

**Product Cycle Dynamics and Intellectual Property Rights:
Theory and Evidence**

by

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Product Cycle Dynamics and Intellectual Property Rights: Theory and Evidence

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“Product cycle” refers to the dynamics of production location shifting from an innovative advanced country (the “North”) to a lower-cost developing country (the “South”), by means of imitation of traded goods or foreign direct investment. Starting from Vernon (1966), all goods are subject to this identical pattern in research. My dissertation provides both theoretical and empirical evidences that product cycle only exists in a portion of products.

The first chapter builds up a general-equilibrium quality ladder model with endogenous outsourcing decision: a final good assembler chooses to acquire low-technology inputs from South and high-technology inputs from North. Only the low-technology inputs have the product cycle. The second chapter discovers that trade in product cycle goods is more likely to emerge in relatively-low-technology industries and originate from less developed countries; furthermore, these interesting findings are proving to accentuate over time. The third chapter investigates product cycle dynamics with industrial heterogeneity in R&D productivity, accounting for the imperfect protection of intellectual property rights. Stronger intellectual property protection in the South only increases the extensive margin of trade in product cycle goods, but not its intensive margin. Fractional probit estimations using a panel of detailed U.S. trade data find support for it.

Dedication

To my daughter, Georgia.

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Chapter 1

Introduction

In trade, “product cycle” refers to the dynamics of technology transfer and production location movement across borders. At the beginning, a typical commodity is manufactured in the advanced country where it is invented. When production becomes standardized, it migrates to a developing country where manufacturing costs are lower. Literature on this topic, originating from Vernon (1966)[86], indicates that product cycle is a common pattern for all goods. However, technique of some cutting-edge sophisticated goods, such as the engines of giant passenger aircraft and the design of CPUs, never diffuses to any lagging areas.

My dissertation aims at providing evidence that product cycle only exists in a portion of products. Another key contribution is to investigate the likely influence of strengthening intellectual property rights protection (IPP) in developing countries on product cycle. For that purpose, the second chapter develops a theoretical quality ladder model in which a final good assembler outsources two kinds of inputs globally. Furthermore, the third chapter empirically examines the product cycle pattern of parts and components. The last chapter studies product cycle when industries are heterogenous in research and development (R&D) productivities.

Based on a simplified dynamic quality-ladder framework, the second chapter adds to this body of knowledge by setting up a North-South general-equilibrium model with every final good made from two intermediate inputs. Quality increment of the high-tech input is higher than that of the low-tech input after each successful innovation; however, the former input demands more resources to make a possible R&D achievement. I discover an endogenous specialization of global

production sharing. In a steady-state equilibrium, the Southerners choose to imitate and produce the low-tech input and the Northerners specialize in the high-tech input. Thus, the product cycle in this model just appears in the low-tech input but not in the high-tech one. I argue that the relative wage increases if the quality difference between the high- and low-tech inputs rises, and the international technology flows flourish. The strengthening of intellectual property rights in the South retards the incentive to innovate and slows down the speed of the product cycle.

The third chapter lends empirical support to the second chapter with the help of data about parts and components U.S. imports of the Harmonized Tariff Schedule (HS) chapter 85¹. To distinguish the high-tech and low-tech inputs, I compute the average unit value for each HS10 product and compare it with the median within each HS4 industry. If the average of this particular product is bigger, it is recognized as a high-tech input; otherwise, it is a low-tech input. This definition is consistent over time and across countries. I run regressions for these two inputs separately and compare the results. I discover that trade in product cycle goods is more likely to emerge in relatively-low-technology industries and originate from less developed countries; furthermore, these interesting findings are proving to accentuate over time.

Finally, the fourth chapter investigates product cycle dynamics with industrial heterogeneity in R&D productivity, accounting for the imperfect protection of intellectual property rights. I develop a North-South model with endogenous Northern innovation, and foreign direct investment (FDI) which may face Southern imitation risk. Within each industry, innovation occurs in a quality ladder. In equilibrium, the product cycle only appears in industries with intermediate technology levels. Further, the risk of imitation shrinks the number of industries exhibiting product-cycle dynamics. Stronger intellectual property protection in the South only increases the extensive margin of trade in product cycle goods, and has no impact on its intensive margin.

Estimations using a panel of detailed U.S. trade data from 54 developing countries find support for the theoretical predictions in Chapter Four. Following Zhu (2005), a HS10 product is identified as a product cycle good if a country converts from a pure importer from the U.S. to an

¹ This chapter contains a variety of products related to electrical machinery, sound recorders and television.

exporter to the U.S. Then I create a measure of product-cycle trade as the share of trade volume of product-cycle goods within each Standard Industrial Classification (SIC) 4-digit industry. I find that this intensive margin of product-cycle trade reaches its maximum when the industries' R&D productivity is moderate. Tighter IPP significantly encourages industries to participate in product-cycle trade, especially for the medium-technology ones. However, its effect on the intensive margin of product-cycle trade is ambiguous.

To sum up, I contribute to the literature on quality ladder models by addressing the likelihood that some products do not demonstrate the product cycle pattern. I consider two different frameworks under quality ladder structure: outsourcing and heterogenous industries. I also find strong evidence supporting my theoretical predictions.

Chapter 2

Outsourcing Multiple Inputs: Theory

2.1 Introduction

With the rapid increase of trade liberalization, global production sharing is commonplace. Companies begin to slice their value chain into pieces and relocate some stages overseas. Empirical evidence shows that international outsourcing of the production process accounts for at least 30 percent of total world trade in manufacture products annually (Yeats, 1998[94]). Moreover, there is reported to exist a specialized pattern of some manufacturing segments.

Take the semiconductors and integrated circuits industry (HS 8542) as an example. The outputs of this group, including electronic integrated circuits, processors, controllers, memories and etc., are components of most electronic devices. On one hand, fabrication activities that remain in the advanced regions tend to yield products with higher unit values (*Shift in U.S. Merchandise Trade 2009*), which is an indication of higher quality in empirical tests (Schott, 2004[75]; Hummels and Klenow, 2005[44]; Krishna and Maloney, 2011[54]; etc.); on the other hand, foundries in Asia not only have strengthened their participation in this particular market, but also started to dominate (*Shift in U.S. Merchandise Trade 2004*). Figure B.1 illustrates this phenomenon. The dynamic read-write random access memory (DRAM, HS 854232) is one typical variety invented in the U.S. decades ago. Nowadays China is one of the largest production bases around the world¹. We compare the customs value of Chinese exports to the U.S. with that of Germany and find an obvious downtrend as the DRAM sizes increase.

¹ <http://en.wikipedia.org/wiki/DRAM>.

Starting from Vernon (1966)[86], trade economists have examined the “product cycle” hypothesis, which refers to the shift of production from advanced to developing countries over time. One framework in particular, the quality ladder model (e.g. Grossman and Helpman, henceforth GH, 1991b[32]; Yang and Maskus, 2001[93]; Glass and Saggi, 2002[28]), studies vertical quality improvement while keeping the number of varieties stable. After each successful R&D investment, the quality of a product makes a significant jump. However, with the exception of Antras (2005)[2], this literature rarely pays attention to the split of production process across borders.

This chapter examines input specialization in a quality ladder framework. Based on GH (1991b), we add to the literature by building up a dynamic North-South general-equilibrium model with every final good made from two intermediate inputs. The high-tech input is higher up in the quality ladder than the low-tech one. During each instant of time, they try to climb up the ladder simultaneously and independently. Different from the previous works, R&D activities take place in intermediate sectors. For simplicity, we only permit innovation to occur in the North and imitation to occur in the South. The final good assembler procures inputs from the global upstream market, searching for the lowest quality-adjusted price. By making the above assumptions, the quantities of all goods are dependent on a combination of instantaneous input prices and qualities. Then we manipulate the ratio of quality jumps between two inputs and check its effect on the steady-state equilibrium choices.

We find a specialized pattern of global input production in the steady state. Due to the technological disadvantage, the Southerners are only able to imitate and produce the low-tech input, although it also invests in copying the high-tech input. The Northerners are capable of producing both inputs, but they choose to specialize in the high-tech input, which they have a comparative advantage in. Hence, the product cycle in our model just shows up in the low-tech input but not in the high-tech one.

Here are the major implications of our calibrated results. The relative wage between the North and South increases with the quality difference between the high- and low-tech inputs, the degree of Southern IPRs protection and Northern labor endowment, and decreases with Southern

labor endowment. Furthermore, the bigger is the quality difference, the more prosperous are the international technology flows.

The rest of Chapter 2 is organized as follows. There is a brief literature review in Section 2.2. We discuss the basic setup of our modified quality ladder model with two inputs in Section 2.3. The main results in the steady-state equilibrium are derived in Section 2.4. Then we perform extensive calibrations in Section 2.5 according to our theoretical predictions. Section 2.6 concludes.

2.2 Literature Review

What does the life cycle of a typical commodity look like? Raymond Vernon (1966)[86] first discusses this “product cycle” hypothesis: a good is initially produced in the country where it is innovated. When designs are improved and the production process becomes standardized, the manufacturing is moved into less advanced foreign locations with lower marginal costs.

Krugman (1979)[55] is the first qualitative model to analyze the horizontal differentiation of the product cycle. The global economy in his framework consists of two countries: an innovating North and a non-innovating South. Labor is the only factor. New varieties come out continuously in the North and production gradually shifts to the South after a while. This time lag results in the necessity of international trade. Any speed-up in innovation or slow-down in transfer enlarges the wage gap between two countries. In Krugman’s model, both innovation and technology transfer rates are exogenously given. This assumption has been modified in subsequent research². Grossman and Helpman (henceforth, GH, 1991a[31]) further endogenize the technology transfer rate as a function of costly Southern imitation efforts, whose intensity is a Poisson arrival rate. Southern imitation, which is treated as the only diffusion channel in their paper, will ultimately accelerate Northern innovation³. However, the effect on relative wage is to the opposite of Krugman’s (1979)

² Early attempts (Dollar, 1986[14]; Jensen and Thursby, 1986[48], 1987[49]) to endogenize the speed of product cycle are criticized by Grossman and Helpman (1990)[34] as failing to “incorporate all general equilibrium interactions, and ignore other economic factors that drive the innovation rate, or other features” (Page 1262). Later, Segerstrom et al. (1990)[78] make a significant contribution to the literature by using the “invention lottery” of Schumpeter (2013)[76], in order to endogenize the innovation process. Starting from this paper, economists begin to presume that firms take research and development (R&D) races with a probability of winning, which is proportional to the resources involved. But the time length between innovation is deterministic in Segerstrom et al. (1990)[78].

³ Segerstrom (1991)[77] extends Grossman and Helpman’s framework (1991a) and allows firms in both countries

result.

On the basis of GH (1991a), Helpmen (1993)[41] evaluates the welfare consequences of Southern intellectual property rights protection (IPP), despite of an exogenously-given imitation rate. Taking the form of a higher imitation intensity, he discovers a positive feedback of weakened IPP to innovation and transfer. Moreover, Lai (1998)[59] further investigates this issue by allowing the North to undertake foreign direct investment (FDI). Imitation no longer targets firms in the North directly, but aims at multinationals set up in the South. He points out that stronger IPP has inverse impacts on innovation rate, technology diffusion and relative wage in the different situations of imitation and FDI. The wage differential between the North and South is cut down with FDI, even when both channels co-exist. Besides, Lai (1998)[59] is the first one to assume that the efficiency of innovation is positively related to current knowledge stock.

In fact, innovations are not only reflected in inventing new types of products, but also in improving the quality of existing goods. For example, the function of Windows 97 was far away from a recent generation of Windows 8, though both are called Windows systems by Microsoft. Gabszewicz et al. (1981)[20] attempt to elaborate this consideration and argue that the total number of coexistent products is bounded. However, their model is a partial equilibrium analysis and the quality levels are exogenously given. In Flam and Helpman's (1987)[19] static framework, product cycle is realized by introducing high-quality products to the North while replacing lowest-quality products in the South with relatively-low-quality ones⁴.

GH (1991b, c) [32] [33] construct a dynamic general-equilibrium model with a fixed continuum of products. Each product can climb up its quality ladder infinitely⁵, with a significant quality jump after each successful innovation investment in the North. The Southern firms learn to catch up the quality frontier via costly imitation. Since consumers would like to purchase goods with the lowest quality-adjusted price, the international market structure acts as Bertrand competition. In particular, there is an optimal investment intensity for Northern inventors in GH (1991c); however,

to invest in costly imitation.

⁴ Stokey (1991)[81] provides more necessary conditions of this kind of shifting.

⁵ This repeated innovation feature first appears in Segerstrom et al. (1990)[78] and Aghion and Howitt (1990)[1].

the time period between each innovation is still stochastic. GH claim that a bigger quality jump not only promotes the incentive to innovate but also spurs economic growth.

In Glass and Saggi (2002)[28], all innovation, imitation and FDI decisions become endogenously determined. Southern firms now copy from both multinational corporations and Northern companies, with disparate successful probabilities. Thus, the IPP enforcement results in a decline in FDI and further retards the innovation incentive in the North. Later, Glass and Wu (2007)[29] combine the two invention dimensions in a single paper, and presume innovation to be endogenous and imitation to be exogenous. In their discovery, tighter IPP can move innovation from quality improvement to variety expansion.

There are few papers working on the heterogeneity of product cycle. Glass (1997)[24] investigates product cycle specifically from the demand aspect. There are two quality levels for each product ascribing to diversified consumers' willingness-to-pay. Through manufacturing the low-quality good at the beginning, the South accumulates the know-how of high-quality product and gradually penetrates into the global market. On the other side, Taylor (1993)[83] introduces the Ricardian explanation into the basic setup of GH (1991b, c), since R&D activities across industries are discovered to be asymmetric in data. With this adjustment, the new framework allows intra-industry resource reallocation and is easy to work with. In addition, on a basis of Taylor (1993), Lu (2007)[60] further assumes that the quality increment of each innovation is positively related to industry's technology rank. After losing its market dominance, an ex-leader chooses between innovation or FDI, depending on what kind of industry it belongs to. It is interesting to see that the product-cycle dynamics take place in industries with moderate technology levels. High-technology industries are restricted to the North, and low-technology industries stagnate in the South after diffusion.

Vernon (1966) mentions that a part of production is difficult to shift out of country. However, nowadays imports and exporters in intermediate goods take up a considerable part of international trade (Feenstra, 1998[17]). Evidence shows that for U.S. alone, the share of capital goods (a rough indicator of intermediate goods, including machinery, electrical parts, and other components) in

total imports increased from 0.4% to 33.6% in the period of 1950 - 1995; meanwhile, its share in total exports increased from 8.7% to 42.4%. (Glass, 2004[25]) In a nutshell, it is very important to take a look at the fragmentation of production stages across borders.

From our knowledge, Glass and Saggi (2001)[27] is the first one to examine the role of outsourcing in the emergence of product cycle, especially in the vertical differentiated framework. With endogenous innovation and outsourcing, production is consisted of two stages: a basic stage takes place in the South; an advanced stage remains in the North and then combine with the basic stage to assemble the final good. A lower adaption cost and a larger portion of the basic stage gives rise to a greater extent of international outsourcing. Correspondingly, innovation is further encouraged, since outsourcing saves Northern labor from manufacturing to R&D sectors. In addition, wage differential between two countries is cut down.

There are two papers extending Glass and Saggi's work (2001) by adding exogenous imitation targeting outsourced production: Glass (2004)[25] and Sayek and Sener (2006)[73]. By and large, there are three major differences between these two papers: Firstly, they are different in model setup. Glass follows the assumption of unique factor in production, i.e. labor, as the mainstream of product cycle literature. However, Sayek and Sener distinguish labor into skilled and unskilled in both countries, and suppose both are required in production. Second, the mechanism of product cycle dynamics is different. In Glass (2004), the advanced stage always stays in the North, and the basic stage is likely to move from Southern affiliates to local firms via successful imitation. While in Sayek and Sener, a high-quality good experiences three periods of development: initially produced in the North, then segmented between the North and South after successful exogenously-determined outsourcing, and finally wholly produced in the South after successful imitation. Third, they are interested in different aspects of economy. Glass (2004) focuses on the influence from imperfect IPP. A better enforcement of IPP encourages outsourcing and innovation and also brings down Northern relative wage to the South. In contrast, Sayek and Sener investigate relative wage domestically.

In the past, studies on this topic are almost macroeconomic analysis. Antras (2005) contributes significantly to the literature by developing a firm-decision model. There is one final good

made by two intermediate inputs: the high-technology input is restricted to be produced only in the North, and the low-technology input can be contracted to both regions. The trade-off between expensive incomplete contract and cheap manufacturing cost in the South creates the product cycle. Once the research center, which is the final good assembler in Antras' paper (2005), starts outsourcing in the South, its profit is rising with the share of low-technology inputs in the final good production. He specifies this share of low-technology input to increase through time, in order to rationalize Vernon's (1966) standardization process. In the end, a profit-maximizing research center will contract its entire demand of the low-technology input to the South. However, the traditional R&D dynamics are missing and Antras' main focus is the significance of incomplete contract⁶.

2.3 The Model

We begin with the description of the model. There are two countries in the world: a developed North and a less-developed South. Similar to other product-cycle studies, these two countries differ in technology level⁷ and population size. Labor is the only factor and is assumed to be immobile across borders. Trade is assumed to be costless.

2.3.1 Consumers

There is a continuum of final goods in the world, indexed by $y(i)$ with $i \in [0, 1]$. Consumers are homothetic and share identical constant elasticity substitution (CES) preferences.

The intertemporal utility function for an infinitely-lived representative consumer is denoted as

$$U = \int_0^{\infty} e^{-\rho t} \log u(t) dt \tag{2.1}$$

⁶ Antras (2005) also has some general equilibrium analysis in his working paper version.

⁷ Xiang's (2007)[92] empirical results indicate that there is a sizable technology gap between the developed and developing countries.

where ρ is the common subjective discount factor. Instantaneous utility at time t is

$$u(t) = \left(\int_0^1 y(i, t)^\alpha di \right)^{1/\alpha}, 0 < \alpha < 1 \quad (2.2)$$

where $\epsilon = 1/(1-\alpha) > 1$ is the elasticity of substitution among final goods and $y(i, t)$ is the quantity of final good i consumed at time t ⁸.

A representative consumer maximizes the lifetime utility subject to the intertemporal budget constraint given by

$$\int_0^\infty e^{-R(t)} E(t) dt = \int_0^\infty e^{-R(t)} Y(t) dt \quad (2.3)$$

where $R(t) = \int_0^t r(s) ds$ is the cumulative interest rate from time 0 to time t , and $Y(t)$ is the aggregate factor income at time t . Total world expenditures on all final goods at time t is characterized as

$$E(t) = \int_0^1 p(i, t) y(i, t) di \quad (2.4)$$

where $p(i, t)$ is the price of the final good i at time t .

Consumers maximize their utility through two stages: they first allocate lifetime spending across different time periods; then they make a decision on how to spread instantaneous expenditure across final goods at each point in time. With the CES utility function, the expenditure at every instant of time is the same, and the spending on each final good is even.

The representative consumer's utility maximization problem((2.2) s.t. (2.4)) shows that final good i faces the following isoelastic demand function at date t

$$y(i, t) = \phi(t) p(i, t)^{-1/(1-\alpha)} \quad (2.5)$$

where $\phi(t) = \frac{E(t)}{\int_0^1 p(j, t)^{-\alpha/(1-\alpha)} dj}$ is taken as given by the final good assembler. In other words, final good i 's share of total world expenditures is negatively related to its own price and the world's price index.

⁸ The quality parameters here do not show up directly in this utility function as other papers do, but they are contained in the term of $y(i, t)$ indirectly. That is because our R&D activities occur in intermediate input markets rather than the final good one. Therefore, we put the quality increment parameters into the final good production function instead.

Note that the number of final goods is fixed and all final good varieties are identical in the quality ladder framework. For simplicity, we suppress variety index i from now on.

2.3.2 Firms

Following Antras (2005), there exists one final good assembler and many manufacturing plants of intermediate inputs. The assembling of final good y requires two inputs: a low-tech input x_l , and a high-tech input x_h . They are distinct in their quality increments and R&D requirements. Since the high-tech input is more skill- and technological- intensive, it requires more resources in order to be improved upon or imitated. As noted before, we assume that all research endeavors take place within the manufacturing plants instead of the final good sector, which is different from the literature. To be more specific, the manufacturing plants located in the North have the capacity to innovate and push forward the quality frontier of a certain input; while the Southern manufacturing plants are only able to imitate existing quality levels from the North.

Production of one unit of either input demands one unit of labor force. The South is supposed to have larger labor endowment than the North. Thus, it must have a lower wage rate and hence have a comparative advantage in manufacturing. We normalize the wage rate in the South to 1 and the wage rate in the North is denoted as ω , which should be greater than 1. It is apparent that ω is also the relative wage between the North and South.

2.3.2.1 Manufacturing Plants

Manufacturing plants are classified into four categories: Northern low-tech plants, Northern high-tech plants, Southern low-tech plants and Southern high-tech plants. Their firm measures are n_l^N , n_h^N , n_l^S and n_h^S , respectively. All manufacturing plants can engage in production of their specific input type and conduct R&D activities on both types. That is to say, we allow a low-tech plant changing into a high-tech one if its research investment succeeds, and vice versa.

As we have mentioned previously, innovation only takes place in the North. There are profitable incentives for these Northern manufacturing plants to enhance their product qualities.

Extending GH (1991b), we presume that both low- and high-tech inputs stochastically and independently climb up their own quality ladders and their qualities can be promoted infinitely. The probability of successful innovation in the next instant of time, or the hazard rate, depends on firm's R&D investment during the current period: ι_l for the low-tech input and ι_h for the high-tech one. A Northern low-tech (high-tech) plant undertaking innovation intensity ι_l (ι_h) during time interval dt exploits $a_l \iota_l dt$ ($a_h \iota_h dt$) units of labor, at a cost of $\omega a_l \iota_l dt$ ($\omega a_h \iota_h dt$). a_l (a_h) is the fixed labor requirement for every unit of innovation intensity of the low-tech (high-tech) input, with $a_l < a_h$. Yet, no investment can make sure the success.

Each successful innovation leads to one step higher for each input up its quality ladder. The quality increment for every step is a factor $\lambda_l > 1$ for the low-tech input and $\lambda_h > 1$ for the high-tech one. q_l (q_h) is defined to be the highest quality available for the low-tech (high-tech) input currently. Without further loss of generality, we assume that the initial qualities for the low- and high-tech inputs are both equal to 1. Consequently, it is $q_l = \lambda_l^\eta$ after η times of quality improvement and $q_h = \lambda_h^\theta$ after θ times of improvement. Due to the intrinsic differentiated characteristics of input types, the ratio of quality increment $\lambda_R = \lambda_h/\lambda_l > 1$. Alternatively, we have $\lambda_h > \lambda_l > 1$. The value of λ_R , whether it is big or small, has considerable impact on our steady-state predictions.

On the other hand, the function of the Southern plants is similar to that of the Northern ones in the sense of manufacturing both intermediate inputs. But the Southerners do not know how to invent the next generation of inputs, so they reverse engineer the imported goods from the North and try to learn the state-of-the-art technology through costly imitation. Analogous to the precursors (e.g. Krugman, 1979; GH, 1991a, b, c; Segerstrom, 1991; Glass, 1997), imitation is assumed to be the unique possible channel of international technology diffusion⁹. The hazard rates for imitation are given by μ_l and μ_h for the low- and high-tech inputs separately. The total cost during time period dt is defined as $(1 + \kappa)c_l \mu_l dt$ ($(1 + \kappa)c_h \mu_h dt$) for the low-tech (high-tech) input, where c_l (c_h) is the cost of unit imitation intensity. The patent law enforcement in the

⁹ Besides imitation, economists have studied various forms of technology diffusion, such as foreign direct investment (FDI) (e.g. Vernon, 1966; Lai, 1998; Glass and Saggi, 2002; Antras, 2005; Lu, 2007), licensing (Yang and Maskus, 2001) and subcontracting (Antras, 2005).

South is imperfect, and we use κ to measure the degree of Southern IPRs protection. The increase in κ indicates a strengthening of IPRs so that Southern manufacturing plants must spend more resources for a given level of imitation intensity.

The specific manufacturer discovering the top-of-the-line technology, denoted as the leader, earns positive profits for a while. We name the rest of manufacturing plants in both regions as followers. For convenience, we focus on the framework of “inefficient follower” in GH (1991b)¹⁰. It is supposed that Northern innovation bases on an input currently produced in the South and Southern imitation only targets the Northern leaders. The Northerners are not allowed to further improve upon an input until their most recent generation has been copied. Similarly, once a manufacturer wins the imitation competition, no one else in the South undertakes R&D activities unless the Northerners reclaim the input. To sum up, the North and South alternatively control the production, and technology diffusion occurs across borders instead of within borders. Clearly, there exists an imitation lag. When all Northern plants are making efforts to enhance the top quality from current λ_l^η (λ_h^θ) to $\lambda_l^{\eta+1}$ ($\lambda_h^{\theta+1}$), the Southern ones are aiming at imitating λ_l^η (λ_h^θ).

