the Technology Frontier: The Dichotomy between Innovation and Imitation," 2010. Available at http://mpra.ub.uni-muenchen.de/21701/.

Mayer, Thierry, and Soledad Zignago, "Notes on CEPII's distances measures (GeoDist)," *CEPII Working Paper 2011-25*, 2011.

Melitz, Marc, "The Impact of Trade on Intra-Industry Reallocations and Aggregate Industry Productivity," *Econometrica*, 2003, *71(6)*, 1695–1725.

Melitz, Marc and Stephen J. Redding, "Heterogeneous Firms and Trade," *NBER Working Paper No. 18652*, 2012.

OECD, "STAN Industry Rev. 3, 2008," STAN: OECD Structural Analysis Statistics (database), 2008.

OECD, "STAN Indicators Rev.3, 2011," STAN: OECD Structural Analysis Statistics (database), 2011.

OECD, "Business enterprise R-D expenditure by industry," OECD Science, Technology and R&D Statistics (database), 2012.

OECD, "Labour Force Statistics," OECD Stat (database), 2012.

Parente, Stephen and Edward Prescott "Monopoly Rights: A Barrier to Riches," *American Economic Review*, 1999, *89*, 1216–1233.

Rivera-Batiz, L. A. and P. M. Romer "Economic Integration and Endogenous Growth," *Quarterly Journal of Economics*, 1991, *106(2)*, 531–555.

Santos Silva, J.M.C., and S. Tenreyro, "Trading Partners and Trading Volumes: Implementing the Helpman-Melitz-Rubinstein Model Empirically," *CEP Discussion Paper No. 935*, 2009.

Schott, PK., "Across-Product versus Within-Product Specialization in International Trade," *Quarterly Journal of Economics*, 2004, *119(2)*, 647–678.

Stokey, Nancy L., "Human Capital, Product Quality, and Growth," *Quarterly Journal of Economics*, 1991, *106(2)*, 587–616.

Unel, Bulent, "R&D Spillovers Through Trade in a Panel of OECD Industries," *Journal of International Trade & Economic Development*, 2008, *17(1)*, 105–133.

Unel, Bulent, "The Interaction Between Technology Adoption and Trade When Firms are Heterogeneous," *Review of International Economics*, 2013, *21(4)*, 797–808.

UNESCO "Regional Totals for R&D Expenditure and Researchers, 2002 and 2007," 2010. Available at http://stats.uis.unesco.org/unesco/ReportFolders-/ReportFolders.aspx.

Verhoogen, Eric, "Trade, Quality Upgrading and Wage Inequality in the Mexican Manufacturing Sector," *Quarterly Journal of Economics*, 2008, *123*, 489–530.

Appendix A
Proof of Proposition 2

Since the welfare function (16) is an increasing function of the total output Y_t, maximizing it subject to given g and N_t is equivalent to maximizing the total output Y_t^S.[50] Perfect competition in the production of final goods implies that the output value of final goods is the sum of output value of the two sectors. It then follows from (10) that

$$Y^S = (P_L^S/P_Y^S)^{\frac{1}{1-\beta}} N_L L^S + (P_H^S/P_Y^S)^{\frac{1}{1-\beta}} N_H H^S, \tag{47}$$

where I dropped the time index to simplify the notation.

Using (4) and (10) implies that

$$\frac{P_L^S}{P_H^S} = \left(\frac{L^S N_L}{H^S N_H}\right)^{-\frac{1-\beta}{\beta+\epsilon(1-\beta)}}. \tag{48}$$

Let $N_L/N_H = x$, then $N_L = xN/(1+x)$ and $N_H = N/(1+x)$, where $N = N_L + N_H$ is taken as given. Substituting these into (47) and using (11) yields

$$Y^S(x) = \frac{H^S N}{1+x}\left[1 + (ax)^{\frac{(1-\beta)(\epsilon-1)}{1+(1-\beta)(\epsilon-1)}}\right]^{\frac{1+(1-\beta)(\epsilon-1)}{(1-\beta)(\epsilon-1)}}, \tag{49}$$

where $a = L^S/H^S$. Note that Y^S is a concave function of x over the domain $[0, +\infty)$, and the first-order condition yields that Y^S reaches its maximum value when

$$x \equiv \frac{N_L^S}{N_H^S} = \left(\frac{L^S}{H^S}\right)^{(1-\beta)(\epsilon-1)},$$

as also indicated by equation (17).