Under these circumstances, we are now in a position to discuss the manufacturers’ behavior. The manufacturers maximize their instantaneous profits by choosing the price of output. Because of the quality ladder structure, those manufacturers with the lowest quality-adjusted price, p_l/q_l for the low-tech inputs and p_h/q_h for the high-tech inputs, dominate the market¹¹. This feature results in a Bertrand competition in the global market. Every plant tries to set a price that just prevents its rivals earning a positive profit and drives them out of the market. In equilibrium, this price is equivalent to “the second highest marginal cost in quality-adjusted terms” (Glass and Saggi, 2002, p.394). In that case, there are two possible scenarios for each input: we say, Scenario S and Scenario N.

Scenario S: If the Southern manufacturing plant masters the state-of-the-art technology of either input via imitative investment, it can set a price equal to the Northern wage rate ω (or a

¹⁰ This “inefficient follower” framework is the basic setup in Yang and Maskus (2001) and Glass and Saggi (2002).

¹¹ The final good producer is indifferent between quality level of the low-tech (high-tech) input η (θ) and $\eta - 1$ ($\theta - 1$) if the quality-adjusted price is the same.

small δ below it) and take over the entire market. Its marginal cost is 1 due to the normalized wage rate in the South. Other input suppliers with lower quality levels and Northern competitors with equal technology capacity all earn zero profits. The Southern imitator's instantaneous profits are presented as

$$\pi_l^S = (\omega - 1)x_l^S \quad (2.6)$$

for a low-tech producer, and

$$\pi_h^S = (\omega - 1)x_h^S \quad (2.7)$$

for a high-tech producer. x_l^S and x_h^S are the respective quantities of inputs sold during that time period. $p_l^S = p_h^S = \omega$.

Scenario N: This scenario arises when one Northern plant successfully upgrades the quality level of an input manufacturing in the South recently. In order to squeeze out its competitors, this plant charges a price equal to the Southerner's marginal cost after quality adjustment (or δ below). Recall that there is an imitation lag for the South. In consequence, its instantaneous profits after subtracting total variable costs are given by

$$\pi_l^N = (\lambda_l - \omega)x_l^N \quad (2.8)$$

for the low-tech plant, and

$$\pi_h^N = (\lambda_h - \omega)x_h^N \quad (2.9)$$

for the high-tech plant. ω is the marginal cost for any Northern manufacturer. x_l^N (x_h^N) is the quantity of low-tech (high-tech) inputs supplied to the final good assembler. The input prices are $p_l^N = \lambda_l$ and $p_h^N = \lambda_h$ in light of their respective quality increments. Be careful that this scenario applies only when the wage gap is not too large. That is, we only consider the case where $\lambda_h > \lambda_l > \omega$, or the narrow-gap wage situation in GH (1991a)¹².

¹² In GH (1991a), they take both wide-gap wage situation ($\omega > \lambda$) and narrow-gap wage situation ($\omega < \lambda$) into account. But GH (1991b) only pays attention to the narrow-gap one.

It is obvious that these two scenarios cannot come out at the same time. Either input is provided by exactly one plant in equilibrium. The firm measures of each type must sum up to 1. For the low-tech input, it is required that

$$n_l^S + n_l^N = 1 \quad (2.10)$$

Also, for the high-tech input, it is required that

$$n_h^S + n_h^N = 1 \quad (2.11)$$

A manufacturer's expected value should not exceed its total R&D costs in every instant of time, otherwise there will be infinite investment. Meanwhile, the expected value should be no smaller than the costs of research works due to the profitability requirement. Taking both conditions into account, we obtain the zero-profit constraints as follows

$$v_l^S = (1 + \kappa)c_l \text{ if } \mu_l > 0 \quad (2.12)$$

for the Southern low-tech plants if the imitative activity takes place and

$$v_h^S = (1 + \kappa)c_h \text{ if } \mu_h > 0 \quad (2.13)$$

for the Southern high-tech plants.

Analogously, for Scenario N,

$$v_l^N = \omega a_l \text{ if } \iota_l > 0 \quad (2.14)$$

for the Northern low-tech plants if the innovation happens and

$$v_h^N = \omega a_h \text{ if } \iota_h > 0 \quad (2.15)$$

for the Northern high-tech plants.

2.3.2.2 Final Good Assembler

We are now concerned with the role of the final good assembler and its equilibrium choice. Adding this agent into consideration is new to the quality ladder literature, thereby facilitating deriving our prediction of input specialization. It is readily shown the final good assembler purchases two inputs from the global market searching for the lowest quality-adjusted price. Then it produces the final good without additional cost. In fact, it has a Cobb-Douglas production function.

$$y^{jk} = \zeta_z (q_l x_l^j)^z (q_h x_h^k)^{1-z}, 0 \leq z \leq 1 \quad (2.16)$$

where $\zeta_z = z^{-z} (1-z)^{-(1-z)}$ is a parameter used to normalize the final good quantity. z in equation (2.16) denotes the share of low-tech inputs used, which is exogenously given in our model. By plugging this function (2.16) into instantaneous utility (2.2), the quality parameters go into the consumer's welfare indirectly.

Since each input has two distinct pricing scenarios S and N, the Northern final good assembler is likely to meet with four combinations of input prices. We redefine the price for the low-tech input to be p_l^j ($j \in \{S, N\}$) and the price for the high-tech input to be p_h^k ($k \in \{S, N\}$). Then x_l^j and x_h^k are corresponding input quantities respectively. The instantaneous input prices are equivalent in the international economy under the assumption of free trade.

In fact, it is Antras (2005) which introduces this upstream-downstream production structure into the product cycle studies, for the purpose of rationalizing Vernon's (1966) standardization process of a typical commodity. The trade-off between expensive incomplete contracting and cheap manufacturing expenditures in the South creates his product cycle, whose dynamics result from an increasing function of z over time. In particular, the low-tech input is initially produced in the North until a unique threshold of time, and then the final good producer begins to contract with the Southerners and outsource the low-tech input overseas. However, his model fails to induce a product cycle if the costly contract disappears.

Departing from Antras (2005), we conduct the basic structure of the quality ladder model

into the consideration of production function (2.16) rather than contracting expenses, in order to activate the product cycle. The Southern plants have an active role as an imitator in our model and have the freedom to resolve how much R&D intensity to undertake. On the contrary, all decisions are made by the Northern final good producer and the Southerners are passive in Antras (2005). Furthermore, we assume that the high-tech input may be produced in both countries, instead of being limited to the North.

The expected instantaneous profits π^{jk} for the final good assembler is calculated by sales revenue $R^{jk} = p^{jk}y^{jk} = \phi^{1-\alpha}\zeta_z^\alpha(q_l)^{\alpha z}(x_l^j)^{\alpha z}(q_h)^{\alpha(1-z)}(x_h^k)^{\alpha(1-z)}$ minus its costs of acquiring both inputs. The final good assembler's problem is to maximize its earnings by choosing the amount of inputs used, since the input prices and qualities have been decided in the upstream market already. The following function illustrates its consideration

$$\max_{x_l, x_h} \pi^{jk} = \phi^{1-\alpha}\zeta_z^\alpha(q_l)^{\alpha z}(x_l^j)^{\alpha z}(q_h)^{\alpha(1-z)}(x_h^k)^{\alpha(1-z)} - p_l^j x_l^j - p_h^k x_h^k \quad (2.17)$$

As a result¹³, the function below indicates the optimal final good price in terms of input price and quality level.

$$p^{jk} = \frac{1}{\alpha} \left(\frac{p_l^j}{q_l}\right)^z \left(\frac{p_h^k}{q_h}\right)^{1-z} \quad (2.18)$$

Next, the quantity for the final good is

$$y^{jk} = \phi \left[\frac{1}{\alpha} \left(\frac{p_l^j}{q_l}\right)^z \left(\frac{p_h^k}{q_h}\right)^{1-z} \right]^{-\frac{1}{1-\alpha}} \quad (2.19)$$

Substituting equations (2.18) and (2.19) back into the original profit function (2.17), we derive the expected profits of the final good assembler in equilibrium as

$$\pi^{jk} = \phi(1-\alpha) \left[\alpha \left(\frac{q_l}{p_l^j}\right)^z \left(\frac{q_h}{p_h^k}\right)^{1-z} \right]^{\frac{\alpha}{1-\alpha}} = \phi(1-\alpha) \left[\alpha \left(\frac{\lambda_l^\eta}{p_l^j}\right)^z \left(\frac{\lambda_h^\theta}{p_h^k}\right)^{1-z} \right]^{\frac{\alpha}{1-\alpha}} \quad (2.20)$$

¹³ All calculations in this subsection are in Appendix A.1.

The final good price p^{jk} increases with input price and decreases with quality levels. To the opposite, the quantity y^{jk} is negatively associated with input price and positively associated with input quality. When these two offsetting effects act together and combine to be the assembler's profit, the impact from y^{jk} overwhelms. Put differently, a higher quality level of both inputs increases the assembler's profit, while a higher input price deteriorates it.

Additionally, the quantity of the low-tech input purchased is written as

$$x_l^j = \phi z \alpha^{\frac{1}{1-\alpha}} (p_l^j)^{-1} \left(\frac{q_l}{p_l^j}\right)^{z \frac{\alpha}{1-\alpha}} \left(\frac{q_h}{p_h^k}\right)^{(1-z) \frac{\alpha}{1-\alpha}} \quad (2.21)$$

and the quantity of the high-tech input is embodied as

$$x_h^k = \phi (1-z) \alpha^{\frac{1}{1-\alpha}} (p_h^k)^{-1} \left(\frac{q_l}{p_l^j}\right)^{z \frac{\alpha}{1-\alpha}} \left(\frac{q_h}{p_h^k}\right)^{(1-z) \frac{\alpha}{1-\alpha}} \quad (2.22)$$

Note that in scenario S our input price is the endogenous relative wage ω . Thus, we leave more detailed comparative static analysis to the later part.

2.3.3 Market-clearing Conditions

The labor endowment are assumed to be fixed over time, which is L^N in the North and L^S in the South, with $L^N < L^S$. There is no international immigration of workers. Upstream plants consider how to allocate their limited labor resources between manufacturing and R&D sectors. Constant return to scale ensures that the number of labor involved in production equals the quantity of inputs sourced. The research costs have been stated in the previous subsection. Moreover, the final good assembler does not utilize any resource. The factor clearance in equilibrium requires that the total number of labor demanded in all plants and sectors is equal to labor supplied in each region. Thus, we specify the resource constraint for the South as

$$n_l^N \mu_l (1 + \kappa) c_l + n_h^N \mu_h (1 + \kappa) c_h + n_l^S x_l^S + n_h^S x_h^S = L^S \quad (2.23)$$

The first two terms together stand for the labor employed in imitative R&D sector, by multiplying the imitation costs with the measure of plants aimed for. The last two terms on the left-hand-side (LHS) are the sum of labor participating in manufacturing in the South.

By the same logic, the Northern labor market clearing condition is

$$n_l^S \iota_l a_l + n_h^S \iota_h a_h + n_l^N x_l^N + n_h^N x_h^N = L^N \quad (2.24)$$

where the first two terms show those workers who take part in the innovative R&D activities and the following two terms represent labor force in the manufacturing sector in the North.

In equilibrium, the aggregate expenditures E should be the same as the aggregate factor income Y ¹⁴. $Y = L^S + \omega L^N + \pi^{jk}$ where the terms on the right-hand-side (RHS) are the gross wage earnings in the South and North, respectively, plus the instantaneous profits of the final good assembler. The input plants break even since they have one-time R&D costs. Hence,

$$E = L^S + \omega L^N + \phi(1 - \alpha) \left[\alpha \left(\frac{\lambda_l^\eta}{p_l^j} \right)^z \left(\frac{\lambda_h^\theta}{p_h^k} \right)^{1-z} \right]^{\frac{\alpha}{1-\alpha}} \quad (2.25)$$

2.4 Endogenous Specialization

2.4.1 Steady State Equilibrium

We first explore the general conditions where all types of R&D investments take place (i.e. $\mu_l > 0$, $\mu_h > 0$, $\iota_l > 0$, $\iota_h > 0$), and then we proceed to analyze the four particular cases in accordance with different input price combinations. In these cases, some R&D intensities might be null and hence help to draw our striking inference about input specialization.

As is well-known, all nominal values must move at the same constant rate in steady state, which equates the difference between interest rate r and consumer's subjective discount factor ρ . This differential relationship is exhibited as

¹⁴ This is according to the CES utility function and equation (2.3).

$$\dot{v}_l^j/v_l^j = \dot{v}_h^k/v_h^k = \dot{E}/E = r - \rho \quad (2.26)$$

These four equations below ((2.27) to (2.30)) demonstrate the no-arbitrage value conditions for each category of plants in steady state. In each equation, the first term is a manufacturing plant's dividend ratio calculated by its instantaneous profits over its expected value. The next term is its instantaneous return to capital on equity holdings. In all, the LHS represents the total expected return to a plant. It is equal to instantaneous interest rate plus the probability of being imitated or innovated, which reveals the plant's overall potential loss.

$$\pi_l^S/v_l^S + \dot{v}_l^S/v_l^S = r + \iota_l \quad (2.27)$$

$$\pi_h^S/v_h^S + \dot{v}_h^S/v_h^S = r + \iota_h \quad (2.28)$$

$$\pi_l^N/v_l^N + \dot{v}_l^N/v_l^N = r + \mu_l \quad (2.29)$$

$$\pi_h^N/v_h^N + \dot{v}_h^N/v_h^N = r + \mu_h \quad (2.30)$$

By combining equations (2.26) and (2.27), we figure out the steady-state relationship between the Southern low-tech plant's profits and its expected value in Scenario S

$$v_l^S = \frac{\pi_l^S}{\rho + \iota_l} \quad (2.31)$$

and for the Southern high-tech plant using (2.26) and (2.28) instead of (2.27)

$$v_h^S = \frac{\pi_h^S}{\rho + \iota_h} \quad (2.32)$$

Then plugging (2.6) and (2.12) into the above function (2.31), we build up a detailed free-entry condition for the Southern low-tech plant

$$(\omega - 1)x_l^S = (\rho + \iota_l)(1 + \kappa)c_l \quad (2.33)$$

Similarly, by putting together (2.7), (2.13) and (2.32), we have it for the Southern high-tech plant

$$(\omega - 1)x_h^S = (\rho + \iota_h)(1 + \kappa)c_h \quad (2.34)$$

For either (2.33) or (2.34), the LHS has two endogenous variables ω and x_l^S (or x_h^S), and the RHS has only one ι_l (or ι_h). It seems that an increase in the innovation intensity calls for more workers in the North, thus pushing up the relative wage. The Southern plants' incentive to produce also get encouraged because their output price is set as the relative wage.

On the other hand, for Scenario N, we have

$$v_l^N = \frac{\pi_l^N}{\rho + \mu_l} \quad (2.35)$$

if we join (2.26) and (2.29) together. Also,

$$v_h^N = \frac{\pi_h^N}{\rho + \mu_h} \quad (2.36)$$

if we combine (2.26) and (2.30). After plugging in equations (2.14) and (2.15) separately, we reformulate (2.35) and (2.36) to be

$$(\lambda_l - \omega)x_l^N = (\rho + \mu_l)\omega a_l \quad (2.37)$$

$$(\lambda_h - \omega)x_h^N = (\rho + \mu_h)\omega a_h \quad (2.38)$$

When the imitation intensity rises, the Southern plants request more resources and compete fiercely in the labor market. The Southern wage is pushed up and hence the relative wage goes down. Accordingly, the Northern plants are willing to provide more inputs to the market since their relative cost drops and eventually their instantaneous profits climb up.

From (2.33), (2.34), (2.37) and (2.38), we are able to attain the reduced-form expressions for R&D intensities. When looking back to (2.21) and (2.22), we find that the quantities of inputs

x_l^j and x_h^k are functions of input price, quality levels and other parameters. Recall that the input price may be the relative wage (in Scenario S) or quality increment (in Scenario N). Quality related parameters are predetermined at some point in time. Thus, the following functions from (2.39) to (2.42), which display intensities of R&D efforts in each category, are in terms of various parameters $(\lambda_l, \lambda_h, \rho, a_l, a_h, c_l, c_h, \kappa, z, \alpha, L^N, L^S)$ and one endogenous variable ω ¹⁵.

$$\mu_l = \frac{(\lambda_l - \omega)x_l^N}{a_l\omega} - \rho \quad (2.39)$$

$$\mu_h = \frac{(\lambda_h - \omega)x_h^N}{a_h\omega} - \rho \quad (2.40)$$

$$\iota_l = \frac{(\omega - 1)x_l^S}{(1 + \kappa)c_l} - \rho \quad (2.41)$$

$$\iota_h = \frac{(\omega - 1)x_h^S}{(1 + \kappa)c_h} - \rho \quad (2.42)$$

According to its intrinsic property, it is impossible to conduct any negative amount of R&D investment. So the value of the above four intensities should be non-negative.

It is worth noting that all reduced-form R&D intensities above are endogenous. However, in the quality ladder literature, these intensities are assumed to be Poisson arrival rates, which are given exogenously. The only exception is GH (1991c)¹⁶, where the optimal innovation intensity can be figured out but the imitation intensity is still exogenous.

Since x_l^j and x_h^k are all complicated functions of $a_l, a_h, \lambda_l, \lambda_h$ and other parameters, it is difficult to predict the effects of these parameters on R&D intensities respectively. It is only easy to find that $\partial\mu_h/\partial\omega < 0$, but unclear what the sign of $\partial\iota_l/\partial\omega$ is. When the relative wage rises, the

¹⁵ The input quantity functions contain a specific term ϕ , which is the instantaneous expenditure E divided by price index for all final goods. Price index can be taken as given and we know $E = \omega L^N + L^S$. So still there is only one endogenous variable.

¹⁶ Helpman (1993) and Lai (1998) also give an endogenous innovation intensity. But they look at the horizontal differentiated products instead of vertical quality improvement.

imitative effort of the high-tech input will be dampened. The detailed analytical calculations are displayed in Appendix A.2.3.

Last, we define the aggregate rate of innovation as $\iota = \iota_l n_l^S + \iota_h n_h^S$. It is derived by using the intensity of innovation for each input times its relevant measure of Southern production targeted and then sum them up. Using similar method, we also define the aggregate rate of imitation as $\mu = \mu_l n_l^N + \mu_h n_h^N$. In steady state, all flows-in must equal all flows-out between countries, i.e. the aggregate rate of innovation is equivalent to the aggregate rate of imitation, or $\iota = \mu$. The shift of production to the South is at the same speed as it returns to the North during every instant of time. Consequently, the flow measure of inputs in the international world must satisfy

$$\mu_l n_l^N + \mu_h n_h^N = \iota_l n_l^S + \iota_h n_h^S \quad (2.43)$$

Another important point here is that both ι and μ characterize the frequency of the product cycle. According to GH (1991b), the average length of a product cycle is captured by $1/\mu$ (or $1/\iota$), which reveals the time period that a typical commodity is manufactured in the North before being copied by the South.

In general, our steady state equilibrium system consists of: market structure conditions (2.10), (2.11) and (2.43), labor market clearing conditions (2.23) and (2.24), and R&D intensity functions from (2.39) to (2.42). The final good assembler¹⁷ is likely to confront four pricing strategies in the upstream market since each input type has two scenarios. The steady-state constraints might be a slightly different from case to case, thereby affecting our equilibrium predictions. We now study these four cases one-by-one.

2.4.1.1 Case 1

In this case, we say that both inputs are in the situation of Scenario S ($j = S, k = S$). Hence, the price of both inputs is set at the level of the relative wage, i.e. $p_l^S = \omega, p_h^S = \omega$. No

¹⁷ We do not need to consider the steady-state condition of the final good assembler since there is no entry in the downstream market and all other firms in the economy are in steady-state.

manufacturing occurs in the North. $x_l^N = 0$, $x_h^N = 0$. We assume that the subjective discount factor ρ is 0 in the limit¹⁸ from now on, in order to prevent an economically-meaningless negative R&D intensity. As a result, the imitation intensities in the South are $\mu_l = 0$ and $\mu_h = 0$. It makes sense by the reason that all the plants in the North not engaging in manufacturing would like to make their efforts in research, hoping to regain their leadership; meanwhile, the Southern competitors who are controlling the whole upstream market have no incentive or room to further invest in imitative activities.

The final good assembler expects to receive an instantaneous profit of

$$\pi^{SS} = \phi(1 - \alpha) \left[\alpha \left(\frac{q_l}{\omega} \right)^z \left(\frac{q_h}{\omega} \right)^{1-z} \right]^{\frac{\alpha}{1-\alpha}} \quad (2.44)$$

However, equation (2.43) is simplified to be $0 = \iota_l n_l^S + \iota_h n_h^S$. Since no term on the right-hand-side is zero in this case, there comes a contradiction. Hence, Case 1 is unstable in the steady-state. We rule out this case.

2.4.1.2 Case 2

This case is exactly the opposite to Case 1. All production occurs in the North, i.e. $j = N, k = N$, and all R&D activities occurs in the South. The price is $p_l^N = \lambda_l$ for the low-tech input and $p_h^N = \lambda_h$ for the high-tech input, leading to an instantaneous profit π^{NN} of the final good assembler

$$\pi^{NN} = \phi(1 - \alpha) \left[\alpha \left(\frac{q_l}{\lambda_l} \right)^z \left(\frac{q_h}{\lambda_h} \right)^{1-z} \right]^{\frac{\alpha}{1-\alpha}} \quad (2.45)$$

The current producing firms have no incentive to further research. In that sense, $\iota_l = 0$ and $\iota_h = 0$. Resembling the previous case, there is a contradiction in equation (2.43), which becomes economically senseless $\mu_l n_l^N + \mu_h n_h^N = 0$. Thus, we rule out Case 2 as well.

¹⁸ Although a zero subjective discount factor leads to unbounded intertemporal utility, μ_l and μ_h are unreasonable to become some negative numbers. So we assume that ρ is such a small positive number approaching 0 that we can almost ignore its effect in the steady state. And even in robustness checks with $\rho > 0$, all comparative statics remain the same.

2.4.1.3 Case 3

Here, $j = S, k = N$. The low-tech input is produced in the South and the high-tech is produced in the North. Now innovation targets these Southern low-tech manufacturers and imitation targets these Northern high-tech manufacturers. The final good assembler faces the following price strategy: the price of the low-tech input $p_l^S = \omega$, and the price of the high-tech input $p_h^N = \lambda_h$. We restate the functions of its instantaneous profits as follows

$$\pi^{SN} = \phi(1 - \alpha) \left[\alpha \left(\frac{q_l}{\omega} \right)^z \left(\frac{q_h}{\lambda_h} \right)^{1-z} \right]^{\frac{\alpha}{1-\alpha}} \quad (2.46)$$

The currently producing plants in both countries no longer take part in research, which leads to $\mu_l = 0$ and $\iota_h = 0$ ¹⁹. The non-producing firms participate in R&D, hoping to acquire the market. That is, $\mu_h > 0$ and $\iota_l > 0$.

2.4.1.4 Case 4

In this case, the Southerners specialize in producing the high-tech input and the Northerners specialize in producing the low-tech input. The pricing strategy for inputs are $p_l^N = \lambda_l$ and $p_h^S = \omega$ ($j = N, k = S$) respectively. The price of the low-tech input is greater than the high-tech one. Symmetrically to Case 3, we respecify the final good assembler's profit function in equation (2.47).

$$\pi^{NS} = \phi(1 - \alpha) \left[\alpha \left(\frac{q_l}{\lambda_l} \right)^z \left(\frac{q_h}{\omega} \right)^{1-z} \right]^{\frac{\alpha}{1-\alpha}} \quad (2.47)$$

The rest firms in North invest in innovative R&D to study the high-tech inputs, and the rest firms in South engage in imitative R&D to learn the low-tech inputs. That is, $\iota_h > 0$ and $\mu_l > 0$. Also, $\iota_l = 0$ and $\mu_h = 0$.

¹⁹ In the limiting case of $\rho = 0$, $\mu_l = 0$ and $\iota_h = 0$ are derived by substituting (2.49) into (2.39) and (2.42) respectively.

2.4.2 Final Good Assembler's Decision

Proposition 1 If $\omega > [\frac{\lambda_h^{1-z}}{\lambda_l^z}]^{\frac{1}{1-2z}}$, the Southern low-tech plants and Northern high-tech plants occupy themselves with fabricating inputs, and the Southern high-tech plants and Northern low-tech plants devote to R&D activities. Hence, there is an endogenous specialization of input production coming out in the steady state equilibrium: different countries become specialize in producing one and only one of the intermediate inputs.