[50] Equations in (14) indicate that the growth rate g is a function of N_L/N_H. But notice from Figure 1 that one can keep g constant by choosing κ_L and κ_H appropriately. In other words, one can get any N_L/N_H by choosing κ_L and κ_H in such a way that g remains constant. Consequently, in the optimization problem, one can treat g as given.

Using (11), when $N_L/N_H = N_L^S/N_H^S$, I have:

$$\left(\frac{P_L^S}{P_Y^S}\right)^{\frac{1}{1-\beta}} L^S = \left(\frac{P_H^S}{P_Y^S}\right)^{\frac{1}{1-\beta}} H^S,$$

which together with (10) implies that the contribution of each intermediate good to GDP in the low-skill sector is the same as that in the high-skill sector.

Appendix B
Proof of Lemma 1

As discussed in Appendix A, maximizing the welfare function (16) is equivalent to maximize the total output in the South

$$Y^S = (P_L^W)^{\frac{1}{1-\beta}} N_L L^S + (P_H^W)^{\frac{1}{1-\beta}} N_H H^S, \tag{50}$$

with $N = N_L + N_H$ is taken as given. Using (5) and (20) implies

$$P_L^W = \left\{ 1 + \left[\left(\frac{L^S + L^N}{H^S + H^N} \right) \frac{N_L}{N_H} \right]^{-\frac{(1-\beta)(\epsilon-1)}{1+(1-\beta)(\epsilon-1)}} \right\}^{\frac{1}{\epsilon-1}}, \tag{51a}$$

$$P_H^W = \left\{ 1 + \left[\left(\frac{L^S + L^N}{H^S + H^N} \right) \frac{N_L}{N_H} \right]^{\frac{(1-\beta)(\epsilon-1)}{1+(1-\beta)(\epsilon-1)}} \right\}^{\frac{1}{\epsilon-1}}. \tag{51b}$$

Let $x \equiv N_L/N_H$ and $\tilde{a} \equiv (L^S + L^N)/(H^S + H^N)$. Using these together with (51a) and (51b) into (50) yields

$$Y^S(x) = \frac{xNL^S}{1+x} \left[1 + (\tilde{a}x)^{-\frac{(1-\beta)(\epsilon-1)}{1+(1-\beta)(\epsilon-1)}} \right]^{\frac{1}{(1-\beta)(\epsilon-1)}} + \frac{NH^S}{1+x} \left[1 + (\tilde{a}x)^{\frac{(1-\beta)(\epsilon-1)}{1+(1-\beta)(\epsilon-1)}} \right]^{\frac{1}{(1-\beta)(\epsilon-1)}}.$$

Differentiating this function with respect to x yields

$$\frac{1}{NH^S} \frac{dY^S}{dx} = \frac{(\tilde{a} - L^S/H^S)(P_H^W)^{1-\epsilon}(P_L^W)^{\frac{1}{1-\beta}}}{[1 + (1-\beta)(\epsilon-1)](1+x)} + \frac{(P_L^W)^{\frac{1}{1-\beta}} L^S/H^S - (P_H^W)^{\frac{1}{1-\beta}}}{(1+x)^2}, \tag{52}$$

where $\tilde{a} \equiv (L^S + L^N)/(H^S + H^N)$.

Note that when $\tilde{a}x \geqslant (L^S/H^S)^{1+(1-\beta)(\epsilon-1)}$, using (51a) and (51b) implies that $(P_L^W)^{\frac{1}{1-\beta}} L^S \leqslant (P_H^W)^{\frac{1}{1-\beta}} H^S$. Since $L^S/H^S > \tilde{a}$, it then follows that $dY^S/dx < 0$. On the other hand, when $x \leqslant \tilde{a}^{(1-\beta)(\epsilon-1)}$, equation (51b) implies that $(P_H^W)^{1-\epsilon} \leqslant 1/(1+x)$. Substituting the latter into (52) yields

$$\frac{dY^S}{dx} > \frac{NH^S \left[\tilde{a}(P_L^W)^{\frac{1}{1-\beta}} - (P_H^W)^{\frac{1}{1-\beta}} \right]}{(1+x)^2} \geq 0.$$