Proof: The final good assembler decides where to source the two types of inputs by comparing its expected instantaneous profits. Making a ratio of equation (2.46) and (2.47), we have

$$\frac{\pi^{SN}}{\pi^{NS}} = \frac{\phi(1-\alpha)[\alpha(\frac{q_l}{\omega})^z(\frac{q_h}{\lambda_h})^{1-z}]^{\frac{\alpha}{1-\alpha}}}{\phi(1-\alpha)[\alpha(\frac{q_l}{\lambda_l})^z(\frac{q_h}{\omega})^{1-z}]^{\frac{\alpha}{1-\alpha}}} = [(\frac{\lambda_l}{\omega})^z(\frac{\omega}{\lambda_h})^{1-z}]^{\frac{\alpha}{1-\alpha}} \quad (2.48)$$

If $\omega > [\frac{\lambda_h^{1-z}}{\lambda_l^z}]^{\frac{1}{1-2z}}$, we have $\frac{\pi^{SN}}{\pi^{NS}} > 1$. Hence, the instantaneous profits earned in Case 3 is higher than that in Case 4. The final good assembler decides to acquire the low-tech input from the Southern plants, and the high-tech input from the Northern plant.

From now on, our discussion will focus on Case 3. We will probe into more details of Case 4 in Appendix A.4. The comparative statistics results of these two cases are similar.

Intuitively, it is easy and cheap to reverse-engineer the imported low-tech input, so the South consistently produces it after successful imitation. On the other hand, since the high-tech input is difficult to copy, the North is able to keep its manufacturing technology secret to the South. Thus, the production of the high-tech input is persistently maintained in the advanced country. The product cycle is limited to the low-tech input.

The amounts of inputs purchased by the final good assembler are listed below. The quantities obtained from the high-tech plants in the South and low-tech plants in the North are zero.

$$x_h^S = x_l^N = 0 \quad (2.49)$$

And the quantity from the low-tech plant in the South is

$$x_l^S = \phi z \alpha^{\frac{1}{1-\alpha}} (\omega)^{-1} (\frac{q_l}{\omega})^z (\frac{q_h}{\lambda_h})^{(1-z)\frac{\alpha}{1-\alpha}} \quad (2.50)$$

Finally, the quantity from the high-tech plant in the North is

$$x_h^N = \phi(1-z)\alpha^{\frac{1}{1-\alpha}}(\lambda_h)^{-1}\left(\frac{q_l}{\omega}\right)^z\left(\frac{q_h}{\lambda_h}\right)^{(1-z)\frac{\alpha}{1-\alpha}} \quad (2.51)$$

Based on the input prices, the final good assembler decides to charge the consumers a price of

$$p^{SN} = \frac{1}{\alpha}\left(\frac{\omega}{q_l}\right)^z\left(\frac{\lambda_h}{q_h}\right)^{1-z} \quad (2.52)$$

earning it an instantaneous profit of

$$y^{SN} = \phi\left[\frac{1}{\alpha}\left(\frac{\omega}{q_l}\right)^z\left(\frac{\lambda_h}{q_h}\right)^{1-z}\right]^{-\frac{1}{1-\alpha}} \quad (2.53)$$

If there is an increase in the relative wage, it becomes more expensive for the final good assembler to purchase the low-tech input, since its price equals to the relative wage. In response, the final good assembler decides to source fewer inputs and reduces its output level. Despite that the final good price goes up a little, the negative change in total quantity dominates, and the final good assembler's profits shrink as a result²⁰.

Now the steady state conditions (2.10), (2.11), (2.43), (2.23) and (2.24) are simplified to be the following linear system of equations

$$\begin{cases} n_l^S + n_l^N = 1 \\ n_h^S + n_h^N = 1 \\ \mu_h n_h^N = \iota_l n_l^S \\ n_l^S \iota_l a_l + n_h^N x_h^N = L^N \\ n_h^N \mu_h (1 + \kappa) c_h + n_l^S x_l^S = L^S \end{cases} \quad (2.54)$$

From (2.54)²¹, we solve out two equations illustrating the measure of the Southern low-tech plants.

$$SS \text{ curve} : n_l^S = \frac{L^S c_l}{(\omega - 1)x_l^S c_h + x_l^S c_l} \quad (2.55)$$

²⁰ Assume $\frac{L^S}{L^N} > \frac{(1-\alpha-z\alpha)\omega}{z\alpha}$. See Appendix A.2.1 for more information.

²¹ See Appendix A.2.2.

$$NN \text{ curve} : n_l^S = \frac{L^N(1+\kappa)c_l}{(\omega-1)x_l^S(a_l + \frac{a_h\omega}{\lambda_h - \omega})} \quad (2.55')$$

Then we obtain the measure of the Northern high-tech plants using (2.55)

$$n_h^N = \frac{z(\omega-1)\lambda_h a_h L^S}{(1-z)x_l^S[(\omega-1)c_h + c_l](1+\kappa)(\lambda_h - \omega)} \quad (2.56)$$

the measure of the Southern high-tech plants

$$n_h^S = 1 - \frac{L^S c_l}{(\omega-1)x_l^S c_h + x_l^S c_l} \quad (2.57)$$

and the measure of the Northern low-tech plants

$$n_l^N = 1 - \frac{z(\omega-1)\lambda_h a_h L^S}{(1-z)x_l^S[(\omega-1)c_h + c_l](1+\kappa)(\lambda_h - \omega)} \quad (2.58)$$

By equating (2.55) and (2.55)', we can figure out the steady-state relative wage ω^* from the reduced-form quadratic function (2.59). Apparently, the solution to ω^* may be in terms of eight parameters: the Southern labor endowment (L^S), the Northern labor endowment (L^N), unit innovation costs (a_l and a_h), unit imitation costs (c_l and c_h), Southern IPRs protection level (κ) and quality increment of the high-tech input (λ_h).

$$\begin{aligned} & \omega^2[a_l L^S - L^N(1+\kappa)c_h - a_h L^S] \\ & + \omega[a_h L^S - (1+\kappa)c_l L^N - (1+\lambda_h)a_l L^S + (1+\lambda_h)(1+\kappa)c_h L^N] \\ & + [a_l L^S - (1+\kappa)c_h L^N + (1+\kappa)c_l L^N]\lambda_h = 0 \end{aligned} \quad (2.59)$$

Note that x_l^S and x_h^N are both cancelled out during calculation, reflecting that the changes in input quantities have no effect on the reduced-form of the relative wage²². Calibration in the next section will show that only one root for this quadratic function is economically meaningful²³, which is denoted as ω^* . It is unresponsive to quality increment of the low-tech input (λ_l), quality jumps (η and θ) and share of the low-tech input (z). The significance of quality increment of the high-tech input (λ_h) stems from $p_h^N = \lambda_h$. The analytical solutions to the endogenous variables

²² The analytical solution to ω^* is shown in Appendix A.2.4.

²³ The simulated value for ω in Appendix A.3 also demonstrates this point.

of interest are so complex that we leave all detailed comparative static analysis to the calibration part.

After knowing the relative wage, the total world expenditure is given by

$$E = L^S + \omega^* L^N + \phi(1 - \alpha) \left[\alpha \left(\frac{\lambda_l^\eta}{\omega} \right)^z \left(\frac{\lambda_h^\theta}{\lambda_h} \right)^{1-z} \right]^{\frac{\alpha}{1-\alpha}} \quad (2.60)$$

Finally, by incorporating (2.43) and the function of SS curve or NN curve, we get the expression for the aggregate technological flows around the world.

$$\iota = \mu = \frac{L^N}{a_l + \frac{a_h \omega^*}{\lambda_h - \omega^*}} = \frac{(\omega - 1)L^S}{(1 + \kappa)[(\omega - 1)c_h + c_l]} \quad (2.61)$$

Especially, $\partial \mu_h / \partial \omega < 0$ and the sign of $\partial \iota_l / \partial \omega^{24}$ is ambiguous. A higher price of the low-tech input discourages the incentive to imitate the high-tech input.

2.5 Calibration

In this section, we carry out numerical simulations based on Case 3. Table B.1 shows the baseline values of parameters. They mostly come from previous literature and is discussed in detail in Appendix A.3.

We calibrate the relationship between the measure of Southern low-tech plants and the relative wage at first. Specifically, there are two opposing effects in action with a rising relative wage on n_l^S . For one thing, the Southern low-tech plants would like to expand their scale for the sake of a higher price of their product, since now $p_l^S = \omega$. For another, there induces a reduction in the demand of the low-tech input by the final good assembler, which has a negative impact on n_l^S . In equation (2.55), the positive effect dominates and hence $\partial n_l^S / \partial \omega > 0$. We see that an upward-sloping SS curve is sketched out in Figure B.2. Meanwhile, equation (2.55)' tells us that the measure of Southern low-tech plants might also decrease with the relative wage since $\partial n_l^S / \partial \omega < 0$ over there. We then depict NN curve in accordance with this function. By exhibiting in Figure

²⁴ The imitation intensity for the Southern high-tech plants is $\mu_h = \frac{(\lambda_h - \omega)x_h^N}{a_h \omega}$ and the innovation intensity for the Northern low-tech plants is $\iota_l = \frac{(\omega - 1)x_l^S}{(1 + \kappa)c_l}$.

B.2, these two monotonic curves intersect only once and hence there exists a unique solution to the relative wage graphically. In fact, $\omega^* = 1.2839$ as simulated²⁵.

Now starting from the calibrated value of the relative wage, we investigate firm production choices (2.49) to (2.53), firm measures (2.55) to (2.58) and the aggregate rate of technological flows (2.61), and then examine the determinants of these key variables. Comparative statics are performed with respect to changes in quality ladder parameters, the share of the low-tech input in final good production, the strengthening level of IPRs in the South, the relative sizes of two regions, and changes in unit R&D costs.

2.5.1 Changes in Quality Ladder Parameters

With a higher quality level (i.e. any increase in λ_l , λ_h , η or θ), the yield of the final good increases sharply with the same amount of inputs used. Despite the price of the final good declines, the productive activities become more profitable. Hence, the final good assembler would like to expand its output level and the entire upstream market benefits from this decision. It is interesting that the production volumes and instantaneous profits of Southern low-tech plants and Northern high-tech plants move at the same speed, unless there is a change in the quality increment of the high-tech input. In addition, the plants engaging in R&D activities get inspired as well, since their profits are expected to enlarge. There is a positive impact on innovation and imitation intensities (both ν_l and μ_h). As a result of the increased demand for workforce, plants compete fiercely in the labor market. The manufacturing plants are to some extent crowded out by the researching plants. The scale of the former plants (n_l^S , n_h^N) lessens but that of the latter ones (n_2) swells.

The opposing effects of a rising R&D intensity and a reducing measure of targeted plants are offset in most situations so that the total number of labor allocated to each sector is unchanged in both countries. Basically, the quality ladder parameters do not work on the relative wage or total world expenditure except λ_h . Neither is there any significant influence on the aggregate rate of

²⁵ The other value for ω is -1.6256. For robustness, we have simulated several times of different parameter values, and always find that there exists one negative root of equation (2.59).

international technological flows ($\iota = \mu$).

Figure B.3 illustrates the relationship between the ratio of quality increment λ_R and endogenous R&D investment. We see that the curves representing the R&D intensities climb up quickly. When λ_R improves by only 2 times (its value goes from 2 to 4), the multiplier effect makes both innovation and imitation intensities to amplify from as low as 0 to higher than 15. The augment of labor force used in R&D works causes a shortage in the factor market, thereby pushing up the wage rate in both regions. Furthermore, the measure of manufacturing plants declines rapidly from 1 to 0 but the research plants thrive, as λ_R grows from 2 to 4 (see Figure B.4). In particular, the measure of the Southern low-tech plants diminishes more quickly than that of the Northern high-tech plants. Thus, the shortage in the Northern labor market is more severe and thereby raises the relative wage. This process partially explains how advanced technology restricted to the rich world helps maintain the global wage gap. Eventually, a higher λ_R boosts international technological flows and shortens the average length of the product cycle. The speed of global technology diffusion is accelerated.

2.5.2 Changes in the Share of the Low-tech Input

By enhancing the share of the low-tech input (z), the final good assembler is hurt (see Table B.4). In response, it lowers the output level and reduces the quantities of inputs acquired. Specifically, the quantity of the high-tech input becomes a negative function of z , but the quantity of the low-tech input increases at the beginning and declines after $z = 0.1$, as reflected in Figure B.5.

This process is different from Antras (2005). On condition that it is free to select the share of the low-tech input, the final good assembler in Antras (2005) is sure to choose the whole final good made from the high-tech input and does not source any low-tech input, i.e. $z = 1$. However, in our model, the requesting quantity of both inputs approaches zero before $z = 0.5$, with the ratio of input quantity x_R continuously ascends. The Northern high-tech plants lose more than the Southern low-tech plants. Thus, the high-tech manufacturers will be the first to quit the market

as z rises.

It is indicated that an increase in z always discourages Southern high-tech researchers (see Figure B.6) and encourages Northern high-tech manufacturers (see Figure B.7). And the innovation intensity of the low-tech input, which targets the Southern manufacturing plants, reveals an inverse-U shape. On the other hand, there is a U-shape relation between the share of the low-tech input and the number of Southern low-tech manufacturers. When this share is extremely low (smaller than 0.1), the measure of Southern low-tech plants reduces from 1 to less than 0.1. Afterwards, this firm measure picks up fast. Before z increases to 0.5, it almost goes back to 1.

Changes in firm measures and R&D intensities exactly cancel each other. As well as most quality ladder parameters, the share of the low-tech input (z) does not affect the relative wage or total world expenditure since it is unrelated to the distribution of the labor market. The aggregate R&D investment (i.e. ι , μ) is a flat dashed line in Figure B.6 and the average length of product cycle is also unrelated to z .

2.5.3 Changes in Southern IPRs Policy

The intermediate influence of tougher IPRs policy in the South is to retard the imitation behavior. The Southern imitators have to hire more workers in order to continue conducting the same intensity of their research. Their enthusiasm gets harmed, and hence both ι_l and μ_h deteriorate. This finding is consistent with the literature. As the innovation dimension is vertical, a strengthening of Southern IPRs leads to less innovation (e.g. Glass and Saggi, 2002)²⁶. The researching plants become downsized (i.e. n_2 declines) in response; on the contrary, there is a scale-up of plants taking part in manufacturing. (Figure B.8 and Figure B.9)

The tension in the labor market pushes up the relative wage. And this increase in the Northern labor cost pulls down global production level and obstructs the willingness-to-produce of the final good assembler. Consequently, the output level in both upstream and downstream

²⁶ If the inventive change is horizontal, a strengthening of Southern IPRs leads to more innovation (e.g. Helpman, 1993; Lai, 1998).

markets falls. Compared with the Northern high-tech plants, the Southern low-tech plants suffer less since their relatively-lower production cost smooths their potential decline in profits.

In all, the strengthening IPRs protection in the South prolongs the Northern inventors' monopoly period by slowing down the international technological flows. Hence, the average length of the product cycle is extended.

2.5.4 Changes in Labor Endowment

Now we consider the effect of labor endowment on the steady state. First of all, we pay attention to the relative wage and aggregate expenditure. Turn back to Figure B.2. From the original steady-state, if we double the Southern labor endowment L^S , SS curve shifts up to SS_1 and NN curve shifts down to NN_1 . The new relative wage in equilibrium is lower than before. To the contrary, if we double the Northern labor endowment L^N , the new SS_2 curve locates below SS and NN_2 is a little high up the NN curve. In this case, we obtain a higher relative wage. To sum up, the impact of labor endowment in different countries is distinct (see Figure B.10).

There is an enlargement in total world expenditure E by reason of a larger Northern labor force. The influence of Southern labor endowment is a little ambiguous. On one hand, the increase in Southern labor endowment brings the relative wage down, thereby reducing the total factor income in the North. On the other hand, it generates a rise in the Southern aggregate earnings when the number of workers is higher over there. These two effects work together and make the world total expenditure to demonstrate a U-shape relationship in Figure B.11.

With more workers in the South, it is much easier for plants to fill in their jobs and hence local labor-force becomes relatively cheaper. The final good assembler has more incentive to exploit this low cost and provide more products to the consumers. Then the manufacturing plants in both regions receive bigger orders from the downstream assembler. However, since the relative wage has been brought down, the Southern low-tech plants need to set a lower price in accordance with the Bertrand competition. The increase of their profits is smaller than that of the Northern high-tech plants.

Southern workers accumulate to the researching sector, although the manufacturing sector recruits more workers as well. As shown in the left panel of Figure B.12, imitation intensity rises quickly. The Northern innovators are encouraged but the Northern manufacturers are squeezed out. n_l^S increases and n_h^N decreases (see left panel of Figure B.13). Totally, the latter influence overwhelms the former and the aggregate measure of manufacturing plants contracts. In contrast, the researching plants boom. Technological flows around the world speed up.

Differently, the augment in the Northern population has an ambiguous effect on the profits of the final good assembler. We have already known that the relative wage rises as a result of this change. The Southern low-tech plants benefit and the Northern high-tech plants suffer from this large in L^N . It is obviously less profitable for the final good assembler at the first glance, since it needs to pay more to the upstream suppliers. However, when the Northern population grows so large that consumers have a lot of earnings in hand to spend, the final good assembler's profits pick up again. Thus, these two opposite effects mutually interact and result in a U-shape curve of π^{SN} .

The expanded Northern labor is allocated to both manufacturing and R&D sectors. There is an amplification in the intensity of innovating the low-tech input (see the right panel of Figure B.12). Meanwhile, Southern workers are hired away from the low-tech producing plants to the high-tech imitative ones, but this phenomenon is still unable to prevent a worsening trend in the imitation intensity. The surge in the measure of Northern high-tech plants offsets the drop in the measure of Southern low-tech plants; thus, the aggregate measure of plants engaging in manufacturing keeps an escalating trend (see the right panel of Figure B.13). Similarly, the aggregate technological flows also develop in this event.

2.5.5 Changes in Unit R&D Costs

A potential reduction of unit R&D costs (i.e. a_l , a_h , c_l , c_h) might stem from a positive technology shock which improves total factor productivity, or a decrease in government tax on research activities, or an increase in government subsidy. These possible shocks are taken as given

by the plants²⁷.

Figure B.14 reveals different levels of variation in the relative wage if there is an equal cut of different unit R&D costs respectively. The solid line displays the benchmark situation. Generally, the relative wage falls off if the shock happens to imitation costs, but moves up if the shock occurs to innovation costs. It is intuitive to understand this because that the innovation takes place in the North and the imitation takes place in the South. The starred line locates highest and the triangle-shaped line locates lowest. It means that the relative wage goes up most if the reduction happens to the high-tech innovation, and it shifts down most if the reduction happens to the low-tech imitation.

When the cost reductions are in the Northern innovation sector, we know that $\partial\pi^{SN}/\partial a_l > 0$ and $\partial\pi^{SN}/\partial a_h > 0$ (Table B.7). The final good assembler's profits get impaired because of a consequent rise in the relative wage; thus, it supplies less output to the market. As a_l falls, the innovation intensity of the low-tech input ascends gradually and the imitation intensity of the high-tech input rapidly descends (top left panel of Figure B.15). The measure of manufacturing plants (both n_l^S and n_h^N) mounts up and the aggregate measure of plants engaging in R&D (n_2) diminishes (top left panel of Figure B.16). On the other hand, the imitation intensity of the low-tech input climbs up slightly and the innovation intensity of the high-tech input picks up sharply from less than 5 to more than 35, when a_h drops from 10 to 0. Therefore, there is a downward trend for n_h^N and an upward trend for n_l^S . n_2 almost has no change until a_h approaches 1. (see top right panels of Figure B.15 and Figure B.16).

When the cost reductions occur in the Southern imitation sector, the influence on the profits are opposite to the previous situation: $\partial\pi^{SN}/\partial c_l < 0$ and $\partial\pi^{SN}/\partial c_h < 0$. All firms' profits are promoted consequently. As c_l falls, labor is moved from the manufacturing sector to the researching sector, bringing about an increase in R&D intensities (ι_l and μ_h) and crowding out manufacturing plants. Nevertheless, a negative movement in c_h issues in slightly distinguished results. In the South, workers quit their jobs from the imitation sector in order to join in the manufacturing

²⁷ We suppose that R&D costs are suddenly cut down by 40 percent.

sector; in the North, workers shift in the opposite direction. Hence, the lower is the imitation cost of the high-tech input, the more is the corresponding intensity, and the innovation intensity of the low-tech input drops consistently after a short upturn. n_l^S increases, n_h^N decreases and n_2 represents an inverse-U shape. (see the bottom panel of Figure B.15 and Figure B.16)

In all changes mentioned above, the offsetting trends of R&D intensity and firm measure almost level out. Thus, the aggregate technological flows are sketched as an approximately horizontal line (see Figure B.15). Actually, it downgrades in some small way as any unit cost experiences an expansion.

2.6 Conclusion

In this chapter, we try to incorporate a simplified Grossman-Helpman vertically-differentiated product cycle model (Grossman and Helpman, 1991b) with Antras' (2005) production function with every final good made from two intermediate inputs. A final good assembler sources the two inputs world-widely based on quality-adjusted prices and fabricates them without additional costs. The high-tech input is intrinsically of better quality and hence requires more R&D expenses than the low-tech input.

There are two principal predictions in the steady state: first, there is an endogenous specialized pattern for inputs with different technology levels; second, only the low-tech input has the product cycle, but the high-tech one does not. More intuitions will be considered later.

Chapter 3

Outsourcing Multiple Inputs: Evidence

3.1 Introduction

The idea of product cycle has been proposed by Vernon (1966)[86] a few decades ago. It is very intuitive to think that commodities exhibit a life cycle: at first, the production locates in the developed country where it is invented; later, when technology in developing areas becomes mature, manufacturing will transfer there to pursue a lower cost. Most works on this topic is theoretical¹. Only a small fraction of studies lend empirical support to it (e.g. Feenstra and Rose, 2000[18]; Xiang, 2007[92]).

It is worth noting that previous literature focuses on the product cycle of final goods, and barely pays attention to the dynamic trade pattern in intermediate inputs, with the exception of Antras (2005)[2]. But Antras (2005) realizes its the product cycle via incomplete contract, rather than traditional research and development (R&D). In order to fill in the gap, I incorporate Antras' (2005) production structure into Grossman and Helpman's (1991)[32] quality ladder framework, and research on the effect of global production sharing on product cycle. There are two types of inputs produced in the upstream market, a high-tech one and a low-tech one. They are distinct in their R&D requirements, and climb up their own quality ladders individually. Innovation only takes place in the Northern manufacturing plants, and imitation only happens in the Southern competitors. Meanwhile, an assembler in the downstream market sources both inputs from the global market,

¹ There are two dimensions of theory models. One discusses horizontal variety expansion and the other discusses vertical quality increment. The later is also called as the "quality ladder model".

searching for the lowest quality-adjusted prices, and then sells the final good to consumers. The steady-state equilibrium shows that the Southern plants will specialize in manufacturing the low-tech input and the Northern plants will specialize in the high-tech input. In other words, only the low-tech input has a product cycle to the South.

The primary goal of this chapter is to provide evidence for the core predictions of my theoretical model. Without loss of generality, I select only one chapter from the U.S. imports data to conduct empirical estimations. This particular chapter, the Harmonized Tariff Schedule (HS) 85 category², contains a variety of products related to electrical machinery, sound recorders and television, and is intensive in parts and components down to 10-digit level. This is the finest disaggregated comprehensive dataset publicly available, covering years from 1989 to 2006. By grouping the OECD members as the North, I am interested in the time-series impact of this membership on the trade flows with respect to different technology levels of intermediate goods.

There are two major problems in practice. First of all, it is difficult to identify the product cycle, while taking both input quality and exporter's income level into account. I examine the trade pattern of the high-/low-tech inputs separately and then make a comparison between the estimated results. This methodology helps to eliminate other influencing macroeconomic factors, such as national growth and consumer preference (Xiang, 2007[92]). Then I realize capturing the average changing impact throughout the years, by adding an interaction term between the OECD indicator and time. For sensitivity, I further divide the sample period into six 3-year bins and measure the effect in each slot of time.

The second big issue is how to distinguish the high-tech and low-tech inputs. Referring to the literature, unit value (or average price) is a common indicator of product quality. In order to keep the classification of an input consistent across all countries and years, I take the following steps: by pooling over all observations of any HS 10-digit product, I calculate out the average unit value and compare it with other products within the same HS 4-digit industry. If this specific

² Products in this chapter are summarized as “electrical machinery and equipment and parts thereof sound recorders and reproducer, television image and sound recorders and reproducers, and parts and accessories of such articles”.

average is smaller (or equal to) the median value of the industry, I classify it to be a low-tech input. Otherwise, it is a high-tech input. By this method, the classification should be consistent all the time. In this sense, I almost divide my sample into two subgroups with equal size.