Since $Y^S(x)$ is continuous in its domain $[0, +\infty)$, the above analysis ensures that there exists an x^* such that $\tilde{a}^{1+(1-\beta)(\epsilon-1)} < \tilde{a}x^* < (L^S/H^S)^{1+(1-\beta)(\epsilon-1)}$, and x^* maximizes the total output in South. Using the last inequality for x^* together with (51a) and (51b) implies that South's desired relative world price has the following relationship,

$$\left(\frac{L^S}{H^S}\right)^{\beta-1} < \frac{P_L^W}{P_H^W} < \left(\frac{L^S + L^N}{H^S + H^N}\right)^{\beta-1}.$$

Appendix C
Data Description and the Sample of Countries

C1, Data for the Calculation of A_{is} and c_{is}

I have complete data for only twenty OECD countries. Limited by this data availability, I can only estimate sectoral product quality for these 20 countries during 1995-2006.

Sectoral productivity, A_{is} is measured as the Solow residuals. For this purpose, I make use of the sectoral data of current value added, value added deflator, current fixed capital formation, gross fixed capital formation deflator, and total employment. All these data are from the STAN database, OECD (2008a). Real output is measured by sectoral real value added in 2000 U.S. dollars. I first use the value added deflator to convert current value added into the real one in 2000 local currency, which is then transformed into U.S. dollars using the exchange rate in 2000. In the same way, the sectoral fixed capital formation data (current) is also transformed into the real one in 2000 U.S. dollars. When the fixed capital formation deflator is missing for some sectors, the deflator for the whole manufacture will be used instead.[51] The real capital stock is then calculated using the perpetual inventory method:

$$K_{is,t+1} = (1 - \delta)K_{is,t} + I_{is,t}, \tag{53}$$

where $K_{is,t}$ and $I_{is,t}$ are the real capital stock and fixed capital formation, respectively, and δ is the depreciation rate. The initial capital stock is estimated as follows:

[51] For some countries, the deflator for the whole manufacture is still missing for some years. In this case, I get the aggregate gross fixed capital formation deflator for the whole economy from the World Development Indicators (WDI). The base year of this deflator is then changed to 2000, and I use it to fill the missing deflators. The involved countries include Denmark (1991-1992), Hungary (1991-1994), New Zealand (1991-2006), Portugal (1995-1999), Slovakia (1993-1996), Sweden (1991-1992) and the United Kingdom (1991-1995).

$$K_{is,1991} = \frac{I_{is,1991}}{g_{is} + \delta}, \tag{54}$$

where g_{is} is the average growth rate of the real fixed capital formation during 1991-2006. Following Unel (2008), I choose 8% as the depreciation rate.

Considering the difference in daily working hours across countries (Unel, 2008), I multiply sectoral employment data by the average annual working hours per worker, and take it as the labor input. The data of average annual hours worked per employee are available from the labor force statistics, OECD (2012).[52] In light of Harrigan (1997) and Unel (2008), I estimate the labor share, $1 - \beta_{is}$, by running the following regression:

$$\alpha_{ist} = \alpha_{is} + \gamma_s ln \left(\frac{K_{ist}}{L_{ist}} \right) + \varepsilon_{ist}, \tag{55}$$

where α_{ist} is the share of labor compensation in the value added of sector s in country i at year t. K_{ist} is the real capital stock and L_{ist} is total working hours. The predicted α_{ist} is used as the estimate of $1 - \beta_{is}$ at year t. As Unel (2008) points out, this estimator is advantageous in that it is less noisy and less likely to exceed one. I then estimate the sectoral productivity, A_{is} by the Solow residual:

$$A_{is} = \frac{Q_{is}}{K_{is}^{\beta_{is}} L_{is}^{1-\beta_{is}}}, \tag{56}$$

where Q_{is} is the real value added in that sector.

To calculate c_{is} in (29), I need the data of interest rate (or the rental price of capital) r_i, and the wage rate w_i. The wage rate is calculated as the labor compensation of the whole manufacture divided by the total manufacturing working hours. It is then transformed into U.S. dollars using the exchange rate of that year.

[52] Slovenia lacks average annual hours worked per employee data during 1995-1999. I extrapolate the missing data by the average of 2000-2002, since the change of this data during that time was negligible.

Following Caselli and Feyrer (2007) and Fadinger and Fleiss (2011), the rental price of capital is estimated as follows:

$$r_i = \beta_i \frac{GDP_i}{K_i}, \tag{57}$$

where β_i is the capital share in national income of country i, which is one minus the labor share. The share of labor is calculated as the total labor compensation of the economy divided by total value added, which is then averaged across 1995-2006. The total labor compensation and value added data are from OECD (2008a). GDP_i is from the WDI, in current U.S. dollars. K_i is estimated using the perpetual inventory method. For this purpose, I use the gross fixed capital investment volume data from the WDI; the depreciation rate is set to 8%, and the initial year is 1985.[53] The real capital stock data is then transformed into U.S. dollars using the exchange rate in 2000.

To estimate the product quality, I still need estimates of sectoral elasticity of substitution, ε_s, which cannot directly be estimated in this paper. I draw on estimates from Imbs and Mejean (2009), who first calculate sectoral elasticity of substitution on the basis of 3-digit ISIC Rev.3. I then calculate the elasticity for each 2-digit ISIC Rev.3 industry by averaging the elasticities of the 3-digit industries below it. The elasticities for 2-digit industries are again averaged to get the sectoral elasticity of substitution if the sector consists of two or more 2-digit industries.[54]

[53] The base year is 2000; and it is in local currency units.

[54] Some other studies provide the estimates of sectoral elasticity of substitution at the Standard International Trade Classification (SITC) 2-digit level (Hummels, 1999), or SITC 5-digit level (Broda and Weinstein, 2006). So far, however, there is no reliable correspondence table between SITC and ISIC Rev.3, which makes Imbs and Mejean (2009) the only source from which to get the sectoral elasticity of substitution on the basis of ISIC Rev.3.

C2, Data for the Extensive and Intensive Analysis

I extract the export data from the UN Comtrade database via the World Integrated Trade Solution (WITs). The export data are based on the ISIC Rev.3 2-digit industry classification, which are summed when the sector consists of two or more 2-digit industries. Comtrade claims that the import data might be more accurate than the export data because the value of import is used by governments to calculate customs duty. The import data, however, cannot be used in this study, because the countries who report their imports are too few, especially in the first portion of 1995-2006. Some of these twenty countries of interest might export to all the countries that report imports; consequently, the fixed effects of these countries cannot be estimated in the extensive analysis. To mitigate the measurement error, I first choose the sample of exporting countries to be the 85 countries that did not report their exports at least once during 1995-2006.[55] These countries are generally more important in the world economy and their export data is of higher quality. Second, I drop the export records whose value is less than the 15th percentile of US's export records in that sector in 2000.[56] This helps reduce the measurement error, since the least important small exports are more likely to be inaccurately reported.[57]

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[55] See Appendix E for the list of these countries.

[56] When cleaning the UN Comtrade data (1984-2000), Feenstra et al. (2005) drop the trade flow of a SITC Rev.2 4-digit industry if it is less than 100,000 US dollars. My data cleaning is less stringent than theirs. For example, Sector ISIC15 has 17 4-digit industries. If the 4-digit ISIC Rev.3 industry classification is comparable to the 4-digit SITC one, according to the standard of Feenstra et al. (2005), the cutoff value will be 1,700,000 US dollars. The 15th percentile of US exports in that sector, however, is only 289,000 US dollars in 2000. I also tried different cutoff values, and the results are quite similar.

[57] Another reason for this treatment is that I need zero exports when I analyze the selection into trade. If some country exports to (or imports from) nearly all other countries, then its exporter (importer) fixed effect will not be accurately estimated. Neither will its sectoral product quality. If there are not enough zero trade flows, this problem will be more severe when I use the bootstrap method to estimate the standard errors of product quality estimates.