Since the development of intra-industry trade (IIT) is very prosperous these days, it is almost impossible to find perfect specialization pattern in reality, which is claimed in my theoretical framework. Still, I figure out that the OECD membership promotes trade in the high-tech inputs more than the low-tech ones. In some cases, it even obstructs trade in the latter subgroup. With the passage of time, the hinder effect on the low-tech inputs becomes more severe. These findings imply a higher possibility for the product cycle to lie in the low-tech inputs, because these inputs are more likely to be imported from the non-OECD countries. Hence, to some extent, my theoretical prediction is justified. Besides, it is very robust in a variety of alternative econometric specifications, including Heckman selection correction.

The remainder of this chapter is organized as follows. Section 3.2 introduces a brief outline of previous literature on this topic. Section 3.3 summarizes my theoretical chapter and derives the econometric hypotheses I would like to test. Section 3.4 discusses data source and takes over the definition of the low/high-tech inputs in detail. Section 3.5 provides some interesting descriptive statistics and Section 3.6 presents the estimated results. Finally, Section 3.7 concludes and discusses future work.

3.2 Literature

Compared with the large amount of theories on product cycle, the progress on related empirical work is unbelievably slow. As mentioned before, one thorny point is how to tackle the dynamic pattern in international trade. A survey written by Deardorff (1984)[13] quotes some early attempts, for example, Hirsch (1965)[42], Gruber et al. (1967)[35], Wells (1969)[89], and Parry (1975)[71]. Although these efforts are lack of direct evidence, they confirm the feasibility of testing product cycle with trade data. Subsequently, Cantwell (1995)[12] raises two hypothesis

related to patents³, but only provides some descriptive statistics.

Up till now, there are four empirical methods successfully seizing the existence of product cycle. The first technique is put forward by Gagnon and Rose (1995)[21]. They claim that if a certain commodity's trade balance switches from a net exporter to a net importer, it can be thought as a product cycle good. Zhu (2005)[95] also makes use of this definition to check whether product cycle trade is a tangible reason for skill upgrading. However, by Gagnon and Rose's (1995) estimation, the trade balances are highly persistent over time, which is against the product cycle.

Feenstra and Rose (2000)[18] interpret the matter of product cycle from another point of view, which accords with its intrinsic intuition as well. They argue that commodities start exporting to the U.S. in an order of complexity. That is to say, the later a good appears in the global market, the less sophisticated it is. When this logic is applied to rank countries, the correlation becomes opposite. The earlier a country begins to export, the more advanced it is. Feenstra and Rose (2000)[18] affirm the existence of product cycle and also reveal consistence between the order in the data and macroeconomic phenomenon such as technological prowess and national growth. Their method is undoubtedly tractable and justifiable; yet, dealing with missing entries⁴, even at the aggregation level of SITC⁵ 5-digit, is a heavy workload. Moreover, Besedes and Prusa (2003)[7] take another method by ranking countries on a basis of their survival experience. Their ranking is strongly correlated with Feenstra and Rose's (2000)[18] calculation, and imply a short duration of product cycle followers, with a median of two to four years.

Based on a HS 10-digit level dataset, Schott (2002)[74] examines two dimensions of product cycle in one paper. On one side, the degree of intra-industry trade is considered as a striking signal of production shifting, which he calls "move out". The IIT extent with high-wage countries is significantly higher than with low-wage countries, in line with the product cycle theory. On the other side, in spite of the shrink in U.S. exports as international competition rises, the unit values

³ The first hypothesis is that innovation most takes places in the "home country of the parent company". The second hypothesis is "international investment is led by technological leaders, as a means by which they increase their share of world markets and world production".

⁴ "Missing" means that a given commodity is never exported by a given country in the sample. If each country had exported each commodity at least once during the sample period

⁵ SITC is short for Standard International Trade Classification.

of U.S. exports are still higher than those from low-wage countries. Schott (2002)[74] names this phenomenon as “move up”.

The most recent contribution to the literature is Xiang (2007)[92]. In light with product cycle, he bears out that the ratio of relatively new product exports displays a U-shape over time, where the new products are those recently produced in the U.S. between 1972 and 1987. The time lag between the U-shape’s bottom and the initial year is the length of product cycle, which is 15 years on average as estimated. One big merit of this chapter is that other possible influences on bilateral trade have been ruled out; therefore, this method are applicable and the results are convincing.

In a nutshell, the extant research is scarce but promising. From my knowledge, no one has specifically examined the product cycle of intermediate trade yet. Also, I generate another simple means of identification specification, in order to quality and income

3.3 Strategic Identification

This chapter is an empirical test of my theoretical work on international technology transfer with quality ladders as a source of endogenous growth. I try to incorporate a simplified Grossman-Helpman vertically-differentiated product cycle model (1991[32]) with Antras’ (2005[2]) production function with every final good made from two intermediate inputs. The high-tech input is intrinsically of better quality and hence requires more R&D expenses than the low-tech input. A final good assembler sources the two inputs world-widely based on quality-adjusted prices and fabricates them without additional costs.

There are two principal predictions in the steady state: first, there is an endogenous specialized pattern for inputs with different technology levels; second, only the low-tech input has the product cycle, but the high-tech one does not. Specifically, the Southern manufacturers choose to produce the low-tech input and export it back to the North after successful imitation. On the other hand, the manufacturing of the high-tech input remains in the Northern countries.

To examine with realistic data, the above predictions can be translated into the following

relationship: the U.S. inclines to import the high-tech inputs from the Northern countries and the low-tech inputs from the Southern countries. Furthermore, this correlation will be strengthened over time. Without loss of generality, I group the OECD member countries as the North, and the rest countries as the South⁶. The actual customs values vary widely from product to product. For instance, a 10-digit code, HS 8516404000 (electronic flatirons, nesoi), has the lowest customs value in my imports sample, which is \$250 in total. But another product, HS 8525209070 (cellular radiotelephones for pcrs, 1kg), has a customs value as much as \$1.09e+10, since its aggregate trading quantity is over 102 million units. In order to make it comparable among thousands of products, I create a key variable “ $share_{ijt}$ ”. It is calculated by country j ’s export volume to the U.S. over that from all countries’ for a particular input i in year t and then multiplied by 100 (shown in equation (3.1)). Hence, “ $share_{ijt}$ ” is presented in percentage and has a range from 0 to 100.

$$share_{ijt} = \frac{EX_{ijt}}{\sum_j EX_{ijt}} \times 100 \quad (3.1)$$

where EX_{ijt} is the customs value of input i from country j in year t ⁷.

Now I set up the baseline reduced-form function in equation (3.2). Regressions are run for the high-tech and low-tech inputs separately.

$$share_{ijt} = \alpha_I + \beta_j + \theta \cdot OECD_{jt} + \theta_0 \cdot OECD_{jt} \cdot t + \delta \cdot t + X'_{jt} \cdot \phi + \epsilon_{ijt} \quad (3.2)$$

The dummy variable $OECD_{jt}$ equals to 1 if country j is an OECD member country in year t . α_I and β_j stand for industry- and country-specific fixed effects respectively. I do not contain any year fixed effects here, since there is already a variable t indicating time in the specification. X_{jt} is a list of control variables affecting bilateral trade from the literature, including market size (measured by population), contiguity, common language, colonial history, trade costs (measure by simple distance between most populated cities) and etc. Correspondingly, ϕ is a vector of parameters to be estimated for these controls. ϵ_{ijt} is an error term. Note that equation (3.2) is quite similar to

⁶ Other measures proxy for the North and South, such as GDP per capital, will also be tested in robustness checks.

⁷ Usually, I use “customs value, imports for consumption”. For where this value is missing, I substitute it with “customs value, general imports” since it is not zero. This substitution makes 2497 changes in my sample.

the general gravity equation for bilateral trade, but I do not take account of the importer fixed effects because the observations share one common importer in my sample - the United States.

I am interested in the sign of the coefficient on the key explanatory variable $OECD_{jt}$, i.e. θ . To distinguish the estimators of different subgroups, a superscript H is used for the high-tech inputs and L is used for the low-tech inputs. As discussed above, the ideal case is that for the high-tech inputs, there is a positive correlation between a country's share in U.S. imports and its OECD membership; that is, $\theta^H > 0$. On the contrary, for those low-tech inputs, we would expect the relationship to be $\theta^L < 0$, since the Southern countries specialize in producing them. The exports share from the non-OECDs is likely to be larger than that from the OECDs in this case. However, another possibility is that the estimated coefficients are both positive, but with $\theta^H > \theta^L > 0$. The correlation between $OECD$ and $share$ is more closely linked for the high-tech inputs. It indicates that the high-tech input is more likely to be imported from a developed country and this relationship is weaker for a low-tech input.

In addition, I also pay attention to the coefficient in front of the interaction term $OECD_{jt} \cdot t$, i.e. θ_0 . This variable investigates the shift of low-tech input production from the North to the South over time. Year after year, the negative impact for the low-tech inputs will be reinforced, as presented by $\theta_0^L < 0$. However, the impact for the high-tech inputs does not change much. I expect θ_0^H to be statistically insignificant.

For robustness, I exchange the single interaction term to a product vector of $OECD_{jt}$ and time-bin indicators $year_T$, where $year_T$ is a vector of three-year-block dummies. The total number of T is $T = t/3$ rounding up to the nearest integer. The corrected estimation function becomes

$$share_{ijt} = \alpha_I + \beta_j + \theta \cdot OECD_{jt} + \Theta \cdot OECD_{jt} \cdot year_T + X'_{jt} \cdot \phi + \epsilon_{ijt} \quad (3.3)$$

The sign of θ has the same prediction as before. The coefficient vector on the interaction terms can be written as $\Theta = [\theta_1 \ \theta_2 \ \theta_3 \ \dots \ \theta_T]$. I would expect that $\theta_1^H = \theta_2^H = \theta_3^H = \dots = \theta_T^H$ for the high-tech inputs. The association between $share$ and $OECD$ remains statistically stable over time. On the other hand, for the low-tech inputs, $0 > \theta_1^L > \theta_2^L > \theta_3^L > \dots > \theta_T^L$ if estimated coefficients

are negative, or $\theta_1^L > \theta_2^L > \theta_3^L > \dots > \theta_T^L > 0$ if coefficients are positive. With the passage of time, the production of the low-tech inputs gradually moves to the developing countries.

However, there might be a selection bias for the fixed effects identifications (3.2) and (3.3). The original dataset I have contains all trade activities take place in reality. Hallak (2006)[39] points out that omitting zero-valued observations may cause a bias in the coefficient magnitude, although it usually has no effect on the sign. A number of papers (e.g. Helpman, Melitz, and Rubinstein, 2008[72]; Johnson, 2008[50]; Baldwin, Harrigan, 2011[3]) take advantage of Heckman 2-stage statistical approach to correct this problem. Following the previous work, I also use a binary outcome model at the first step and then use the predicted probability as an additional explanatory variable at the second step.

By supposing each input potentially importing from every country each year, I am now able to expand the dataset into a balanced one. $share_{ijt} = 0$ for all trade activities nonexistent in reality. The latent-variable $notzero_{ijt} = 1$ if country j does export input i to the U.S. in year t , otherwise it equals to 0. The incidence of positive import share is a function of exporter characteristics and the input's intrinsic property.

$$Prob(notzero_{ijt} = 1 | OECD_{jt}, X'_{jt}) = F(\alpha_I + \beta_j + \gamma_t + \theta \cdot OECD_{jt} + \theta_0 \cdot OECD_{jt} \cdot t + \delta \cdot t + X'_{jt} \cdot \phi) \quad (3.4)$$

F is a standard normal distribution function of the independent variables. Therefore, I employ a probit model for the first stage.

On the second stage, I drop the instrumented fixed effects, keep other independent variables used in equation (3.4), and add the estimated probabilities. In particular, the individual probability is calculated by the product of ρ , σ_μ and λ , where ρ is the correlation between unobserved determinants of propensity to import and import share, σ_μ is the standard deviation of error here⁸

μ and λ is the evaluated inverse Mills ratio from equation (3.4).

$$E(\text{share}_{ijt} | \text{OECD}_{jt}, t, X'_{jt}, \text{notzero}_{ijt} = 1) = \theta \cdot \text{OECD}_{jt} + \theta_0 \cdot \text{OECD}_{jt} \cdot t + \delta \cdot t + X'_{jt} \cdot \phi + \rho \sigma_{\mu} \lambda (\alpha_I + \beta_j + \gamma_t + \theta \cdot \text{OECD}_{jt} + \theta_0 \cdot \text{OECD}_{jt} \cdot t + \delta \cdot t + X'_{jt} \cdot \phi) \quad (3.5)$$

I would expect that θ has the same sign as the previous OLS regressions predict.

3.4 Data

3.4.1 Data Source

The fundamental dataset I rely on is unbalanced U.S. import panel in years 1989-2006 from the NBER⁹. It is the most disaggregated data publicly available, down to 10-digit Harmonized System (HS10) level. I denote a HS10 code as a product and a HS4 code as an industry. My analysis only focuses on a small portion of the U.S. imports, the HS 85 chapter. Products in this chapter are summarized as “electrical machinery and equipment and parts thereof sound recorders and reproducer, television image and sound recorders and reproducers, and parts and accessories of such articles”¹⁰. Since I would like to test the product cycle of intermediate inputs, my sample restricts to all products with a word “parts” in their description¹¹. Later I will expand the basic dataset to a balanced panel including all potential trade flows.

GDP per capita information is from the World Bank indicators¹², population sizes are from the Penn World Table 7.0, and the other country characteristics (distance, common language, contiguity and colonial history) are from the CEPii website. The list of the OECD countries comes from its official website. Specifically, a country is thought as an OECD member since the year it joined this group. For example, Hungary started to be a part of the OECD on May 7th, 1996. So it is treated as an OECD member from 1996.

⁸ Specifically, μ is the standard error of the conditional expectation of *share* given various independent variables. $E(\text{share}_{ijt} | \text{OECD}_{jt}, t, X'_{jt}, \text{notzero}_{ijt} = 1) = \theta \cdot \text{OECD}_{jt} + \theta_0 \cdot \text{OECD}_{jt} \cdot t + \delta \cdot t + X'_{jt} \cdot \phi + E(\mu | \alpha_I, \beta_j, \gamma_t, \text{OECD}_{jt}, X'_{jt}, \text{notzero}_{ijt} = 1)$.

⁹ Data is available on www.internationaldata.com.

¹⁰ <http://www.usitc.gov/tata/hts/bychapter/index.htm>

¹¹ List of HS4 codes included is in Table B.9.

¹² Instead, Taiwan data comes from <http://www.economywatch.com/economic-statistics/Taiwan/>.

Apart from the standard gravity controls, I consider three extra factors that might affect the import decision from a certain country: the stock of foreign direct investment (FDI), intra-industry trade (IIT) index, and tariff ratio. First of all, FDI is discovered to play an active role in bilateral trade (e.g. Goldberg and Klein, 1997). For example, over 40% of U.S. imports in 1992 consists of intra-firm trade between multinational enterprise affiliates (Feenstra, 2004[16], page 372). However, the Bureau of Economic Analysis provides open access to limited information about U.S. direct investment abroad, at a total of only 59 countries. So I choose the annual records of inward FDI stock from all countries instead, which is available on the UNCTAD website.

Second, Schott (2002)[74] claims that a remarkable signal of product cycle is that the similarity of U.S. product portfolio with a high wage country is higher than that with a low wage country. This feature is discovered to be the strongest in machinery industries across manufacturing department. That is why I need to take IIT index, the measure of product overlapping, as a control. By compiling both U.S. imports (IM_{It}) and exports (EX) values from the NBER dataset, I derive IIT index for industry I in year t . The computation method is dependent on Schott (2002)[74].

$$IIT_{It} = 1 - \frac{|EX_{It} - IM_{It}|}{EX_{It} + IM_{It}} \quad (3.6)$$

Finally, tariff on imported goods is one of the recognized major barriers to trade. When an input crosses a border, a tariff is incurred, and hence the production cost of the final good increases. Hence, the level of tariff ratio seems to be intuitively related to the import share. The tariff dataset of the U.S. imports is downloaded from Romalis' website¹³. It provides various information for each HS 8-digit code without country of origin from 1989 to 2001. I pick up the estimated ad valorem equivalent of complete MFN rate to proxy the total tariff rates and use the same rate for HS10 products within the same HS8 category.

3.4.2 Definition of Low-/High-tech Inputs

The lack of R&D data at HS10 makes it difficult to distinguish the quality of inputs by their actual technology capacities. Here, I give a potential definition to distinguish the high-tech and

¹³ <http://faculty.chicagobooth.edu/john.romalis/index.htm>

low-tech inputs. It is inspired from the vertical differentiation literature.

Unit value is a common proxy for quality in empirical tests of vertical differentiated products. It is derived by computing total export values over total quantities for product i from country j in year t . In their seminal paper, Greenaway, Hine and Milner (1995)[30] state that, “The rationale for using unit values is that, assuming perfect information, a variety sold at a higher price must be of higher quality than a variety sold more cheaply.” However, it is not an ideal index. Differences in unit values may also reflect the dispersion of product composition within the category besides price variations (Hallak, 2006[39]). The best way to reduce the composition problem is to use unit values at the most detailed level of aggregation, which is HS 10-digit level.

The unit values¹⁴ vary considerably in three dimensions: product, country and time. Figure B.17 is an illustration of the variation across countries and years. I only consider one type of input in this example: HS 8504210020 (“transformers, nesoi, unrated”). In total, there are 83 countries exporting this product to the U.S., and the unit value ranges from 0.05 to 15070, with a mean of 115. I randomly pick up two OECD countries (Canada and Japan) and two non-OECD countries (Thailand and Dominican Republic) from the group. It is obvious that the unit value curve of Canada lies above that of all other countries. Although owning an OECD membership, the unit value of Japan is slightly greater than those non-OECD regions, and gets exceeded by Thailand in 1996 and by Dominican Republic around 1999. The unit value of Thai transformers is even higher than that of Canada in 1989, but drops dramatically to 0.23 in 1990, then picks up slowly and arrives at 8.32 in 2006. Last, for Dominican Republic, the unit value curve is almost a flat line near 0, rises suddenly in 1999, surpasses Canada in 2004 and declines to 7.32 in 2006.

From the above instance, it is too easy to emerge a switch in technology type if I define low-/high-tech inputs by country-year combination with HS10 category. The transformer made in Thailand might be considered as a high-tech input at the very beginning of the period, but instantly becomes a low-tech one in the second year. Such a rapid status change seems to be unrealistic.

¹⁴ For some entries, it is unable to calculate unit values using “customs value, imports for consumption” data. So I use “customs value, general imports” data instead. 2119 replacements are made. Then I drop all entries without unit values, since I am unable to define their technology capabilities.

Moreover, it might be reasonable to think that an input imported from a Southern country turns from low-tech to high-tech, but difficult to imagine that a Northern country starts to export a low-tech input after several years' exporting the same input with a higher technology. As a result, I need a larger scope to define the technical content of an input and create a stable definition for each product from each country.

To prevent potential confusion, I take the following measures: by pooling over all observations of any HS 10-digit product, I calculate out the average unit value and compare it with other products within the same HS 4-digit industry. If this specific average is smaller (or equal to) the median value of the industry, I classify it to be a low-tech input¹⁵. Otherwise, it is a high-tech input. By this method, the classification should be consistent all the time.

In fact, the distribution of average unit value for each industry is quite skewed in my sample. The smallest value is 0.32 (HS 8533100025, "fixed carbon cmp/film resistors, smd, >"), while the largest one is as big as 1 million (HS 8504230080, "liquid dlvtc transformer > 100,000 KVA"). 75% of them are less than \$775, but the mean is surprisingly such a large number, that is, \$4030.26. In that case, if I use the mean of unit value to be the cutoff of technology level, there will be too many low-tech inputs. So I use the median value instead.

The reason for why I compare average unit values within a HS 4-digit category instead of more disaggregated HS 6-digit code is that there are at least three HS 10-digit codes in any HS 4-digit industry, but the minimum number of codes at the HS 6-digit level is one. Table B.9 lists the distribution of products in each industry. In addition, at this aggregation level of industry, the dispersion of unit values might not be that large since they are allied products. Here are some examples of HS4 descriptions:

¹⁵ If excluding the average equal to the median, the empirical results do not change statistically.

HTS Code	Description
8509	Electromech domestic appliances, parts
8522	Parts & access of record play, mag tape record etc
8531	Electric sound or visual signaling apparatus, pts
8542	Electronic integrated circuits & microassembl, pts

Accordingly, I think that HS 4-digit level seems to be an acceptable choice to denote an industry.

3.5 Descriptive Statistics

In this section, I focus on some interesting phenomena directly told by the data. Basically, I have 162,177 observations in my censored dataset, coming from 180 countries. There are 29 HS 4-digit intermediate industries, listed in Table B.9, involving 818 different kinds of HS10 products in total. Among them, 442 products are defined as low-tech inputs and the rest are high-tech inputs. 53% of all the entries (or 55.6% of the HS10 codes) are categorized to be low-tech inputs according to my definition. So the unbalanced panel is almost divided into two equal-size subgroups. When I stretch up the sample to be a balanced panel, there are 832,158 observations in all. The zero entries (when *notzero* = 0) take up around 70.9%.

Table B.10 shows some fundamental summary statistics, and Table B.11 makes comparison between the two subsamples. As mentioned before, the variation in unit value is enormous. The maximum value is over 5 trillion times as much as the minimum, with an average of \$4390.52. Not surprisingly, the mean of the high-tech inputs (\$8450.569) is significantly much larger than that of the low-tech ones (\$794.691). The year variable $t = 1$ for all entries happened in the first year of the sample, 1989. $t = 2$ for the second, and so forth. The average t is 10.272. Since the whole sample covers 18 years, it means that there are more observations in the latter years.

The average share is as low as 4.633 for the censored sample, although its feasible range is from 0 to 100. The mean shares of the two subgroups do not differ much from each other. To look into more details of the data, Figure B.18 displays a 100-bin histogram of log of *share* and also an

overlaid normal density function. This normal distribution is heavily skewed to the left side. And the majority of observations are clustered in the first bin. It is indicative that the market share of a typical product is split by several countries, and each country only exports a small portion to the U.S. Only less than 1% of the *shares* is greater than 70, though they are very difficult to observe from the figure. Note that there are 19 products coming from a unique exporter. That is, 2.32% of all HS10 codes in my sample. It is so interesting that some products' unique suppliers have switched over time and no one lasts for more than 6 years. For example, there are five exporters of HS8540121040 ("cathode ray TV pic tube mono, non-hd, pro") throughout the sample period. Specifically, Japan occupies the whole market in 1995, 1998, and 2001, but Mexico dominates for more years (1999, 2000, 2002, 2004 and 2005).

There are 24 countries possessing an OECD membership within the sample period, which is also significant between two subgroups. For the observations in the censored sample, 7.6% are contiguous to the U.S., 27.9% share the common language as America, and 11.7% were in a colonial relationship with the single importer. The average distance between most important cities is 8.43 thousand kilometers. On average, the low-tech inputs has a higher share, lower GDP per capita, is less possible to be an OECD country, farther away from the U.S., and has larger real GDP than the high-tech inputs. Only a third observations have tariff data at HS 8-digit level. Estimated MFN rates range from 0 to 0.15, with an average of 0.027. The FDI stock changes from null to 1140 million dollars. Finally, IIT measures the extent of product overlap. From my calculation, at HS 4-digit level, the average IIT index is 0.734, suggesting a high volume of intra-industry trade across the world.

I further look at the relationship between a country's import share and its relative income level. Figure B.19 shows the fitted curve of share respect to GDP per capita by technology of inputs. The correlation is positive for the high-tech inputs, but negative for the low-tech inputs, which seems to be in accordance with my theoretical prediction.

The histogram in Figure B.20 depicts the number of products exporting from different countries over all years. The normal function has a heavy tail on the left as well. Between the period

1989-2006, the average number of exporting products is 176 types per country, starting from 1 (i.e. Benin, Cuba and Central Africa Republic) to 814 (Japan). Half of the countries exports less than 54 kinds of products. In addition, I illustrate the relationship between the number of products from a certain country and that country's average GDP per capita. The fitted line in Figure B.21 is upward-sloping, which indicates a positive relevance in general. Though the majority of dots are close to the fitted line, there are some outliers worth mentioning. Some Southern countries on the top-left corner of this graph, such as China, Thailand, the Philippines, and Indonesia, manufacture various intermediate inputs and export them to the U.S.

Last but not least, I investigate the change in trading partners during the sample period. The total number of countries export high-tech or low-tech inputs are almost the same, around 180. Figure B.22 discusses the number of exporting countries for each product using histograms and normal density curves. The top-left panel lays out the density for all years. The median number of export countries is 36 per product, and the mean is 38.71. A quarter of products export from at least 25 countries. Then I divide 18 years into three 6-year bins and sketch the histograms respectively. The normal curves are all biased to the left, but its mean has statistically significantly moved to the right over time. It is indicative that more countries participate in exporting to the U.S. as time moves forward.