The bilateral tariff data are from the TRAINS database, via the WITs. The tariff is based on the ISIC Rev.3 2-digit industry level, which is then weight-averaged to the sectoral level if the sector consists of two or more 2-digit industries. The weight is the import value of the industry. The tariff used is the Most-Favored Nation (MFN) tariff, which is further adjusted by any possible preferential rates between the trade pair. The number of countries reporting their import tariffs is growing over time, but in the early stage of 1995-2006, not many did. Thus, if I use all the available tariff data, the sample of importing countries will be subject to constant change and the estimates will be biased if the selection into reporting the tariff is not random.[58] To minimize this problem, I limit the sample of importing countries to the 48 countries who missed at most 2 years' tariff during 1995-2006, when analyzing the intensive margin.[59] I then extrapolate the missing tariff data by the average of neighboring two years'. The potential harm of this treatment is minimal, since in most cases the change of tariff over time is rather slow, but the benefit is that it helps keep the sample of importing countries large enough for analysis.

I extract other gravity variables from various sources. The bilateral distance data are from the CEPII database, which first calculates the distance between cities, and then averages the distances weighted by the proportion of cities' population in the whole country (Mayer and Zignago, 2011). Other dichotomous variables from the CEPII database include: if the two countries share a common border, if they share the same official language, if they have the same legal origin, and if they have some

[58]The countries who import more are more likely to report their tariff earlier and more consistently.

[59]See Appendix E for the list of these countries. The number of countries who consistently report their tariffs during 1995-2006 is few, while the extensive analysis needs the sample of importing countries as big as possible to produce enough zero trade flows. I thus cannot use the tariff data in the extensive analysis. This leads to the sample of importing countries in the extensive analysis different from the intensive analysis.

colonial relationship (including if they are in colonial relationship post 1945; if they have the same colonizer post 1945; and if they were ever in colonial relationship).

The data indicating if the trade pair shares the same currency and if they are both in some free trade agreements (FTA) are from De Sousa (2012). I also draw on Helpman et al. (2008) to get the dummies showing if the pair of countries are both islands or landlocked. Helpman et al. (2008) provide an exclusion variable for the extensive analysis, i.e., the religion of the trade pair. When constructing this variable, they first multiply one country's proportion of some religion in the population by the other country's, and then add it across different regions (e.g., Protestant, Catholic, Muslim, etc.). In this paper, I create an additional exclusion variable, Economic Freedom, using the Index of Economic Freedom database from the Heritage Foundation. It is a dummy indicating if both the exporting and importing country have an overall economic freedom score higher than the median of the sample.

C3, The Sample of Countries in the Analysis

For the extensive analysis, I would like to include as many countries as possible in the sample. Then there will be enough zero trade flows and it is less likely that some country exports to (or imports from) all other countries, which leads to the situation where the exporting (importing) country fixed effect cannot be precisely estimated. However, I cannot take all available countries in the sample, since the number of countries who report their exports is increasing over time, which would cause a sample selection problem. I thus include 82 countries in the sample of exporting countries, who failed to report at most one year's data during 1995-2006. The sample size of importing countries is 155, which is dictated by the availability of the Index of Economic Freedom data.

When performing the intensive analysis, the sample of exporting countries is the same as that in the extensive analysis. Because I make use of tariff data in the intensive analysis, the sample of importing countries consists of only 47 nations whose tariff data are missing for at most 2 years during 1995-2006.

The samples of countries for the extensive as well as intensive analyses are listed in Appendix E.

Appendix D

D1, The Calculation of $E\left[u_{ijs}|E_{ijs}=1\right]$

Rewrite (39) as $\mathbf{z}_{ijs}=[.]+\overline{v}_{ijs}$, then $E_{ijs}=1$ implies that $\mathbf{z}_{ijs}=[.]+\overline{v}_{ijs}>0$. And thus $\overline{v}_{ijs}>-[.]$. Mathematically,

$$\begin{pmatrix} X_1 \\ X_2 \end{pmatrix} \sim N\left(\begin{pmatrix} 0 \\ 0 \end{pmatrix}, \begin{pmatrix} 1 & \rho \\ \rho & 1 \end{pmatrix}\right) \quad \Rightarrow \quad E(X_1|X_2>s)=\rho\frac{\phi(s)}{\Phi(-s)}.$$

Thus, I have:

$$\begin{aligned} E\left[u_{ijs}|E_{ijs}=1\right] &= E\left[u_{ijs}|\overline{v}_{ijs}>-[.]\right] \\ &= \sigma_u E\left[\frac{u_{ijs}}{\sigma_u} \mid \frac{\overline{v}_{ijs}}{\sigma_v}>-\frac{[.]}{\sigma_v}\right] \\ &= \rho\sigma_u\frac{\phi([.]/\sigma_v)}{\Phi([.]/\sigma_v)} \\ &= \rho\sigma_u\frac{\phi(\Phi^{-1}(\widehat{Pr}_{ijs}))}{\Phi(\Phi^{-1}(\widehat{Pr}_{ijs}))} \\ &= \rho\sigma_u\frac{\phi(\Phi^{-1}(\widehat{Pr}_{ijs}))}{\widehat{Pr}_{ijs}}, \end{aligned}$$

where ρ is the correlation coefficient between u_{ijs} and $\overline{v}_{ijs}$.

D2, The Calculation of $E\left[\psi_{ijs}|E_{ijs}=1\right]$

Following Helpman et al. (2008), I approximate (40) by a polynomial to the order of three, i.e., $\psi_{ijs}=d_0+d_1\mathbf{z}_{ijs}+d_2\mathbf{z}_{ijs}^2+d_3\mathbf{z}_{ijs}^3$. Then $E[\psi_{ijs}|E_{ijs}=1]=d_0+d_1E[\mathbf{z}_{ijs}|E_{ijs}=1]+d_2E[\mathbf{z}_{ijs}^2|E_{ijs}=1]+d_3E[\mathbf{z}_{ijs}^3|E_{ijs}=1]$.

Because $\mathbf{z}_{ijs}$ is subject to a normal distribution, $E[\mathbf{z}_{ijs}|E_{ijs}=1]$, $E[\mathbf{z}_{ijs}^2|E_{ijs}=1]$ and $E[\mathbf{z}_{ijs}^3|E_{ijs}=1]$ are actually moments of a truncated normal distribution. Using

the arithmetic of Dhrymes (2005), they can be calculated as follows:

$$
\begin{aligned}
E[\mathbf{z}_{ijs}|E_{ijs}=1] &= \widehat{\mathbf{z}}_{ijs} + \sigma_v u^*_{ijs}, \\
E[\mathbf{z}^2_{ijs}|E_{ijs}=1] &= \widehat{\mathbf{z}}^2_{ijs} + \sigma_v \widehat{\mathbf{z}}_{ijs} u^*_{ijs} + \sigma_v^2, \\
E[\mathbf{z}^3_{ijs}|E_{ijs}=1] &= \widehat{\mathbf{z}}^3_{ijs} + \sigma_v \widehat{\mathbf{z}}^2_{ijs} u^*_{ijs} + 3\sigma_v^2 \widehat{\mathbf{z}}_{ijs} + 2\sigma_v^3 u^*_{ijs},
\end{aligned}
$$

where $\widehat{\mathbf{z}}_{ijs} = \sigma_v \Phi^{-1}(\widehat{Pr}_{ijs})$ and $u^*_{ijs} = \phi(\Phi^{-1}(\widehat{Pr}_{ijs}))/\widehat{Pr}_{ijs}$.

Thus, $E[\psi_{ijs}|E_{ijs}=1] = (d_0 + d_2\sigma_v^2) + (d_1 + 3d_3\sigma_v^2)\widehat{\mathbf{z}}_{ijs} + d_2\widehat{\mathbf{z}}^2_{ijs} + d_3\widehat{\mathbf{z}}^3_{ijs} + (2d_3\sigma_v^3 + d_1\sigma_v)u^*_{ijs} + d_2\sigma_v\widehat{\mathbf{z}}_{ijs}u^*_{ijs} + d_3\sigma_v\widehat{\mathbf{z}}^2_{ijs}u^*_{ijs}$. I then write this equation as: $E[\psi_{ijs}|E_{ijs} = 1] = f_0 + \sum_{p=1}^{3} f_p \widehat{\mathbf{z}}^p_{ijs} + \sum_{q=0}^{2} g_q \widehat{\mathbf{z}}^q_{ijs} u^*_{ijs}$, where f_p and g_q are coefficients.