3.6 Empirical Results

In this section, I discuss the results of the empirical estimation. The technique I use is OLS model for the unbalanced sample and Heckman 2-stage correction for the expanded balanced panel. All regressions are run for the low-tech and high-tech inputs respectively, with robust standard errors¹⁶. Chow-test is conducted to test whether there are significant difference between major coefficients of the subgroups.

¹⁶ When the standard errors are clustered at country level, we lose significance of various coefficients. The errors in F-test and Chow-test are also robust.

3.6.1 Preliminary Estimates

Table B.12 displays initial attempts to explore the relationship between import share and OECD membership, without any interaction term. Direct linear correlations are tested in column 1 and 2. OECD membership is the only explanatory factor here and none of the dummies have been taken into account yet. We can see that the estimated coefficients for both low-tech and high-tech inputs are significantly different from zero, with the one for high-tech inputs twice the size of that for low-tech inputs. It means that possessing an OECD membership promotes exporting to the U.S., especially for the high-tech inputs. When dummies representing year, industry and country are included in column 3-4, the magnitude of the coefficients becomes smaller, but the signs remain. Additional variables are added into column 5-12 gradually: the set of gravity controls (column 5-6), IIT index (column 7-8), FDI stock (column 9-10), and tariff (column 11-12). The results for OECD dummy coefficients are stable across all specifications, except the one in column 11. This particular estimator for the low-tech inputs is still positive, but no longer significant. This might be because that only 146 out of 313 HS8 codes in my sample have tariff data throughout 1989-2001, which makes the sample size in the last two columns reduced to one third of the full sample. Finally, the Chow-test at the bottom of the table gives the p -value of a hypothesis test that the two subgroups have the same coefficient for the OECD dummy. This null hypothesis is rejected in every column with extremely high confidence - above 99.9999% in fact.

Table B.13 provides regression outcomes for our baseline equation (3.2), by bringing the interaction term $OECD \cdot t$ and year variable t to all specifications in Table B.12. Recall that the OECD-year interaction is used to capture the transition effect of OECD membership on import share over time, which is my major indicator of product cycle. As before, in order to focus on ideas about the combined effect of OECD membership and product cycle, the first two columns are results without any controls. The coefficient for the low-tech inputs is a significantly positive 2.618 and that for the high-tech inputs is even bigger, that is, 4.487. It is indeed a great influence since the average import share is as small as 4.6 for the unbalanced panel. Therefore, as an OECD

member country, the import share of a typical high-tech input to the U.S. is expected to be doubled. However, one additional year will pull down the share by 0.0356 for the low-tech inputs and 0.0466 for the high-tech inputs on average. Moreover, the share will be further lowered by 0.119 per year if a low-tech input is imported from an OECD country, which is a 4.5% reduction. Similarly, it is a 3.2% reduction (a magnitude of 0.146) if a high-tech input is imported from an OECD country. Hence, the negative coefficients of the interaction and year variable make the magnitude of the OECD-dummy coefficients here a little larger than the corresponding ones in Table B.12. The Chow-test also suggests that the OECD-series estimates are jointly different from zero at the 5.30% significance level.

The results in column 3 and 4 are not very different from the previous two columns, by adding industry and country fixed effects. R-squares have been improved. Year dummies are ruled out in the whole Table B.13 to prevent unnecessary collinearity. By this change, the estimated value of OECD dummy for the high-tech inputs becomes closer to that for the low-tech inputs, only 12.5% higher, and also the coefficients on the year variable, γ_3 , turn out to be remarkably greater than zero. Every year the import share of a representative low-tech input will still be cut down slightly more (8.53% versus 7.01%) than that of a representative high-tech input as an OECD member state, although initially the former is smaller in size. However, within the sample period, the total effect of OECD is always positive, especially favorable to the high-tech inputs.

It is worth noting that increasing the number of controls barely alters the main findings on the diverge product cycle pattern. It means these variables are complementary explanations for determining import shares. We look at column 5-6 first. The estimates on year variable, contiguity dummy, language dummy and colony dummy are insignificant at all. Similar to the bilateral trade literature, distance has a negative impact on the import share and exporting country's market size (population) has a small promoting effect for both types of inputs. If a country is 1.02 thousand kilometers far away, it will never have a chance to export a low-tech input to the U.S., and the threshold distance is 1.82 thousand kilometers for a high-tech input. From column 7 to 12, the IIT index generally has no importance from the statistical sense, with the exception of column 9.

Its estimates for the low-tech inputs are negative, but those for the high-tech inputs are positive. It suggests that a high-volume of intra-industry trade might harm trade in low-tech inputs, but stimulate trade in high-tech inputs. Finally, using FDI stock and tariff as extra controls entails a substantial drop in the sample size. It is very intuitive to believe that the more is the FDI stock in a country, the more likely it will export to the world. However, it is so surprising that tariff also plays an active role, and this influence is comparably much stronger for the high-tech inputs.

In Table B.14, I employ an alternative approach to control for the temporal variation. The details of this specification has been discussed in equation (3.3), as the OECD dummy interacted with five 3-year-bin dummies. The dummy for 2004-2006 is excluded to prevent collinearity. We can see that the correlations between import share and OECD dummy for the low-tech inputs are some negative numbers in a few columns. In particular, they are statistically significant in column 3 and 9. The identity of the OECD member hurts exporting the low-tech inputs to America, though it still encourages the trade in the high-tech inputs. This discovery is even more consistent with my theoretical predictions than previous specifications. However, the chow-test in all but one column shows that the joint difference of those OECD-related variables are not significant any more. In addition, the magnitude of the estimates on the interactions slowly declines as the time goes by. The F-test hypothesis that the OECD-related variables have equal parameters is examined as well. The calculated p -values represent that this hypothesis is rejected across all specifications with very high degree of confidence. It implies that at different time periods the influence from the OECD membership is substantially weakening.

3.6.2 Heckman Correction

To save place, I do not report all Heckman Correction estimates. Table B.15 and B.16 are corresponding results to previous Table B.13 and B.14. There are four panels in each table. In each panel, the second stage results are shown in the first column, and the first stage results are in the second column. Industry and country dummies are used as instruments on the first stage, and are dropped afterwards. The inverse Mills ratio listed in the third column, λ , is evaluated from Stage

1 and also included in Stage 2.

Specifically, Panel A and B in Table B.15 is a re-estimation of column 3-4 in Table B.13. It is obvious that the impact of OECD membership goes in the same direction as before, though the magnitude of coefficients get adjusted. Now the coefficient on OECD dummy for the high-tech input is twice that for the low-tech inputs. Each year, the OECD membership reduces the import share by an average of 5.91% for the low-tech inputs, and by 3.53% for the high-tech inputs. When adding back the full set of gravity controls in Panel C and D, the difference becomes smaller. But the major empirical results of product cycle still remain.

Compared with the estimates shown in Table B.14, the sign of OECD coefficients turns significantly positive in column 4 and 7. It means that the original OLS model is biased downward. Only the coefficient in column 1 keeps its negative value; however, it is no longer statistically significant, and its value has increased a little bit. The descending trend of interactions is unchanged as well.

3.7 Conclusion

To summarize, both OLS and Heckman estimations lend support for my theoretical predictions. It is more likely to import a low-tech input from a non-OECD country and a high-tech input from an OECD country. And these correlations are strengthened over time, which implies a dynamic product cycle.

However, the findings are not perfect. One possible reason is that I use an dependent variable *share*. It does not reflect any increase in customs values, since the sum of import share is always 100 for each year. It might also explain why I get a negative coefficient on time variable. Another possibility is that trade in parts and components is different from trade in final goods (Baldwin and Taglioni, 2011[4]).

Moreover, though my definition of high-/low-tech inputs is consistent, I lose the information on unit value variation over time. So I am unable to test quality upgrading as Schott (2002)[74].

Chapter 4

Heterogenous Industries

4.1 Introduction

Many manufacturing goods seem to go through a standard international product cycle, in which they are invented and initially produced in an advanced economy (the “North”) and production of a standardized version is eventually shifted to lagging economies (the “South”) via some form of technology transfer, whether foreign direct investment (FDI) or simple imitation of traded goods. In Vernon (1966)[86] classic conception, all products are subject to these basic dynamics and a continuous cycle of birth, death and rebirth of new goods occurs. This assumption of homogeneity persists through many extensions of the product cycle model, including the dynamic, general-equilibrium versions begun by the seminal model of Grossman and Helpman (1991a)[31]. However, not all goods can be characterized as identical in this context. Some proceed rapidly through the process of technology transfer but remain in production in the South rather than expire. Others go through the standard dynamics as noted. Still others, generally very high-technology goods, seem resistant and both innovation and production remain in the advanced countries Lu (2007)[60].

Put in other terms, goods may broadly be placed into three categories in this context. First would be lower-technology products that, once transferred, remain relatively stagnant in terms of innovation and production remains permanently in developing nations. An obvious example would be labor-intensive, standardized goods, such as footwear, mass-produced apparel items, and toys. Second would be inherently high-technology products that are so complex it is effectively impossible to separate production from technology sources. Examples here would be final assembly

of passenger aircraft and sophisticated capital goods. Third, and most interestingly, are goods that exhibit product-cycle characteristics of innovation, technology transfer, and subsequent newer innovation. Examples here would include semiconductors, cellular phones, and automobile parts.

To see this, consider the evidence in Figure ???. The product cycle measure is the export share of product cycle trade in an industry's total exports. Industries are ranked by their research and development (R&D) intensity, which is the proxy for R&D productivity. Details are described in Section 6. I first produce a scatterplot of the product-cycle measures on R&D intensities using the U.S. imports data from 32 Southern countries every five years from 1990 to 2005. Then I plot an ordinary least squares (OLS) quadratic fitted line with year, industry and country fixed effects, truncating all predicted values lower than 0. Conditional on R&D productivity, fitted values of the product cycle measure reveal a reserve-U shape. The product cycle measure reaches its maximum in moderate R&D productivity industries. Moreover, in relatively high-technology industries, there is predicted to be no product cycle trade at all.

This heterogeneity seems fundamental and it is important to develop a theory that explains it. In this chapter I develop a model, based on concepts of quality-ladder improvements in technology (Grossman and Helpman, 1991b)[32]. However, here the industries are differentiated by the step size of improvements, with larger steps indicating higher-technology sectors. In this regard, I build on the model set out by Lu (2007)[60], which features continuous innovation and technology transfer through FDI and generates cutoff levels of technological sophistication that segment low-technology, medium-technology (product cycle), and high-technology industries. In particular, Lu solves for cutoffs determining industries that “move out” (i.e., goods that transfer permanently through FDI or become product-cycle goods) or “move up” (i.e., innovation and production remain in the advanced economies). In this context, a product that remains in the South is always produced within an FDI affiliate.

An important element of competition missing in her model is the possibility that local Southern firms may imitate goods transferred to their countries via FDI. Adding imitation, which is the objective of this chapter, changes the results in significant ways. First, all products in low-

technology industries ultimately are produced by firms owned in the South. Second, the fact that owners of multinational firms must concern themselves with this imitation threat means that in equilibrium fewer technologies are transferred from the North. In particular, the range of technological sophistication within which products remain always in the North expands. One immediate implication is that stronger intellectual property protection (IPP) in the South, which reduces the rate of imitation aimed at FDI, is likely to reduce this range and increase the average technology levels of goods transferred abroad. However, the trade volume of existing product-cycle industries is unaffected.

The above theoretical predictions can be translated into three testable hypotheses. I first examine whether the PC trade is the most pronounced in industries with R&D productivity of intermediate magnitude. Then I test the potential impact of tighter IPP enforcement in developing countries on the intensive and extensive margins of PC trade. With the help of the U.S. trade panel from 54 underdeveloped countries, I confirm the first hypothesis and also the significant promoting effect on the number of industries participating in product cycle trade. Yet, the influence of the strengthen in IPP on the export share of product-cycle goods is mixed.

The remainder of this chapter is organized as follows. In the next section, I offer a brief literature review to help set up the problem. In Section 4.3, I describe the basic setup of the model. In Section 4.4, I analyze the model to figure out the relevant industry thresholds, and determine in steady-state equilibrium which industries are subject to product cycles and which are not. Since the analytical solution of the model is complex, in Section 4.5 I conduct comparative statics on such factors as labor endowment, quality increments, innovation costs, FDI adaptation costs and imitation intensities. In Section 4.6, I describe the datasets and provide empirical evidence of my major theoretical predictions. I offer concluding remarks in the last section.

4.2 Literature Review

The role of technological change in international trade and FDI had been long neglected by economist. Vernon (1966)[86] is the first to mention the relocation of product manufacturing over

time and its subsequent influence on the direction of trade. At the early stage of a commodity's life cycle, it is produced in the country where it is invented, usually the United States, since there is a large domestic market. As technology becomes more and more standardized, production will migrate to less developed countries to exploit low marginal cost over there. This dynamic process of introducing new products and then migrating out the production line is called "product cycle". However, Vernon only mentions FDI as the only way to transfer technology. Besides, he elaborates his idea with examples. Theories and empirical evidences are anticipated.

Afterwards, a whole literature on "product cycle" has emerged to further address this issue. Basically, there are two dimensions of development, implying different theoretical results. One branch of framework depends on horizontal differentiation. Innovation takes the form of product expansion. New varieties come out in the North and old products shift to the South. The other branch considers vertical differentiation. Innovation improves product quality continuously while abandoning the out-of-date generations. The dominance of manufacturing a particular good transfers between the North and South due to successful R&D investments.

4.2.1 Horizontal Differentiated

As a precursor, Krugman (1979)[55] formalizes the leakage of technology to developing countries by building up a dynamic horizontally-differentiated model. Labor is assumed to be the only input¹. There is a continuing process of innovation, in the form of creating new products. The North specializes in inventing, producing and exporting these new goods. Meanwhile, new goods gradually turn into old goods and their technology are learnt by the South. Then the North begins to import these goods from the South. Hence, the "imitation lag" gives rise to international trade. Note that both rates of innovation and transfer are taken as exogenous here. Although labor in the two countries is equally productive, wage in the North is relatively higher. Either a slow down in innovation or a speed up in transfer may narrow this differential in relative wage.

¹ Krugman (1979) also spends a short section to discuss the possibility of international mobile of capital, which leads to foreign investment. However, that is not the focus of his paper.

Dollar (1986)[14] further takes factor-price equalization of the neoclassic model into account. Capital is introduced as the second factor and moves slowly across borders. The most important adjustment is to assume that there is a difference in production costs between the North and South, which positively determines the rate of transfer, while keeping the rate of innovation exogenous. Meanwhile, Jensen and Thursby (1986)[48] suppose that a Northern monopolist and a Southern planner decide the rates of innovation and imitation respectively. Afterwards, Jensen and Thursby (1987)[49] modify the number of innovators to greater than one, but reverts to the exogeneity of imitation.

On the basis of Krugman (1979), Helpman (1993)[41] considers the welfare consequences of tighter IPP in the South. Innovation is then endogenized. The strength in IPP is expressed by a decrease in the exogenous imitation intensity. It not only sets back the pace of Northern innovation, but also may hurt the South by reallocating production towards Northern firms. Previously, Krugman (1979) also considers a model with FDI; however, innovation in that case is exogenous.

Still with exogenous imitation, Lai (1998)[59] confirms Helpman's (1993) positive feedback of the rate of imitation to the rate of innovation. However, he claims that this relationship only holds when imitation is the unique channel of technology transfer. When endogenous FDI decision is taken into consideration, the correlation can be negative as long as the rate of multinationalization is high enough or the rate of pre-FDI imitation is negligible. Stronger IPP enhances the incentive to innovate in the North, and also promotes transferring technology to the South. In addition, the Northern relative wage is reduced.

Not only transfer method is important, but also the endogeneity of imitation is crucial. Intuitively to think, imitation is a costly activity. Firms response to its cost and optimally allocate their resources between imitation and production. Taking imitation activity as given obviously misinterprets firms' behavior.

In their seminal paper, Grossman and Helpman (1991c)[33] set up a general equilibrium model and endogenize both rates of costly innovation and imitation. The Northern oligopolist constantly faces a threat from the Southern imitators and is likely to lose its market leadership

after a random period of time. However, faster imitation will ultimately improve the incentives to innovate. If the wage gap is not too large, an increase in the relative size of Northern population will retard imitation, and hence raise the share of varieties located in the North. Also, it will pull up the Northern relative wage, which is the opposite to Krugman's finding.

Branstetter and Saggi (2011)[10] extends Grossman and Helpman (1991c)[33] by adding endogenously-determined FDI. They also let the Northern firms to choose production location by themselves. In their paper, a strengthening of IPP in the South (as measured by an increase in imitation cost) brings down the possibility of imitation, but encourages FDI. As a result, the share of Southern products in the global market gets enlarged. If the price of multinationals' products is higher than that of Southern imitators, the real wage of Southern workers will increase, while that of Northern workers will fall.

Further more, Gustafsson and Segerstrom (2011)[36] modify previous work by treating transfer within multinational firms with a price. At first, new varieties are invented and manufactured in the North. Then Northern firms conduct adaptive R&D and later shift production to the low-wage South in order to get more profits. However, the foreign affiliates is exposed to imitation risk from Southern local firms. Once the imitation is successful, Southern imitators occupy the entire market and drive out the Northern innovators. Specifically, the strength in Southern IPR is modeled as a reduction in imitation rate. This change in IPP leads foreign affiliates to raise their R&D expenditures, accelerating transfer speed.

Starting from Krugman (1979), each variety is treated identically. They enter consumer's utility function systematically and their R&D efforts are equally productive. A recent paper by Ivus et al. (2013)[46] extends the literature by assuming heterogeneity across industries, based on a general-equilibrium framework of an innovative North and an imitative South. The more complex is the industry's technology level, the lower is its risk of imitation. In industries with relatively-low imitation risk, production is transferred to the South via arms length licensing contracts. To the other end of technology spectrum, the imitation risk is so high that production stays in the North. Finally, production is migrated to the South via FDI in the middle group. With stronger IPP in the

South, more industries will be switched from FDI to licensing. Yet, both innovation and imitation are supposed to be exogenous in their model and hence requires no labor cost.

4.2.2 Vertical Improvement

In a partial equilibrium model, Gabszewicz et al. (1981)[20] begin to discuss the existence of trade in terms of different quality levels. However, the quality levels in his paper are all exogenously given.

Both Flam and Helpman (1987)[19] and Stokey (1988)[80] work on a framework with continuously introducing new high-quality goods and eliminating low-quality ones. In the former paper, the incentive to upgrade the product qualities stems from faster technology progress in the South and also consumer income differences. Gradually, relatively-low-quality goods shift their production to the South. However in Stokey (1988), learning-by-doing is the driving force behind transfer.

Segerstrom et al. (1990)[78] assume that the time interval between two successive innovations is a deterministic decreasing function of resources devoted and R&D is conducted sequentially to a fixed number of industries. The portion of industries located in the South is exogenously given by the patent duration in the North. In GH (1991b)[32], each product climbs up its own quality ladder simultaneously and stochastically. With Bertrand competition, the firm with the lowest quality-adjusted price controls the entire market share. Both innovation and imitation are endogenous, and optimal resource allocation determines the split of production between the North and South.

Glass (2002)[28] add endogenous FDI into GH's (1991b) framework and also consider the effect of strengthened IPP in the South. There are two possible targets for Southern imitators: Northern firms and multinationals in the South. Glass casts doubt on whether stronger Southern IPP always encourage FDI and innovation. They argue that it is possible to reach a different prediction, if IPP was modeled as an increase in the cost of imitation rather than as an exogenous decrease in the imitation intensity. By only allowing imitating from the multinationals, Glass and Wu (2007)[29] confirms Glass's (2002) finding about tighter IPP on FDI and innovation in the case of quality improvements, but points out that it has a positive effect if the direction of innovation

is horizontal.

Taylor (1993)[83] calls back the Ricardian explanation of trade and provides a workable framework with different technologies and R&D opportunities across industries. On account of Taylor (1993), Lu (2007)[60] generalizes a heterogenous industry model with endogenous innovation and FDI. Industries are ordered by their R&D productivity. All innovations take place in the North, by the form of improving product quality. When a Northern leader loses its market due to other firms' innovative endeavors, it may choose between further innovate (called "moving-up strategy") and invest in the South (called "moving-out strategy"). Since firms' potential returns are related to the instinct heterogeneity of technological complexity, their decisions are likely to differ across industries².

In particular, the ex-leaders in high R&D productivity industries always prefer moving-up strategy and keep on inventing new generations of products. The Northern leader is the dominant exporter and the top-of-the-line blueprint owner. None of the product lines migrates to the South. To the contrary, in industries with medium or low R&D productivity, the ex-leaders prefer moving-out strategy and reap cost savings in the South. These relocated firms control production of the whole market. It is worth noting that medium-technology industries experience product cycle between the two countries. When manufacturing is directed by multinationals, the Northern inventors deploy resources in R&D and then win back their world market. Afterwards, the followers invest in the South again with a previous version. Finally, for low-technology industries, no firm is willing to innovate. Technology stagnates in the South.

This chapter further extends Lu (2007) by allowing imitation, since it is a very common channel of international technology transfer. An important goal of this paper is to determine whether the Northern firms' moving-up and moving-out decisions are affected by the exposure to imitation, and how stronger IPP in the South affects the steady-state equilibrium. I find that the range of product cycle industries does get smaller with the risk of imitation; however, the tighter protection helps the multinationals regain confidence in the Southern market.

² More details of Lu's (2007) predictions are shown in Appendix A.5.

4.3 The Model

This section makes a brief description of the model. Basically I develop a dynamic framework in which industries differ in their R&D productivity and intellectual property rights in the South are imperfectly protected.

There are two countries in the world, an industrialized North and an underdeveloped South. Labor is the only factor in the economy and is immobile between countries. Hence, the labor endowments in the North and South are fixed to be L and L^* respectively. The wage in the South is normalized to be 1. The wage in the North is supposed to be $\omega > 1$, which is also the relative wage between two countries. Following Lu (2007)[60], $\omega(t)$ is exogenously given and only can be changed by the relative labor endowment. Finally, trade is frictionless across borders.

There is a continuum of industries around the world, indexed by $z \in [0, 1]$. Within each industry, there is a continuum of varieties $y \in [0, 1]$, available at different quality levels. As a result, the product space is defined on a unit square indexed by $(z, y) \in [0, 1] \times [0, 1]$. The quality of version j of product (z, y) is denoted by $q(z, y, j) = \lambda(z, y)^j$, where $\lambda(z, y)$ is the step size of quality increment and also indicates its R&D productivity. Moreover, I assume that $\lambda(z, y) = \lambda(z)$, $\lambda(0) = 1$, and $\lambda(z)' > 0$. The quality increment within each industry is the same. The industries are ranked by their R&D productivities, which is increasing in z .

High z industries produce technological sophisticated goods. A typical example is the passenger aircraft industry, which contains a number of varieties that differ in capacities, manufacturers, speed and etc. The most heavy-use variety, Boeing 737, went into sky in 1967 and usually serves the domestic routes. Each serious modification, starting from Boeing 737-200 to Boeing 737-900, can be considered as an improvement up its quality ladder. Another variety, Airbus A380, is designed for transcontinental routes and hence its body is relatively giant. On the other hand, low z industries produce labor-intensive, standardized goods, such as footwear and toys.

Similar to other product cycle works, the North and the South are thought to have different technology capacities. Moreover, the patent environment in the North is perfect, but it is imperfect

in the South so that imitation is likely to occur. Supplied by highly-trained workers and equipped with advanced machines, the Northern firms can put forward the quality frontier through costly innovation. They also can choose to transfer existing blueprints to the South and become multinational enterprises (MNEs), in order to exploit the cost advantage over there. On the other side, the Southern firms are inefficient in innovation; therefore, imitative activities are undertaken to copy the existing designs of multinationals. Once the Southern imitators succeed, the multinationals will lose their dominance in the market.

4.3.1 Consumer's Problem

The specification of the consumer's problem is similar to Lu (2007). Consumers around the world share identical and homothetic preference. For simplicity, I only show the utility function of the Northern consumers here. The Southern consumers follow the same rule to make their decision. In particular, a representative consumer seeks to maximize his/her intertemporal utility below

$$U = E_0 \left[\int_0^{\infty} e^{-\rho t} \log u(t) dt \right] \quad (4.1)$$

where E_0 is expectation conditional on the information available at time 0, and ρ is the common subjective discount factor. The instantaneous utility $\log u(t)$ at time t over different generations of products is of the form:

$$\log u(t) = \int_0^1 \int_0^1 \log \left[\sum_{j=0}^{J(z,y,t)} q(z,y,j) X(z,y,j,t) \right] dy dz \quad (4.2)$$

where $X(z,y,j,t)$ denotes the consumption for quality level j of product (z,y) at time t , and $J(z,y,t)$ denotes the highest quality level available of product (z,y) at time t .

The representative consumer maximizes his/her lifetime utility (4.1) subject to an intertemporal budget constraint $\int_0^{\infty} e^{-R(t)} E(t) dt \leq A(0)$. $E(t)$ is the aggregate expenditure of consumers at time t , and $A(0)$ is the present value of lifetime income plus initial asset holdings. In addition, $R(t) = \int_0^t r(s) ds$ is the cumulative interest rate up to time t , where $r(t)$ is the instantaneous interest rate. Accordingly, the optimal path for spending $E(t)$ is specified as

$$\dot{E}(t)/E(t) = r(t) - \rho \quad (4.3)$$

There are three stages of a consumer's maximization problem: firstly, how to allocate lifetime wealth over time; then at each instant, how to allocate expenditures across products in each industry; and lastly at each instant for each product, how to allocate spending across different quality levels. Actually, for all quality ladder structure, there is Bertrand competition around the world. Firms set prices to rule out their rivals, and then consumers pick up quantities. The provider with the lowest quality-adjusted price wins the whole market. For the situation here, only the version $\underline{j}(z, y, j, t) = \operatorname{argmin}_{j \in \{0, \dots, J(z, y, t)\}} \frac{p(z, y, j, t)}{q(z, y, j)}$ will be purchased, where $p(z, y, j, t)$ denotes its price at time t . Hence, the world demand functions are:

$$X(z, y, j, t) = \begin{cases} E^W(t)/p(z, y, j, t), & \text{if } j = \underline{j}(z, y, t) \\ 0, & \text{otherwise} \end{cases} \quad (4.4)$$

where $E^W(t) = LE(t) + L^*E(t)^*$ is the world aggregate expenditure at time t .

4.3.2 Firm's Problem

There are three kinds of firms producing goods around the world: Northern firms (Firm N), multinationals set up by Northern firms in the South (Firm F), and Southern local firms (Firm S). I suppose that leapfrogging to a higher version is allowed. Hence, Northern firms are exposed to innovation and adaptation risk, multinationals are exposed to innovation and imitation risk, and Southern firms are only exposed to innovation risk. Firm characteristics are summarized in Table B.17, which will be explained one-by-one.

A firm needs one unit of labor to manufacture one unit of output. Since the relative wage is higher than 1, there exists a production cost advantage in the South. Further more, by assuming free entry to R&D, there is an infinite pool of potential competitors for all three kinds of firms. However, under Bertrand competition, each product is produced by exactly one manufacturer in equilibrium, likely to be any kind. Only the firm offering the lowest quality-adjusted price occupies the whole market share of its specific variety. It limits the price to just keep its closest rival from earning a positive profit from production. Hence, the rest of firms either engage in R&D activity

to strive for the leadership, or just quit the market.

4.3.2.1 Northern Firms

I make a description of the Northern firms' behavior first. As discussed before, they are the only ones that can develop quality improvements. I name these firms devoted to introducing new generations of products as Firm N . In each product line, the one holds the state-of-the-art technology is the Northern leader, and I denote it by J . The rest of firms are Northern followers, and I denote them by $j \in \{0, 1, \dots, J-1\}$ (subscripts suppressed). In equilibrium described later, only three most recent versions of a product may exist: the latest version J , the second-to-top version $J-1$, and the third-to-top version $J-2$. All out-of-date blueprints have been obsolete.

Climbing up the quality ladder requires investment of resources and entails uncertainty of success. The labor requirement per unit of innovation is a_N , which is supposed to be constant across all industries for simplicity. An innovator engages in R&D intensity $\iota(z)$ for a time length of dt requests a total of $a_N \iota(z) dt$ units of Northern labor force, at a cost of $\omega a_N \iota(z) dt$. The probability of success is $\iota(z) dt$, which follows a Poisson process. This intensity is related to the industry rank as well, and can be different from industry to industry. A bigger endeavor of upgrading efforts leads to a higher possibility of success, but no level of investment will guarantee it. Note that the innovation intensity $\iota(z)$ is a function of z and may vary across countries. Additionally, getting a new patent rewards the firm a value of $v_N dt$. In order to prevent unlimited R&D, the expected benefits should not exceed the relative costs. That is to say, for each industry,

$$v_N \leq \omega a_N \text{ with equality if } \iota(z) > 0 \quad (4.5)$$

In fact, there are two pricing strategies for a producing Northern leader. On one hand, without competitors from the South, the most recent innovator can make a really high mark-up and charge at $p_N(z) = \lambda(z)^{J-J^*} \omega$ (or a tiny ϵ smaller). J^* is the highest level of quality that has been transferred to the South. Obviously, $J^* \leq J$. The unit production cost for Firm N is ω , which is the relative wage between the North and South. Hence, this specific price p_N reflects

consumers' willingness to pay for a higher-quality version multiplied by the marginal cost. The expected instantaneous profits $\pi_N(z) = (p_N - \omega)X_N(z)$, where $X_N(z) = \frac{E^W}{\lambda(z)^{J-J^*}\omega}$ is the quantity sold globally. As a result, the profit function is presented as

$$\pi_N(z) = \left[1 - \frac{1}{\lambda(z)^{J-J^*}}\right]E^W \quad (4.6)$$

On the other hand, Firm N might compete with firms from the South, either imitators or multinationals. Since the manufacturing cost overseas is lower, the Northern leader is unable to set the price as high as before. The highest price possible is the maximal value between the quality difference between regions and its marginal cost. That is, $p_N(z) = \max\{\lambda(z)^{J-J^*}, \omega\}$ (or a tiny ϵ smaller). If $\lambda(z)^{J-J^*} < \omega$, which is more common in lower-technology industry, we have $p_N(z) = \omega$. Then instantaneous profits of the firm are $\pi_N(z) = [p_N(z) - \omega]X_N(z) = 0$, where $X_N(z)$ is the total sales. When further taking the initial R&D cost into account, no firm would like to conduct innovation since they lose money. However, if $\lambda(z)^{J-J^*} > \omega$, which is the case in higher-technology industries, $p_N(z) = \lambda(z)^{J-J^*}$. Making a sale of $X_N(z) = \frac{E^W}{\lambda(z)^{J-J^*}}$, the leader now earns instantaneous profits as follows

$$\pi_N(z) = \left[1 - \frac{\omega}{\lambda(z)^{J-J^*}}\right]E^W > 0 \quad (4.6')$$

As proved in Lu (2007), the leader has no incentive to further innovate if it is currently producing. The incremental rewards to the recent innovator are less than those made by the non-producers, and hence are unable to justify the research cost. Moreover, it is unprofitable for any follower to engage in FDI. Since facing the same marginal adaptation cost, the previous leader $J - 1$ can make more profits. Accordingly, it is always the previous leader $J - 1$ to think how to regain its leadership. There are two different choices: it might conduct innovative R&D to seek for technology breakthrough (Lu calls it the *moving-up strategy*) or transfer manufacturing to the South and exploit a lower cost (Lu calls it the *moving-out strategy*).

4.3.2.2 Multinationals

Firm F refers to those multinational enterprises operated in the South by Northern patent holders. Among them, the company possessing the highest quality blueprint is called the multinational leader (with version J^*). Adaptation uses labor from the South. Its unit resource requirement is a_F , and its intensity $\phi(z)$ varying with industries. It is intuitive to assume that $a_F < a_N$; therefore, it costs less to invest in a foreign country than improve product quality. Similar to innovation, a patent holder undertakes FDI at intensity $\phi(z)$ for a time interval dt has a probability of $\phi(z)dt$ of success. Since Southern labor is hired, $a_F\phi(z)dt$ units of labor will be consumed at a cost of $a_F\phi(z)dt$. The unit labor requirement for multinational production is 1. The Northern followers will invest in the foreign country only if the expected gains are no less than costs. Hence, free entry condition requires

$$v_F \leq a_F \text{ with equality if } \phi(z) > 0 \quad (4.7)$$

The multinationals charge a price of $p_F(z) = \max\{\frac{\omega}{\lambda(z)^{J-J^*}}, 1\}$ (or a tiny ϵ smaller) to undercut their Northern rivals. The price is the maximum between cost premium discounted by their quality disadvantage and the marginal cost. When $\frac{\omega}{\lambda(z)^{J-J^*}} > \omega$, the price $p_F(z) = \frac{\omega}{\lambda(z)^{J-J^*}}$ yields the multinationals one hundred percent of the global and a flow of sales $X_F(z) = E^W/p_F(z) = \frac{\lambda(z)^{J-J^*}E^W}{\omega}$. Correspondingly, the instantaneous profits are

$$\pi_F(z) = [p_F(z) - 1]X_F(z) = [1 - \frac{\lambda(z)^{J-J^*}}{\omega}]E^W \quad (4.8)$$

Otherwise, the instantaneous profits are zero and no firm is interested in FDI since it needs to bear the research cost at the beginning. A multinational faces with two threats to cease its production: imitation from the South, or innovation in the North.

Note that the quality level in Firm F is at least one step behind Firm N , i.e. $J^* \leq J - 1$. The no quality gap situation $J = J^*$ is unfeasible in equilibrium. In that case, the price for Firm N is $p_N(z) = \max\{\lambda(z)^0, \omega\} = \omega$, while the production cost is ω . Hence, $\pi_N(z) = (\omega - \omega)\frac{E^W}{\omega} = 0$. Because of the initial innovation cost, the gains are not sufficient to cover the costs. All firms would

like to migrate to the South. Then the technology stagnates over there. This strong specialization contradicts what really happens in the world. So I need to rule out the possibility of $J = J^*$.

4.3.2.3 Southern Firms

Then I look at the indigenous firms in the South. After the multinationals bring the blueprints to the South, the local firms can hire away skilled labor or visit the factories and hence learn the know-how and reverse engineering. I refer this group of firms as Firm S .

Following a few product cycle literature³, I denote with μdt probability of imitation success during time interval dt for Firm S . This imitation intensity $\mu \geq 0$ is exogenously given and can be interpreted as the level of IPP in the South. When the Southern government takes stricter legal and administrative regulations, the pace of imitation turns slower. Hence, stronger IPP brings down the values of μ . Moreover, I also suppose that once imitation succeeds, technology becomes available to all Firm S . With perfect competition among Southern firms, the price set is $p_S(z) = 1$, which equals the marginal cost. With a total sale of $X_S(z) = E^W / p_S(z) = E^W$, they make instantaneous profits $\pi_S(z) = 0$. The quality level of their products is the same as previous multinational leader, that is, J^* .

Finally, the Southern firms might be the target of Northern R&D efforts. Each success by Firm N migrates production back to the North and reignites a new product cycle.

4.4 The Steady State

My model extends Lu (2007) by allowing Southern imitation. There are two threshold levels of R&D productivity which determine equilibrium choices of firms in different industries. The continuum range of industries are divided into three categories: high-technology, medium-technology and low-technology.

In this section, I introduce my new cutoff points, and compare them with Lu's (2007) results⁴

³ [41], [59], [25], [73], [79].

. Actually, only the first cutoff has changed and moves to the left. The second cutoff is the same as Lu (2007). It means that with the risk of imitation in the South, more Northern firms take “moving-up strategy” and the measure of product-cycle industries shrinks. I am also interested in possible influences on these cutoffs, especially the strengthened IPP in the South. The product cycle composition is presented in Figure B.24.

4.4.1 Industry Characteristics

4.4.1.1 The Cutoffs

I denote the threshold splitting the high-technology and medium-technology industries as the first cutoff \bar{z}' . To make a comparison, it is denoted as \bar{z} in Lu’s (2007) original paper. The second cutoff separates out the medium-technology and low-technology industries, and is denoted as \underline{z} which is the same as Lu (2007). The proof of the propositions below is shown in Appendix A.6. Ranked by industrial R&D productivity, the set $[\bar{z}', 1]$ denotes the high-technology industries, the set $(\underline{z}, \bar{z}')$ denotes the medium-technology industries and the set $[0, \underline{z}]$ denotes the low-technology industries. The characteristics of each industry category are elaborated below.

Proposition 2 Let $F(z) \equiv \frac{-B + \sqrt{B^2 - 4AC}}{2A}$, where $A = a_N L$, $B = a_N L^* - \lambda(z)a_N L - a_N a_F \mu - (1 - \frac{1}{\lambda(z)})a_F L$, and $C = -\lambda(z)a_N L^* - (1 - \frac{1}{\lambda(z)})a_F L^*$. There exists an industry $\bar{z}' \in (0, 1)$ which satisfies $F(\bar{z}') = \omega$. Given that the industry leader J currently occupies the whole market. The nearest follower $J(\bar{z}') - 1$ is indifferent to the moving-up and the moving-out strategies. For any industry $z_H \in (\bar{z}', 1]$, the moving-up strategy is preferred to the moving-out strategy. For any $z_{\bar{H}} \in [0, \bar{z}')$, the moving-out strategy is preferred to the moving-up strategy, and $J(z_{\bar{H}}) - 1$ participate in FDI. When overseas factories are set up, the Southern indigenous firms begin to imitate from these MNEs.

Proposition 3 Let $G(\underline{z}) = \lambda(\underline{z})^2$. There exists an industry $\underline{z} \in (0, \bar{z})$ which satisfies $G(\underline{z}) = \omega$. Given that the MNE leader currently captures the world market. For any $z_L \in [0, \underline{z}]$, non-producing

⁴ A summary of Lu’s (2007) prediction is in Appendix A.5.

Northern firms exit the market, the dominant MNE leader has no incentive to undertake R&D, and thus the industry stagnates in the South. Southern imitators gradually substitute MNEs to occupy the market. At last, all these industries will be dominated by imitators. For any $z_M \in (z, \bar{z}')$, Southern indigenous firms engage in imitation. Non-producing Northern firms engage in innovation, targeting both MNEs and Southern imitators. After successful R&D, these industries return to the North.

4.4.1.2 High-technology Industries

High-technology industries z_H are all located in the North, where $z_H \in Z_H = [\bar{z}', 1]$. The measure of these industries are denoted as n_H . Obviously, $n_H = 1 - \bar{z}'$.

When a new generation comes out in the North, the innovator becomes the leader $J(z_H) = J^*(z_H) + 1$. Without competition from the South, the price charged is a slightly lower than $p_N(z_H) = \lambda(z_H)\omega$, in order to debar all potential rivals. The total sales are $X_N(z_H) = \frac{E^W}{\lambda(z_H)\omega}$ world-widely, making its instantaneous profits $\pi_N(z_H) = (1 - \frac{1}{\lambda(z_H)})E^W$. The leader's expected value is $v_N(z_H)$. No arbitrage condition is $v_N(z_H) = \frac{\pi_N(z_H)}{\rho + \iota(z_H)}$, with the probability that a higher version of quality comes into being. In equilibrium, free-entry into R&D venture requires that the expected benefits equal costs, that is, $v_N(z_H) - \omega a_N = 0$.

Within the total sales, the amount $x_N(z_H) = E^*/p_N(z_H) = L^*/\lambda(z_H)$ is consumed by the Northern population, where $E^* = \omega L^*$ is their aggregate income. The rest, $x_S(z_H) = E/p_N(z_H) = L/\lambda(z_H)\omega$ is exported to the South and consumed over there, since the Southern consumers have a total income of $E = L$. The traded volume for each high-tech industry $EX(z_H) = x_S(z_H)$ is unrelated to the imitation intensity, since $\partial EX(z_H)/\partial \mu = 0$.

Non-producing followers in the North engage in innovation, and $\iota(z_H) > 0$. A successful R&D investment brings the next quality version to light, and makes the current leader lose its dominant position. When a follower turns to be an industry leader, its price strategy is the same as

its predecessor. The optimal research intensity is calculated out from the non-arbitrage condition:

$$\iota(z_H) = \frac{\pi_N(z_H)}{v_N(z_H)} - \rho = \frac{(1 - 1/\lambda(z_H))E^W}{\omega a_N} - \rho \quad (4.9)$$

It is $\partial\iota(z_H)/\partial\lambda(z_H) > 0$, $\partial\iota(z_H)/\partial L > 0^5$, $\partial\iota(z_H)/\partial L^* > 0$, $\partial\iota(z_H)/\partial\omega < 0$, $\partial\iota(z_H)/\partial a_N < 0$, $\partial\iota(z_H)/\partial\rho < 0$. Higher R&D productivity and larger population in both countries promote the Northern firms' interest to innovate, while a higher Northern wage, innovation cost or consumer discount rate reduces it.

In a nutshell, the high-technology industries stay in the North and are free of imitation risk. The quality of products is upgraded continuously. None of the production line shifts to the South.

4.4.1.3 Low-technology Industries

Because of imitation, the low-technology industries present different characteristics from Lu (2007). In fact, they are separated into two parts: the group of Firm F (denoted by z_{L1}) and the group of Firm S (denoted by z_{L2}). It is easy to think that $z_{L1} + z_{L2} = z_L$, where $z_L \in Z_L = [0, \underline{z}]$.

At the beginning, for a low-technology product, the second-to-top follower successfully invests in the South and begins to take advantage of the cheaper manufacturing cost. Hence, the technology leader in the South $J^*(z_{L1}) = J(z_{L1}) - 1$ is one step behind the North on the quality ladder. Its price is set at $p_F(z_{L1}) = \frac{\omega}{\lambda(z_L)}$, discounted by the lower-quality level to appeal to the consumers. With a flow of sales $X_L(z_{L1}) = \frac{\lambda(z_L)E^W}{\omega}$, its instantaneous profits are $\pi_N(z_{L1}) = (1 - \frac{\lambda(z_L)}{\omega})E^W$. The Northern firms will not engage in innovation, since the potential benefits are negative⁶; therefore, there is further innovation and $\iota(z_L) = 0$. However, there is incentive for Southern indigenous firms to imitate, with $M > 0$. As a result, no arbitrage condition makes the market value of $J^*(z_{L1})$ to be $v_F(z_{L1}) = \frac{\pi_F(z_L)}{\rho + M}$. In equilibrium, the free entry condition requires $v_F(z_{L1}) - a_F = 0$.

When imitation is successful, Firm S occupies the dominant position in the market. I call this kind of industries as z_{L2} . The technology level is $J^*(z_{L2}) = J(z_{L2}) - 1$. With a price of $p_S(z_{L2}) = 1$, the firm makes a flow of sales $X_S(z_{L2}) = E^W$, and instantaneous profits $\pi_S(z_{L2}) = 0$.

⁵ It is because $E^W = \omega L + L^*$

⁶ If they win R&D, the price charged is $p_N(z_{L1}) = \lambda(z_L)^2$. The profits are $\pi_N = [p_N(z_L) - \omega]d_N^W < 0$.

Free-entry condition requires that $v_S(z_{L2}) = 0$. When technology is seized by Firm S , Northern innovators still have no incentive to conduct R&D. In addition, Firm F is unable to regain their market, since they charge a higher price. That is to say, $\phi(z_L) = 0$, and $\iota(z_L) = 0$.

In both scenarios, the direction of trade is shipping from the South to the North. The trade volume for each industry is $EX(z_{L1}) = E^*/p_F(z_{L1}) = \lambda(z_L)L^*$ when the production is controlled by the multinationals, and it is $EX(z_{L2}) = E^*/p_F(z_{L2}) = \omega L^*$ when the production is controlled by the Southern imitators. Still, the imitation intensity has no influence on neither of trade volumes in low-technology industries. That is, $\partial EX(z_{L1})/\partial\mu = 0$ and $\partial EX(z_{L2})/\partial\mu = 0$.

Hence, in low-technology industries, the second-to-top technology is migrated to the multinationals first, then copied by the Southern imitators, and finally stagnate in these firms. The measure of multinationals declines over time, and correspondingly that of Southern imitators increases. Eventually, the indigenous firms will dominate all low-technology industries since they can hire labor at a lower cost.

4.4.1.4 Medium-technology (Product-cycle) Industries

For any medium-technology product $z_M \in Z_M = [z, \bar{z}']$. There are three repeatable stages, which makes production to cycle between the North and South. In Stage 1, the multinational leader wins the Bertrand game and its quality is one step behind the industry leader. These industries are denoted as z_{M1} . In Stage 2, the Southern imitators might learn from the multinationals and have possibility to copy the patent. Once they succeed, they capture the entire market. These industries are denoted as z_{M2} . In Stage 3, the Northern leader wins the Bertrand game again and its quality is two steps above the multinational leader. These industries are denoted as z_{M3} . In total, it is $z_{M1} + z_{M2} + z_{M3} = z_M$. A product cycle might complete from Stage 1 to 2 to 3, or jump from Stage 1 to 3 directly.

At first, the nearest follower succeeds in FDI and shifts manufacturing to the South. The quality of this multinational leader's product is $J^*(z_{M1}) = J(z_{M1}) - 1$. Hence, it charges a price at $p_F(z_{M1}) = \frac{\omega}{\lambda(z_M)}$, with quantity sold $X_F(z_{M1}) = \frac{\lambda(z_M)E^W}{\omega}$, and positive profits $\pi_F(z_{M1}) =$

$(1 - \frac{\lambda(z_M)}{\omega})E^W$. No arbitrage condition is $v_F(z_{M1}) = \frac{\pi_F(z_M)}{\rho + \iota(z_M) + M}$, with the displacement probability that the Northern leader recapture the market with an even higher quality level or the Southern imitators steal the technology. Combined with free-entry condition $v_F(z_{M1}) = a_F$, I obtain the research intensity of the Northern innovators:

$$\iota(z_M) = \frac{(1 - \lambda(z_M)/\omega)E^W}{a_F} - \rho - M \quad (4.10)$$

with $\partial\iota(z_M)/\partial\lambda(z_M) < 0$, $\partial\iota(z_M)/\partial\omega > 0$, $\partial\iota(z_M)/\partial L > 0$, $\partial\iota(z_M)/\partial L^* > 0$, $\partial\iota(z_M)/\partial a_F < 0$, $\partial\iota(z_M)/\partial\rho < 0$, and $\partial\iota(z_M)/\partial M < 0$. A higher R&D productivity, adaptation cost, consumers' discount rate, or the extent of imitation decreases the Northern firms' willingness to innovate. However, a higher relative wage and expanded labor endowment in both countries increase it.

It is also possible for Southern firms to acquire the whole market share after successful imitative R&D, with the same quality level of the previous multinational leader, or $J^*(z_{M2}) = J(z_{M2}) - 1$. Products are sold at a price of $p_S(z_{M2}) = 1$ with a quantity of $X_S(z_{M2}) = E^W$. Their instantaneous profits are $\pi_S(z_{M2}) = 0$. Free entry condition makes $v_S(z_{M2}) = 0$. No arbitrage condition requires $v_S(z_{M2}) = \frac{\pi_S(z_M)}{\rho + \iota(z_M)}$, with the probability that the Northern leader wins the pricing game and controls the market again.

Finally, production will return to the North if the innovators achieve success, and then the product cycle completes. There are two sources for the Northern firms to seize market: from a multinational leader or a Southern firm. The quality is now two generations ahead of the South, i.e. $J(z_{M3}) = J^*(z_{M3}) + 2$. Price is set at $p_N(z_{M3}) = \lambda(z_M)^2$, and quantity is $X_N(z_{M3}) = \frac{E^W}{\lambda(z_M)^2}$. The instantaneous profit is $\pi_N(z_{M3}) = (1 - \frac{\omega}{\lambda(z_M)^2})E^W$. No further innovation will take place since it is unprofitable. But the followers try to engage in FDI, and $\phi(z_M) > 0$. Free entry condition is $v_N(z_{M3}) - \omega a_N = 0$. No arbitrage condition is $v_N(z_{M3}) = \frac{\pi_N(z_M)}{\rho + \phi(z_M)}$. The intensity of the Northern followers is

$$\phi(z_M) = \frac{(1 - \frac{\omega}{\lambda(z_M)^2})E^W}{\omega a_N} - \rho \quad (4.11)$$

with $\partial\phi(z_M)/\partial\lambda(z_M) > 0$, $\partial\phi(z_M)/\partial\omega < 0$, $\partial\phi(z_M)/\partial L > 0$, $\partial\phi(z_M)/\partial L^* > 0$, $\partial\phi(z_M)/\partial a_N < 0$, and $\partial\phi(z_M)/\partial\rho < 0$. The extent of adaptation in z_{M3} industries rises with an increase in quality

jump or expanded labor endowment in either country, and a decline in relative wage, innovation cost or consumers' discount rate.