Appendix E
List of Countries

#	Country	#	Country	#	Country
1	Albania *	53	Ghana	105	Pakistan
2	Algeria	54	Greece * †	106	Panama
3	Angola	55	Guatemala	107	Paraguay *†
4	Argentina *†	56	Guinea *	108	Peru *
5	Armenia	57	Guinea-Bissau	109	Poland *†
6	Australia *†	58	Guyana	110	Portugal *†
7	Austria *†	59	Haiti	111	Qatar
8	Azerbaijan *	60	Honduras	112	Republic of Congo
9	Bahrain	61	Hong Kong *	113	Romania *
10	Bangladesh *	62	Hungary *†	114	Russia *
11	Barbados	63	Iceland *	115	Rwanda
12	Belarus	64	India *	116	Saudi Arabia
13	Belgium †	65	Indonesia *†	117	Senegal *
14	Belize	66	Iran	118	Sierra Leone
15	Benin	67	Ireland *†	119	Singapore *
16	Bolivia *†	68	Israel *	120	Slovakia *†
17	Bosnia and Herzegovina	69	Italy *†	121	Slovenia *†
18	Botswana	70	Jamaica	122	South Africa *
19	Brazil *†	71	Japan *†	123	South Korea *
20	Bulgaria *	72	Jordan *	124	Spain *†
21	Burkina Faso *	73	Kazakhstan	125	Sri Lanka
22	Burundi	74	Kenya	126	Suriname
23	Cambodia	75	Kuwait	127	Swaziland
24	Cameroon	76	Kyrgyz Republic	128	Sweden *†
25	Canada *†	77	Laos	129	Switzerland *†
26	Cape Verde	78	Latvia *†	130	Syria
27	Central African Rep.*	79	Lebanon	131	Taiwan
28	Chad	80	Lesotho	132	Tajikistan
29	Chile *†	81	Libya	133	Tanzania
30	China *†	82	Lithuania *†	134	Thailand *
31	Colombia *†	83	Luxembourg †	135	The Bahamas
32	Costa Rica †	84	Macedonia *	136	The Gambia
33	Cote d'Ivoire *	85	Madagascar *	137	The Netherlands *†
34	Croatia *	86	Malawi *	138	The Philippines *†
35	Cuba †	87	Malaysia *	139	Togo *
36	Cyprus †	88	Mali *	140	Trinidad and Tobago
37	Czech Republic *†	89	Malta †	141	Tunisia *
38	Denmark *†	90	Mauritania	142	Turkey *
39	Djibouti	91	Mauritius *	143	Turkmenistan
40	Dominican Republic †	92	Mexico *†	144	Uganda *
41	Ecuador *†	93	Moldova *	145	Ukraine *
42	Egypt *	94	Mongolia *	146	United Arab Emirates
43	El Salvador	95	Morocco *	147	United Kingdom *†
44	Equatorial Guinea	96	Mozambique	148	United States *†
45	Estonia *†	97	Namibia	149	Uruguay *†
46	Ethiopia *	98	Nepal	150	Uzbekistan
47	Fiji	99	New Zealand *†	151	Venezuela *
48	Finland *†	100	Nicaragua	152	Vietnam
49	France *†	101	Niger	153	Yemen
50	Gabon	102	Nigeria †	154	Zambia *
51	Georgia *	103	Norway *	155	Zimbabwe
52	Germany *†	104	Oman *		

Note: The countries in this table are the sample of importing countries in the extensive analysis. Besides, the countries marked by * are the sample of exporting countries in the extensive as well as intensive analyses. The countries marked by † are the sample of importing countries in the intensive analysis.

Vita

Xianliang Tian was born in Wuhan, China. He was employed as a lecturer in Hubei University, China when he earned a Master of Science in Economics from Wuhan University. After years of teaching and industrial service in Hubei University, he came to Louisiana State University to pursue his PhD degree of Economics in August, 2009. His research interests include economic growth, international trade and labor economics. Xianliang will complete the degree of Doctor of Philosophy in May 2014.