Again, I consider the bilateral trade between the North and South. In M_1 industries, the multinationals export $EX(z_{M1}) = E^*/p_F(z_{M1}) = \lambda(z_M)L^*$ to the North. In M_2 industries, the Southern locals export $EX(z_{M2}) = E^*/p_S(z_{M2}) = \omega L^*$ to the North. Lastly, the M_3 industries are located in the North and they export $EX(z_{M3}) = E/p_N(z_{M3}) = L/\lambda(z_M)^2$ to the South. Similarly, $\partial EX(z_{M1})/\partial\mu = 0$, $\partial EX(z_{M2})/\partial\mu = 0$, and $\partial EX(z_{M3})/\partial\mu = 0$. Trade volume within industries reacts against the influence by the change in IPP.

To sum up, the medium-technology industries reveal the product cycle pattern. Technology is transferred to the South through FDI first. Later, it may be imitated by indigenous firms over there. Northern firms make endeavor to improve the quality based on multinationals and imitators. Once they succeed, manufacturing shifts back to the North, and a new product cycle starts.

Proposition 4 The strength in Southern IPP has no impact on trade volumes within each industry.

4.4.2 Market Clearing Conditions

Let n_H , n_{M1} , n_{M2} , n_{M3} , n_{L1} and n_{L2} be the measures of industries z_H , z_{M1} , z_{M2} , z_{M3} , z_{L1} and z_{L2} respectively. $n_{L1} + n_{L2} + n_{M1} + n_{M2} + n_{M3} + n_H = 1$. Specifically, the measure of high-technology industries is

$$n_H = 1 - \bar{z}' \quad (4.12)$$

All medium-technology industries aggregate to be

$$n_M = n_{M1} + n_{M2} + n_{M3} = \bar{z}' - \underline{z}' \quad (4.13)$$

The total measure of low-technology industries is

$$n_L = n_{L1} + n_{L2} = \underline{z}' \quad (4.14)$$

Product cycle only appears in medium-technology industries. The flows of goods adapted to the South via FDI and re-innovated in the North are constant in steady state, as shown in equation (4.15). Note that there are two sources of Northern innovation: multinationals and Southern local firms.

$$\phi(z_M) \cdot n_{M3} = \iota(z_M) \cdot (n_{M1} + n_{M2}) \quad (4.15)$$

The labor market in the North is

$$L = \frac{E^W}{\lambda(z_M)^2} \cdot n_{M3} + \frac{E^W}{\lambda(z_H)\omega} \cdot n_H + \iota(z_M)a_N n_{M1} + \iota(z_M)a_N n_{M2} + \iota(z_H)a_N n_H \quad (4.16)$$

The first two terms on the right hand are the workforce engaged in manufacturing, and the last three terms are the workforce engaged in innovative R&D.

The labor market in the South is

$$L^* = \frac{\lambda(z_L)E^W}{\omega} n_{L1} + \frac{\lambda(z_M)E^W}{\omega} n_{M1} + E^W n_{L2} + E^W n_{M2} + \phi(z_M)n_{M3}a_F \quad (4.17)$$

On the right hand, the first two terms are the workers engaged in multinational manufacturing in low-technology and medium-technology industries respectively; the next two terms are the workers employed by Southern local firms in low-technology and medium-technology industries respectively; and the last term is the workers engaged in adaptation; and the last two terms are the workers participated in adaption. There is no labor employed to engage in imitative R&D.

4.5 Comparative Statics

Since the analytical model is sophisticated, I need the help of calibration to facilitate comparing different cutoff functions and their comparative statics graphically. All parameter values are summarized in Table B.1. I assign the quality increment $\lambda(z)$ to be a very simple function of z , i.e. $\lambda(z) = 1 + z^{37}$. It is obvious that $\lambda(z) \geq 1$, $\lambda(z)' = 3z^{36} > 0$, and in the extreme case $\lambda(0) = 1$. Hence, all previous assumptions of $\lambda(z)$ are satisfied. In the benchmark case, I suppose $\omega = 1.2$, $L = 10$, $L^* = 20$, $a_N = 5$, $a_S = 3$, $a_F = 1$, $\rho = 0.05$, and $\mu = 1.05$.

⁷ I derive similar results when using a linear function of $\lambda(z) = 1 + z$.

First of all, I focus on the possible shift of cutoff points due to imitation. Obviously, the second cutoff point is the same as Lu's (2007) original point. I draw my cutoff functions and Lu's in the same Figure B.25. The benchmark values in Table B.1 are taken to sketch. The horizontal line represents the industry index from 0 to 1. $f(z)$ is the first cutoff function before imitation is added (Lu's result), and $F(z)$ is the corrected function with imitation. One of the solutions in equation (A.41) is dropped since it is negative with my parameter values⁸. It is very clear to see that the first cutoff point (where the $F(z)$ and $f(z)$ curves cross the horizontal line $\omega = 1.2$) has moved left from \bar{z} to \bar{z}' . Meanwhile, the second cutoff point \underline{z} (where the $G(z)$ curve cross $\omega = 1.2$) does not change. Part of previous medium-technology industries have switched to be high-technology ones, and hence the collection of product-cycle industries has been narrowed. It becomes safer to stay in the North when the multinationals face the risk of imitation, and then followers in more industries prefer moving-up strategy to moving-out strategy.

Proposition 5 Adding imitation, fewer industries are transferred from the North to the South. The measure of product cycle industries gets narrowed.

Next, I investigate the determinants to the cutoff points. Comparative statics are conducted with respect to various factors, such as the increment to quality, R&D costs, labor endowment and so on. Table B.19 summarizes the simulated results. Further with the help of Figure B.26 to B.31, I show the movement of the cutoff functions as a result of the changes. Except Figure B.31, all solid lines are plotted with the minimum values in Table B.1, while all dashed lines are plotted with the maximum values. For simplicity, the $f(z)$ function is omitted from now on. I only experiment results with my own cutoff functions.

(1) Effect of relative wage ω

The relative wage is the value that the cutoff functions equal to, in order to find out the cutoff points. I suppose it to be exogenous in the theoretical model. As drawn in Figure B.25, with an increase in ω (from 1.2 to 1.25), all cutoff points (\underline{z} , \bar{z} and \bar{z}') move to the right. The

⁸ The one dropped is $F(z) \equiv \frac{-B - \sqrt{B^2 - 4AC}}{2A}$, where $A = a_N L$, $B = a_N L^* - \lambda(z)a_N L - a_N a_F \mu - (1 - 1/\lambda(z))a_F L$, and $C = -\lambda(z)a_N L^* - (1 - 1/\lambda(z))a_F L^*$.

measure of low-technology industries expands, and that of high-technology industries shrinks. It is difficult to predict the change in medium-technology industry sizes. However, under reasonable parameterizations, there is an expansion in medium-technology industries as well. Intuitively, when the relative wage rises, the manufacturing cost in the North increases, making less appealing to produce over there. The incentive for innovation also gets reduced. More firms will carry out FDI for cost saving. Hence, the measure of firms in the South enlarges.

(2) Effect of quality increment $\lambda(z)$

Hence, Figure B.26 is sketched to test the influence of the increment to quality. From the left panel, the correlation between $\lambda(z)$ and $F(z)$ is discovered to be positive. It means that with an increase in the value of $\lambda(z)$ for each point z , the function should shift up. It is the same case for the $G(z)$ function.

This relationship is further illustrated in the right panel. The solid lines are the initial functions, drawn with $\lambda(z) = 1 + z^3$. And the dashed ones are new functions with an increase in $\lambda(z)$, calibrated with $\lambda(z) = 1 + 2z^3$. For any $z \in [0, 1]$, the value of $\lambda(z) = 1 + 2z^3$ is weakly greater than that of $\lambda(z) = 1 + z^3$ (if and only if $z = 0$, their values are equal). Except of the change in $\lambda(z)$ function, all other parameters remain their benchmark values. The simulation indicates that the dashed line generally locates above the solid one. As a result, the cutoff \bar{z}' is moved to the left. It is because that when innovation productivity raises, it is more profitable to innovate in the North. The Northern firms' price is positively related to quality. Correspondingly, the share of industries preferring moving-up strategy is increased.

(3) Effect of the innovation cost a_N

The effect of an increase in innovation cost is shown in Figure B.27. As the unit innovation cost of the Northern firms a_N increases, the value of $F(z)$ decreases as a result, but the $G(z)$ function does not move. Thus, a right movement of $F(z)$ function makes \bar{z}' to turn right as well. A few industries have switched from always staying in the North to experiencing a product cycle between the two regions. When the relative cost of further innovation rises, followers in more industries prefer to carry out FDI and transfer their production to the South. The range of product cycle

industries is pushed toward the high-technology end of the industry spectrum.

(4) Effect of the adaptation cost a_F

Opposite to an increase of a_N , the adaptation cost a_F and $F(z)$ is positively correlated. Hence, the $F(z)$ function shifts up and then moves the cutoff point \bar{z}' to the left, as displayed in Figure B.28. The industries revealing product-cycle pattern turns to be a smaller group. More costly adaptation leads firms prefer to stay in the North.

(5) Effect of Northern labor endowment L

The left panel of Figure B.29 shows that the relationship between L and $F(z)$ is negative. As the labor resource in the North enlarges, the value of $F(z)$ goes up a little bit, which makes a right shift of the $F(z)$ curve. From Figure B.29, the size of medium-technology industry expands slightly. On the other hand, the pressure in the Northern labor market has relieved, which is likely to pull down the relative wage. The collection of medium-technology industry gets fewer. In the right panel, it is shown that the latter influence overwhelms the former one. At last, the number of medium-technology industries goes down. It makes sense since it is easier and cheaper to hire labor in the North, thus leading to an expansion of high-technology industries.

(6) Effect of Southern labor endowment L^*

As display in Figure B.30, at first, a larger Southern labor force shifts the $F(z)$ function to the right, resulting in a small expansion of medium-tech industry. Meanwhile, the competition in the Southern labor market is loosened, resulting in a lower Southern wage. While the Northern wage is unchanged, the relative wage ω goes up. It makes it relatively more expensive to produce in the North. The second effect dominates the first one. At last, the number of medium-technology industries grows even larger. More followers in the North prefer to carry out FDI in the South.

(7) Effect of imitation intensity μ

Finally, I look at the potential impact from strengthened IPP in the South, with the help of Figure B.31. Different from previous discussion, the solid line now is calibrated with the highest value of μ in Table B.1, and the dashed line is with the lowest value. The shifting from the solid line to the dashed line results from tighter IPP, which is reflected by a drop of μ from 1.5 to 0.5.

The first cutoff \bar{z}' moves to the right, indicating the measure of product-cycle industries turns larger, while the second cutoff \underline{z} is fixed. The protection lets the multinationals feel safer, and makes them to earn a positive profit for a longer period. More Northern followers will join in the group to conduct FDI.

Proposition 6 The strength in Southern IPP expands the number of product-cycle industries.

4.6 Empirical Tests

The theoretical model established a dynamic product cycle with vertical differentiation. Heterogeneity in industrial R&D productivity determines the choice of firms between investing in higher quality or migrating manufacturing to the South. Particularly important is that industries with moderate technology productivity see the production location move back and forth between the North and South. These firms face the risk of being imitated by Southern competitors. Tighter IPP in the South reduces this risk and thereby expands product cycle trade only in the extensive margin. Firms in industries with the lowest R&D productivity move permanently to the South and those with the highest remain in the North, experiencing no cycles.

In this section I test whether the product-cycle trade concentrates in medium-technology industries at first. Then I test whether enhanced IPP enforcement in the South promotes the development of product-cycle industries by increasing their number instead of enlarging trade volumes of incumbents. Note at the outset that the stark prediction of no product cycles in high-technology and low-technology goods is unlikely to hold in actual data for several reasons, including the inevitable differences between industry classification systems and sharp theory. Thus, the basic hypotheses I examine are modified to reflect this fact.

Hypothesis 1 The level of product-cycle trade with the North is the highest in industries with moderate R&D productivity.

Hypothesis 2 A higher level of IPP enforcement in the South has no significant effect on the intensive margin of the product-cycle trade with the North.

Hypothesis 3 A higher level of IPP enforcement in the South leads more industries to engage in the product-cycle trade with the North, especially in industries with moderate R&D productivity.

4.6.1 Basic Specification

I am interested in the degree of product-cycle trade (aggregated from the product level) in industry-level exports from the South to the North, or the intensive margin of product cycle trade. Compared to the substantial theoretical work on the product cycle, empirical investigation lags far behind. One primary empirical question to address is the identification of goods experiencing a product cycle. To date, trade economists have posited that the dynamics in production location result in a switch in trade balance. Thus, Southern firms initiate exporting to the North when the relevant technology and know-how leak into their countries, typically by imitation. Ultimately, this change reduces production of the same good in the North, inducing a shift in the bilateral trade status for the commodity in question.

This basic idea was initially implemented by Gagnon and Rose (1995)[21]. They define a PC good as any Standard International Trade Classification (SITC) 5-digit code in which a developed country's trade balance changes from a net exporter to a net importer. Later, Xiang (2005, 2007)[91] [92] compares the product listings of the 1987 SIC manual and the 1972 SIC manual, and claims that new goods are those most recently produced in the U.S. between 1972 and 1987. Adopting a different approach, Feenstra and Rose (2000)[18] rank goods on a worldwide basis rather than for each individual country. They argue that firms start exporting commodities to the U.S. in an order of complexity. That is, the later a good appears in the global market, the less sophisticated it is. Since any product is exported by a partial list of countries, taking account of these "missing" observations make their work a very complicated process.

I adopt Zhu's (2005)[95] definition, which was based on Gagnon and Rose (1995)[21]. Zhu develops a product-cycle trade measure that may be tracked across time and is comparable across countries. In her definition, if a country converts from a pure importer (positive imports and *zero* exports) from the U.S. to an exporter (of any amount) to the U.S., this specific product is classified

to be a PC good. For example, suppose that country A has imported commodity 1 from the U.S. since 1989 but does not export back any amount of that commodity until 1992. Then commodity 1 from country A is considered to be a PC good. In contrast, suppose country B both imports and exports commodity 1 with the U.S. in 1989, with a positive trade balance. Commodity 1 from country B is not a PC good. Hence, the definition is specific to pairs of countries and products. However, once a good's category is confirmed for a particular country, it is consistent over time.

Let i index products, j index industries, c index countries, and t index years. Then, according to Zhu (2005)[95], I define the product-cycle measure for industry j from country c at year t as follows. As shown in equation (4.18), the measure is the exports of PC goods to the U.S. as a share of total exports to the U.S. in industry j :

$$PC_{cjt} = X_{cjt}^P / X_{cjt} \quad (4.18)$$

where X_{cjt}^P is the total export value of PC goods in each four-digit ISIC industry and X_{cjt} is the export value of all goods in the industry. Note that since this measure is a trade share, it can be any continuous number from 0 to 1. The lower limit of 0 means that though country c does export to the U.S. in industry j at year t , there is no product cycle trade. A higher value of PC_{cjt} implies greater involvement of PC trade in industry j . One significant advantage of measuring a trade share instead of trade volume is that the impacts of common determinants of bilateral trade in both PC goods and other goods can be ruled out. As long as they have symmetric effects on both the PC goods and other products of the same industry, the product cycle measure is not affected.

First, I specify an econometric model of PC trade from Southern countries to the U.S. with respect to the R&D productivity, in order to test Hypothesis 1. An observation is industry j from country c in year t . The baseline specification is as follows.

$$PC_{cjt} = \alpha_j + \alpha_t + \alpha_1 \cdot R\&D_{jt} + \alpha_2 R\&D_{jt}^2 + \sigma W_{ct} + \epsilon_{cjt} \quad (4.19)$$

where $R\&D_{jt}$ is a measure of industry R&D intensity, which is my proxy for industry R&D productivity and is assumed to be the same across countries for each industry. W_{ct} is a vector of

time-variant controls, such as trade costs, financial conditions, factor endowments and the institutional environment, which may have an impact on all trade, including in PC goods. α_j are the industry fixed effects, and α_t are the year fixed effects. I add these fixed effects is to account for unmeasured changes within sectors and over time. Finally, ϵ_{cjt} is the error term. I cluster the regressions by 4-digit industry since I am interested in the level of product cycle measure across industries.

It is expected that the level of product-cycle trade is the largest in medium-technology industries. Hence, a quadratic term of R&D productivity is added to capture the inverse-U shape. $\alpha_1 > 0$ indicates that PC rises with the increase in industrial R&D productivity. With $\alpha_2 < 0$, at certain level of R&D productivity, the PC reaches its maximum level and starts to be lower.

Second, in regard to Hypothesis 2, I try two specifications. The first one (4.20) only takes account of the IPP enforcement measure across countries and its effect on PC trade. The second one (4.21) adds some interaction terms of *IPP* and *R&D* to consider how the effect of IPP enforcement across industries.

$$PC_{cjt} = \beta_j + \beta_t + \beta_1 \cdot IPP_{c,t-5} + \sigma W_{ct} + \epsilon_{cjt} \quad (4.20)$$

where $IPP_{c,t-5}$ is the measure of IPP enforcement in country c at year $t - 5$. I suppose that it takes some time for a change in IPP policy to affect trade in PC goods. It is $t - 5$ since the IPP enforcement dataset is available at a five-year basis. β_j are the industry fixed effects and β_t are the year fixed effects. Now I cluster the errors by countries since I would like to know how the country-level IPP enforcement influences PC measures.

$$PC_{cjt} = \beta_j + \beta_t + \beta_1 \cdot IPP_{c,t-5} + \beta_2 \cdot IPP_{c,t-5} \cdot R\&D_{jt} + \beta_3 \cdot IPP_{c,t-5} \cdot R\&D_{jt}^2 + \sigma W_{ct} + \epsilon_{cjt} \quad (4.21)$$

Since Hypothesis 2 claims that the higher level of IPP enforcement has no significant effect on the intensive margin of product-cycle trade. I predict that the estimated β_1 is indifferent from zero even at a 10-percent level.

Third, I examine whether the change in IPP enforcement deters the extensive margin of the product-cycle trade, which is stated by Hypothesis 3. In particular, I focus on three aspects of

extensive margin adjustments: the probability of an industry becomes, remains, or no longer to contain any product-cycle trade.

The probability of becoming a product-cycle industry is tested as follows

$$Pr(x_{cjt} = 1|x_{cj,t-5} = 0) = \Phi(\gamma_j + \gamma_t + \gamma_1 \cdot IPP_{c,t-5} + \gamma_2 \cdot IPP_{c,t-5} \cdot R\&D_{jt} + \gamma_3 \cdot IPP_{c,t-5} \cdot R\&D_{jt}^2 + \sigma W_{ct} + \epsilon_{cjt}) \quad (4.22)$$

where $Pr(x_{cjt} = 1|x_{cj,t-5} = 0)$ is the probability that an industry has no product-cycle trade five years ago, but has some this year.

Then, the probability of currently have some product-cycle trade

$$Pr(x_{cjt} = 1) = \Phi(\gamma_j + \gamma_t + \gamma_1 \cdot IPP_{c,t-5} + \gamma_2 \cdot IPP_{c,t-5} \cdot R\&D_{jt} + \gamma_3 \cdot IPP_{c,t-5} \cdot R\&D_{jt}^2 + \sigma W_{ct} + \epsilon_{cjt}) \quad (4.23)$$

Lastly, the probability of quitting to be a product-cycle industry

$$Pr(x_{cjt} = 0|x_{cj,t-5} = 1) = \Phi(\gamma_j + \gamma_t + \gamma_1 \cdot IPP_{c,t-5} + \gamma_2 \cdot IPP_{c,t-5} \cdot R\&D_{jt} + \gamma_3 \cdot IPP_{c,t-5} \cdot R\&D_{jt}^2 + \sigma W_{ct} + \epsilon_{cjt}) \quad (4.24)$$

where $Pr(x_{cjt} = 0|x_{cj,t-5} = 1)$ is the probability that an industry has no product-cycle trade this year, but has some five years ago.

The model predicts that with stronger Southern IPP, the likelihood of product-cycle trade would grow larger and this positive effect would be most pronounced in industries with moderate technology levels. A few high-technology industries, which in the model retained production in the North, would now move beyond the cutoff and shift production to the South. Unfortunately, it is not possible determine the exact cutoffs of industries with real data. Thus, I focus on whether more strict implementation of IPP is associated with the increased probability of trade in product cycle goods, implying that $\gamma_1 > 0$.

I am also interested in whether this effect of IPP to expand the number of industries engaged in PC trade is stronger in industries with higher R&D productivity. As the model suggests, the impact should expand with R&D through the PC range but then diminish in industries with relatively high technology, since these are never transferred to the South. Thus, the coefficient

on the linear interaction term is expected to be significantly positive, i.e. $\gamma_2 > 0$, but that on the quadratic interaction term to be negative, $\gamma_3 < 0$. To sum up, the relationship between the probability and $IPP_{c,t-5}$ should display an inverse-U shape in the technology intensity of industries.

4.6.2 Econometric Methodology

The nature of my outcome variable raises an initial challenge for econometric estimation. PC_{cjt} , the product-cycle measure, is a fractional variable that can be any continuous number between zero and one, and there are a large number of observations at the lower bound. There are two possible reasons for PC_{cjt} to have a value of zero: first, this specific industry has no product cycle goods at all; second, this specific industry has at least one product cycle good, but has not exported to the U.S. yet.

OLS estimation is inappropriate in this situation since the regression equation could yield some predicted values of PC_{cjt} outside the range of $[0, 1]$, which makes no sense. Further, use of the beta regression will not work either. This approach is designed for the case where a percentage is the dependent variable, but excludes the lower and upper boundaries. Finally, the logistic regression is appropriate where the dependent variables are binary or multivariate choice outcomes and where the underlying probability fits a logistic distribution. Researchers sometimes apply a log-odds transformation to the logistic regression, but this approach fails when there are responses at the corners (i.e. 0 and 1). Thus, none of these econometric strategies applies to the fractional responses here.

An initial solution to this problem was the fractional logit model. Wedderburn (1974)[88], suggested a quasi-likelihood estimation of this model, which was generalized by McCullagh (1983)[65]. A more recent, and now the most common, strategy was proposed by Papke and Wooldridge (1996)[69]. They employ the quasi-maximum likelihood estimation (QMLE) to obtain robust estimators of the conditional mean parameters with satisfactory efficiency properties. In this framework the mean function takes the logistic form⁹.

⁹ The Stata code is introduced in Baum (2008)[6]. It is `glm dependent_variable independent_variables,`

It should be noted that the QMLE method is most appropriate when applied to cross-section data. For a balanced panel with a large cross-section dimension and limited time periods, Papke and Wooldridge (2008)[70] corrected the functional form to be a probit response. They also added the time averages for all explanatory variables to control for the problem of heterogeneity being correlated with the time-varying covariates. Their methodology can be extended to a two-stage framework to deal with endogenous explanatory variables. Furthermore, Wooldridge (2009)[90] suggested a more general solution to efficiently fit an unbalanced panel, even with nonlinear unobserved effects models. He pointed out that “even though QGLM does not exploit the panel structure, it was almost as efficient” with time averages¹⁰. Hence, I adopt the fractional probit panel model to conduct estimations.

Another important concern of my econometric model is endogeneity. There might be a two-way causation between the dependent variable PC_{cjt} and the primary explanatory variable of interest $IPP_{c,t-5}$. Countries with more product cycle trade may choose to adopt a tighter policy on intellectual property rights, in order to attract more FDI. To deal with this issue, I employ an instrumental-variables (IV) approach. Any valid instruments should be correlated with a country’s IPP enforcement, but uncorrelated with the errors.

In recent literature (Nunn, 2007[68]; Ivus, 2010[45]; Maskus and Yang, 2013[64]), the colonial or historical origin of a country’s legal system is adopted as a natural candidate for an IV. It surely relates to the present degree of IPP, because countries often adopted a legal system brought in by their colonizers, but is unlikely to have direct impact on current trade. A country’s legal system may emanate from any of these five origins: British common law, French civil law, Socialist law, German law and Scandinavian law. Table B.20 categorizes the countries in my sample by their legal origins. No country originates from the Scandinavian law. So I exclude the German law (only South Korea) from the first stage as the reference group, in order to prevent collinearity. A group of dummy variables B_c , F_c and S_c is created to indicate whether a country c ’s legal system comes

link(logit) family(binomial) vce(robust) nolog

¹⁰ See <http://www.stata.com/statalist/archive/2012-05/msg00585.html>

from British, French, or Socialist laws respectively.

4.6.3 Data Description

The fundamental dataset I use is an unbalanced U.S. trade panel in the years 1989-2006 from the NBER¹¹. It is difficult to observe the switch pattern that identifies a product-cycle good at higher levels of aggregation, so I take advantage of the most disaggregated data available to the public¹². A product is defined as a HS10 code shipping from a certain country to the U.S. The same 10-digit code exporting to the U.S. from another country is considered another product. Because the HS codes came into use in 1989, I focus on trade data since that year.

Recall that there are two empirical requirements for a good to be classified as a PC good. First, a country must first import this good from the U.S. since 1989. Second, after importing for at least one year, this country starts exporting this good to the U.S.¹³ Once the detailed goods have been categorized, I aggregate up the data to the industry level, which is a SIC 4-digit code¹⁴, and then calculate out the product cycle measure.

Starting from Vernon (1966), the United States is considered to be among the most advanced countries in the world and is the birthplace of new technologies. As a result, I take the U.S. as the North. The World Bank classifies countries into different income groups. Any country with a gross national income per capita below U.S. \$6,000 in 1988 (calculated using the Atlas method) is considered to be a Southern country. The U.S. GNI per capital was \$22, 740 that year. The list of Southern countries are shown in Table B.20. My sample contains 37 countries, which is a limited number based on available intellectual property rights data.

There are two widely-used measures of IPP enforcement at the country level. The first one is the Ginarte and Park (1997)[23] (GP for short) index, which covers five aspects of patent laws:

¹¹ Data is available on http://faculty.som.yale.edu/peterschott/sub_international.htm.

¹² The U.S. trade dataset from the NBER has changed the goods classification for a few times. Zhu (2005)[95] picks up the longest 1978-88 period with products defined at SITC (Rev. 2) 5-digit level. And her average of product-cycle trade measure is higher than mine.

¹³ More aggregated definition of product and industry with longer sample period will be checked in the robustness part.

¹⁴ The NBER dataset has denoted its SIC industry for each 10-digit HS code.

coverage of fields of technology, membership in international patent agreements, provisions for loss of protection, legal enforcement, and patent duration. Each aspect takes a value between 0 and 1, and these are summed up to get the GP index. This index is available every five years in the period of 1960 to 2010.

The GP index measures the existence or absence of specific IP laws. However, a higher value of the GP index does not necessarily indicate an efficient administrative and judicial enforcement of these laws (Maskus and Yang, 2013[64]). Some countries may have higher GP indexes but the effective enforcement is weak. To deal with this issue, Hu and Png (2013)[43] developed a property rights index (PR for short) comes out to correct for this problem. It is the product of two variables: $PR = GP \times Fraser$, where *Fraser* is the Fraser Institute's index of legal systems and property rights¹⁵. The Fraser index ranges from 0 to 10 and exists at five-year intervals from 1970 to 2010. The PR index, which varies in principle from zero to 50, is my primary proxy for IPP enforcement. The GP index is also employed in the robustness estimations.

The variables of R&D intensity and factor endowments are all from Maskus and Yang (2013)[64], available at five-year interval from 1975 to 2005. The R&D intensity (*R&D*) data is the ratio of R&D expenditure to sales in each SIC4 industry, taken from the COMPUSTAT dataset covering U.S. firms. In cases where there is no record at the 4-digit level, the 3-digit R&D intensity is assigned. I assume that these industry-level R&D intensities are the same for all sample countries. National capital endowments are estimated by the perpetual inventory method using the investment data of each exporting country since 1972. These calculated capital stocks by country are divided by labor forces to derive the relative capital endowment (*Capital*). The skilled-labor endowment for each country is based on measures of average educational attainment for the population aged 25 and over, as reported initially by Barro and Lee (2001)[5]. Specially, the skill endowment is the relative human capital stock, defined as the ratio of the population over 25 that completed at least a secondary education to the population in this group that did not complete high school.

¹⁵ Available at <http://www.freetheworld.com/release.html>.

The measure of financial development (*Finance*) is the amount of credit issued by banks and other financial intermediaries to the private sector as a share of GDP (private credit), which I obtain from the World Bank's Financial Development and Structure Dataset. GDP per capita (*PCGDP*) is gross domestic product divided by midyear population in constant 2005 U.S. dollars. I adopt the simple distance between the most populated cities to proxy for trade cost. All these variables above plus population size (*Population*) for each country all come from the World Bank indicators. Finally, the rule of law (*Law*) and control of corruption (*Corruption*) indices are from the World Governance Indicators¹⁶ explained by Kaufmann et al. (2010)[51]. The rule of law measures the quality of contract enforcement, the police, and the courts, as well as the likelihood of crime and violence. The control of corruption measures the exercise of public power for private gain, including both petty and grand corruption and state capture. The governance estimates are normally distributed with a mean of zero and a standard deviation of one in each period. This implies that virtually all scores lie between -2.5 and 2.5, with higher scores corresponding to better outcomes.

In all, the baseline panel database contains 347 four-digit SIC manufacturing industries from 54 countries every five year from 1990 to 2005. There is a total of 26,763 observations. Major features of the dataset are listed in Table B.21. First, the average of the product cycle measure is 0.191. Second, 53.67 percent of observations have a zero value of PC. Perhaps surprisingly, in 10.78 percent of the observations, spread over 286 industries, $PC = 1$, meaning that all trade within the industry is product cycle in character. More details of *PC* across industries are shown in Table B.22. Also, Table B.23 provides information of the extensive margin of product-cycle industries over the sample years.

Next the measure of R&D intensity averaged 0.022 across industries. The maximum is 0.337 in the industry 2836 Biological Products, Except Diagnostic Substances. The IPP (PR) index has a mean of 11.87 out of a potential maximum of 50. Over time, the average of GDP per capita in constant 2005 U.S. dollars is \$4.163 thousand, and the mean of population is 0.134 billion people.

¹⁶ Available at <http://www.govindicators.org>.

The average distance to the U.S. is 8.413 thousand km and the average financial development index is 0.427. The corruption index ranges from -1.41 to 1.54, with a negative average of -0.166. The rule of law index has a slightly higher average at a value of -0.15, in a range of -1.77 to 1.27. The law environment of these developing countries is lagging behind. Capital endowment per labor force is 20,573 constant 2000 U.S. dollars. Finally, the average of the skilled labor ratio is 0.438.

Moreover, the correlation among the key variables is low. As indicated in Table B.24, the correlation between *PC* and *R&D* is 0.1096, the correlation between *PC* and *IPP* is only 0.0429, and the correlation between the two independent variables *R&D* and *IPP* is 0.0843.

4.6.4 Empirical Results

This subsection provides the empirical findings from the econometric estimation, using the country-industry level panel data. Table B.25 presents estimation of the econometric model (4.19). All columns (1) to (6) are results from the fractional probit QMLE model. Specifically, column (1) - (3) presents QMLE estimates that do not remove any unobserved effect, with a full set of country controls and time-averages of these exogenous controls. Year and industry fixed effects are taken account of in the last three columns. For all columns, the estimates on time-average controls and dummies are not shown. I add more robustness to support the basic results later. Generally, most estimates accord with expected results. Except column (3), the estimated coefficients on *R&D* are positive, though not very significant from zero. The quadratic R&D estimator in column (6) is a statistically significant negative number.

Table B.26 to B.27 shows the results of testing Hypothesis 2. The estimators of IPP enforcement have a significant effect on *PC*, which is contrary to my expectation. However, adding IV corrections in Table B.27 reduces its significance and make the results as expected.

Table B.28 to B.30 shows the results of the extensive margin of PC trade. More discussion will be added later.

4.7 Conclusion

In this chapter, I develop a North-South model of product cycle dynamics in which there exists a continuum of industries that are different in R&D productivity. Northern firms innovate to push forward the quality frontier and also have a choice to move relatively old generations of technology to the South. Manufacturing cost in the South is cheaper but entails risk of imitation by local firms. The firms' decisions in steady state vary across industries. In equilibrium, there is continuous innovation in the high- technology industries, which remain in the advanced North. Production in low-technology industries is carried out by multinationals at first, but copied by Southern firms gradually. Ultimately all products in the low-technology industries are produced by firms owned in the South and remain there. Product cycle dynamics only appear in medium-technology industries. Here, technologies are transferred to the South via FDI and may be imitated by Southern firms. Ultimately these technologies are improved by Northern firms in a quality ladder.

By adding imitation in the South, fewer technologies are transferred from the North in steady-state equilibrium. In particular, the range of technological sophistication within which products remain always in the North expands. Thus, stronger intellectual property protection in the South, which reduces imitation risk, is likely to reduce this range and increase the average technology levels of goods transferred abroad. My paper is the first one in literature to discuss the effect of IPP on intensive and extensive margins by a product cycle model.

There are two limitations of this chapter that I will address in future work. First, I assume that imitation is exogenous and there is perfect competition among Southern imitators. Changing the imitation intensity to be endogenous is likely to shrink the range of product-cycle industries, which is opposite to the above analysis. Second, I suppose that the relative wage rate is fixed across countries, despite the fact that changes in innovation, imitation, and technology transfer should affect it. More work will be undertaken to deal with these remaining problems.

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Appendix A

Derivatives and Proofs

A.1 Final Good Assembler's Problem

The final good assembler's problem is given as

$$\max_{x_l, x_h} \pi^{jk} = \phi^{1-\alpha} \zeta_z^\alpha (q_l)^{\alpha z} (x_l^j)^{\alpha z} (q_h)^{\alpha(1-z)} (x_h^k)^{\alpha(1-z)} - p_l^j x_l^j - p_h^k x_h^k \quad (2.17)$$

$$\partial x_l : \alpha z \phi^{1-\alpha} \zeta_z^\alpha (q_l)^{\alpha z} (x_l^j)^{\alpha z - 1} (q_h)^{\alpha(1-z)} (x_h^k)^{\alpha(1-z)} = p_l^j \quad (A.1)$$

$$\partial x_h : \alpha(1-z) \phi^{1-\alpha} \zeta_z^\alpha (q_l)^{\alpha z} (x_l^j)^{\alpha z} (q_h)^{\alpha(1-z)} (x_h^k)^{\alpha(1-z) - 1} = p_h^k \quad (A.2)$$

Using (A.1) divided by (A.2), we derive the relationship between x_h^k and x_l^j .

$$x_h = \frac{1-z}{z} \frac{p_l^j}{p_h^k} x_l \quad (A.3)$$

Plugging (A.3) into (A.1), we get the reduced-form expression for x_l^j .

$$(x_l)^{1-\alpha} = \alpha z^{1-\alpha} \phi^{1-\alpha} (q_l)^{\alpha z} (q_h)^{\alpha(1-z)} (p_l^j)^{\alpha(1-z)-1} (p_h^k)^{-\alpha(1-z)} \quad (A.4)$$

Continuing from (2.5), we calculate as

$$\begin{aligned}
p^{jk} &= \left(\frac{\phi}{y^{jk}}\right)^{1-\alpha} \\
&= \left[\frac{\phi}{\zeta_z(q_l x_l^j)^z (q_h x_h^k)^{1-z}}\right]^{1-\alpha} \\
&= \left[\frac{\phi}{z^{-z}(1-z)^{-(1-z)} q_l^z q_h^{1-z} (x_l^j)^z (1-z)^{1-z} z^{-z(1-z)} (p_l^j)^{1-z} (p_h^k)^{-(1-z)} (x_l^j)^{1-z}}\right]^{1-\alpha} \\
&= \frac{1}{\alpha} \left(\frac{p_l^j}{q_l}\right)^z \left(\frac{p_h^k}{q_h}\right)^{1-z} = \frac{1}{\alpha} \left(\frac{p_l^j}{\lambda_l^j}\right)^z \left(\frac{p_h^k}{\lambda_h^k}\right)^{1-z}
\end{aligned} \tag{A.5}$$

Then substituting (A.29) back to (2.5), we obtain the function for the quantity of final good

$$y^{jk} = \phi (p^{jk})^{-\frac{1}{1-\alpha}} = \phi \left[\frac{1}{\alpha} \left(\frac{p_l^j}{q_l}\right)^z \left(\frac{p_h^k}{q_h}\right)^{1-z} \right]^{-\frac{1}{1-\alpha}} \tag{A.6}$$

A.2 Miscellaneous Calculations in Case 3

A.2.1 Calculations Related to Good Market

Recall that $\phi = \frac{E}{\int_0^1 p(j)^{-\alpha/(1-\alpha)} dj}$ where $E = L^S + \omega L^N$. We define the price index $P = \int_0^1 p(j)^{-\alpha/(1-\alpha)} dj$, which is thought as exogenous. In order to proceed the calculation, we also need to assume that $\frac{L^S}{L^N} > \frac{(1-\alpha-z\alpha)\omega}{z\alpha}$. Then we take derivatives with respect to the relative wage ω .

$$\frac{\partial x_l^S}{\partial \omega} = -\omega^{-z\frac{\alpha}{1-\alpha}-1} \left[\frac{z\alpha}{1-\alpha} L^N + \left(\frac{z\alpha}{1-\alpha} + 1\right) \frac{L^S}{\omega} \right] \frac{z\alpha^{\frac{1}{1-\alpha}}}{P} (q_l)^{z\frac{\alpha}{1-\alpha}} \left(\frac{q_h}{\lambda_h}\right)^{(1-z)\frac{\alpha}{1-\alpha}} < 0 \tag{A.7}$$

$$\frac{\partial x_h^S}{\partial \omega} = \omega^{-z\frac{\alpha}{1-\alpha}} \left[\left(1 - \frac{z\alpha}{1-\alpha}\right) L^N - \frac{z\alpha}{1-\alpha} \frac{L^S}{\omega} \right] \frac{(1-z)\alpha^{\frac{1}{1-\alpha}}}{\lambda_h P} (q_l)^{z\frac{\alpha}{1-\alpha}} \left(\frac{q_h}{\lambda_h}\right)^{(1-z)\frac{\alpha}{1-\alpha}} < 0 \tag{A.8}$$

$$\frac{\partial p^{SN}}{\partial \omega} = \frac{z}{\alpha} (q_l)^{-z} \left(\frac{\lambda_h}{q_h}\right)^{1-z} \omega^{z-1} > 0 \tag{A.9}$$

$$\frac{\partial y^{SN}}{\partial \omega} = \frac{\omega^{-z\frac{\alpha}{1-\alpha}}}{P} \left[\left(1 - \frac{z\alpha}{1-\alpha}\right) L^N - \frac{z\alpha}{1-\alpha} \frac{L^S}{\omega} \right] \left[\frac{1}{\alpha} \left(\frac{1}{q_l}\right)^z \left(\frac{\lambda_h}{q_h}\right)^{1-z} \right]^{-\frac{1}{1-\alpha}} < 0 \tag{A.10}$$

$$\frac{\partial \pi^{SN}}{\partial \omega} = \frac{(1-\alpha)\omega^{-z\frac{\alpha}{1-\alpha}}}{P} \left[\left(1 - \frac{z\alpha}{1-\alpha}\right) L^N - \frac{z\alpha}{1-\alpha} \frac{L^S}{\omega} \right] \left[\alpha (q_l)^z \left(\frac{q_h}{\lambda_h}\right)^{1-z} \right]^{\frac{1}{1-\alpha}} < 0 \tag{A.11}$$

$$\frac{\partial \pi_l^S}{\partial \omega} = x_l^S + (\omega - 1) \frac{\partial x_l^S}{\partial \omega} \quad (\text{A.12})$$

$$\frac{\partial \pi_h^N}{\partial \omega} = -x_h^N + (\lambda_h - \omega) \frac{\partial x_h^N}{\partial \omega} < 0 \quad (\text{A.13})$$

$$\frac{\partial x_R}{\partial z} = \left[\frac{1}{1-z} + \frac{z}{(1-z)^2} \right] \frac{\lambda_h}{\omega} > 0 \quad (\text{A.14})$$

$$\frac{\partial x_R}{\partial \omega} = -\frac{z}{1-z} \frac{\lambda_h}{\omega^2} < 0 \quad (\text{A.15})$$

$$\frac{\partial \pi_R}{\partial \omega} = \frac{z \lambda_h [(\omega - 1)^2 + \lambda_h - 1]}{1-z [\omega(\lambda_h - \omega)]^2} > 0 \quad (\text{A.16})$$

A.2.2 Calculations Related to Firm Measures

The relationship among firm measures reflected by equation (2.54) is listed from (A.17) to (A.21).

$$n_l^S = \frac{L^S}{\iota_l(1+\kappa)c_h + x_l^S} = \frac{L^S c_l}{(\omega - 1)x_l^S c_h + x_l^S c_l} \quad (\text{A.17})$$

$$n_l^N = \frac{L^N}{\iota_l a_l + \frac{\iota_l}{\mu_h} x_h^N} = \frac{L^N (1+\kappa) c_l}{(\omega - 1)x_l^S (a_l + \frac{a_h \omega}{\lambda_h - \omega})} \quad (\text{A.18})$$

$$n_h^N = \frac{z(\omega - 1)\lambda_h a_h L^S}{(1-z)x_l^S [(\omega - 1)c_h + c_l](1+\kappa)(\lambda_h - \omega)} \quad (\text{A.19})$$

$$n_h^N = \frac{\iota_l}{\mu_h} n_l^S \quad (\text{A.20})$$

$$n_h^S + n_l^N = 1 - \left(1 + \frac{\iota_l}{\mu_h}\right) n_l^S \quad (\text{A.21})$$

From (A.17), we have

$$\frac{\partial n_l^S}{\partial \omega} = -\frac{L^S c_l}{[(\omega - 1)x_l^S c_h + x_l^S c_l]^2} [x_l^S c_h + (\omega c_h - c_h + c_l) \frac{\partial x_l^S}{\partial \omega}] \quad (\text{A.22})$$

Also, from (A.18), we get

$$\frac{\partial n_l^S}{\partial \omega} = -\frac{L^N (1 + \kappa) c_l}{[(\omega - 1)x_l^S (a_l + \frac{a_h \omega}{\lambda_h - \omega})]^2} [x_l^S (a_l + \frac{a_h \omega}{\lambda_h - \omega}) + (\omega - 1) (\frac{a_h \omega}{\lambda_h - \omega}) \frac{\partial x_l^S}{\partial \omega} + (\omega - 1) x_l^S \frac{a_h \lambda_h}{(\lambda_h - \omega)^2}] \quad (\text{A.23})$$

Since $\frac{\partial x_l^S}{\partial \omega} < 0$, it is difficult to tell the sign of (A.22) and (A.23) at this moment.

$$\frac{\partial n_R}{\partial \omega} = -\frac{1 - z}{z} \frac{(1 + \kappa) c_l}{\lambda_h a_h} \left[\frac{1}{\omega - 1} + \frac{\lambda_h - \omega}{(\omega - 1)^2} \right] < 0 \quad (\text{A.24})$$

A.2.3 Calculations Related to R&D Intensities

There are two different signs for $\partial \iota / \partial \omega$ if we use different representative methods.

$$\frac{\partial \iota}{\partial \omega} = -\frac{a_h \lambda_h L^N}{(a_l \lambda_h - a_l \omega + a_h \omega)^2} < 0 \quad (\text{A.25})$$

$$\frac{\partial \iota}{\partial \omega} = \frac{c_l L^S}{(1 + \kappa)[(\omega + 1)c_h + c_l]} > 0 \quad (\text{A.26})$$

$$\frac{\partial \mu_h}{\partial \omega} = \frac{-x_h^N + (\lambda_h - \omega) \frac{\partial x_h^N}{\partial \omega}}{a_h \omega} - \frac{(\lambda_h - \omega) x_h^N}{a_h \omega^2} < 0 \quad (\text{A.27})$$

$$\begin{aligned} \frac{\partial \iota_l}{\partial \omega} &= \frac{x_l^S + (\omega - 1) \frac{\partial x_l^S}{\partial \omega}}{(1 + \kappa) c_l} = \phi z \alpha^{\frac{1}{1-\alpha}} (\omega)^{-1} \left(\frac{q_l}{\omega} \right)^{z \frac{\alpha}{1-\alpha}} \left(\frac{q_h}{\lambda_h} \right)^{(1-z) \frac{\alpha}{1-\alpha}} \\ &\quad - (\omega - 1) \omega^{-z \frac{\alpha}{1-\alpha} - 1} \left[\frac{z \alpha}{1 - \alpha} L^N + \left(\frac{z \alpha}{1 - \alpha} + 1 \right) \frac{L^S}{\omega} \right] \frac{z \alpha^{\frac{1}{1-\alpha}}}{P} (q_l)^{z \frac{\alpha}{1-\alpha}} \left(\frac{q_h}{\lambda_h} \right)^{(1-z) \frac{\alpha}{1-\alpha}} \\ &= \omega^{-z \frac{\alpha}{1-\alpha} - 1} \frac{z \alpha^{\frac{1}{1-\alpha}}}{P} (q_l)^{z \frac{\alpha}{1-\alpha}} \left(\frac{q_h}{\lambda_h} \right)^{(1-z) \frac{\alpha}{1-\alpha}} \left\{ [\omega - (\omega - 1) \frac{z \alpha}{1 - \alpha}] L^N + [1 - (\omega - 1) \frac{z \alpha}{1 - \alpha}] \frac{L^S}{\omega} \right\} \end{aligned} \quad (\text{A.28})$$

A.2.4 Analytical Solution to the Relative Wage

$$\begin{aligned}
& \omega^2[a_l L^S - L^N(1 + \kappa)c_h - a_h L^S] \\
& + \omega[a_h L^S - (1 + \kappa)c_l L^N - (1 + \lambda_h)a_l L^S + (1 + \lambda_h)(1 + \kappa)c_h L^N] \\
& + [a_l L^S - (1 + \kappa)c_h L^N + (1 + \kappa)c_l L^N]\lambda_h = 0
\end{aligned} \tag{2.59}$$

$$\begin{aligned}
\text{Set } a &= a_l L^S - L^N(1 + \kappa)c_h - a_h L^S \\
b &= a_h L^S - (1 + \kappa)c_l L^N - (1 + \lambda_h)a_l L^S + (1 + \lambda_h)(1 + \kappa)c_h L^N \\
c &= [a_l L^S - (1 + \kappa)c_h L^N + (1 + \kappa)c_l L^N]\lambda_h
\end{aligned} \tag{A.29}$$

The analytical solutions to the relative wage ω are

$$\omega_{1,2} = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a} \tag{A.30}$$

Following Glass and Saggi (2002), our Southern working population $L^S = 6$ and Northern working population $L^N = 3$. We consider the unit cost of Northern innovation of the high-tech input a_h as 3 and that of the low-tech input a_l as 2, since the high-tech input is more skill-intensive. On average the cost of imitation is 65 percent of that of innovation (Mansfield Schwartz and Wagner, 1981[63]). As a result, $c_l = 1.3$, $c_h = 1.95$.

We have the quality increment of the low-tech input $\lambda_l = 1.5$, the quality increment of the high-tech input $\lambda_h = 3$, and quality jumps for them respectively $\eta = 2$, $\theta = 3$. Additionally, Case 3 indicates that the final good assembler in the North imports the low-tech input from overseas, and procures the high-tech input domestically. The share of the low-tech input used in the final assembling process is analogous to the proportion of vertical specialization in our model. Thus, we take the value of z to be 0.3 since in the real world vertical specialization accounts for 30 percent of global exports in 1990 (Hummels et al., 2001[44]).

As indicated in Broda and Weinstein (2006)[11], the elasticity of substitution among varieties ϵ is 6.6 in the 5-digit SITC level ($\alpha = 0.848$). The amount of total varieties in their 5-digit level is 2715. Due to our quality ladder framework, there is always no horizontal variety expansion.

Hence we suppose there are 2715 final goods in our economy and make the price index $P = \int_0^1 p(j, t)^{-\alpha/(1-\alpha)} dj = 2715p^{SN}$ to facilitate simulation. Finally, we set the Southern IPRs parameter $\kappa = 0.3$ (He and Maskus, 2012[40]).

Due to the values we set above, one solution to the relative wage is negative, which contradicts our assumption that ω is greater than 1. Thus, the quadratic function only has one meaningful solution for ω , which equals to 1.2839¹. Table B.2 shows our baseline numerical results. This table just shows one possible example of calibration. The sizes of firm measure are economically reasonable in Table B.2. In fact, numerical results change quickly even with minor adjustment of setups, but the comparative statics stand.

A.3 Discussion for Case 4

In Case 4, the Southerners specialize in producing the high-tech input and the Northerners specialize in producing the low-tech input. $j = N, k = S$, and hence $p_l^N = \lambda_l, p_h^S = \omega$. Symmetrically to Case 3, because of $x_l^S = 0, x_h^N = 0$, we have $\iota_l = 0, \mu_h = 0$.

Equations (2.10), (2.11), (2.43), (2.23) and (2.24) can be simplified to be

$$\left\{ \begin{array}{l} n_l^S + n_l^N = 1 \\ n_h^S + n_h^N = 1 \\ \mu_l n_l^N = \iota_h n_h^S \\ n_h^S \iota_h a_h + n_l^N x_l^N = L^N \\ n_l^N \mu_l (1 + \kappa) c_l + n_h^S x_h^S = L^S \end{array} \right. \quad (\text{A.31})$$

Firm measure relationships are given by

$$n_l^N = \frac{L^S}{\mu_l (1 + \kappa) c_l + \frac{\mu_l}{\iota_h} x_h^S} \quad (\text{A.32})$$

$$n_l^N = \frac{L^N}{\mu_l a_h + x_l^N} \quad (\text{A.33})$$

¹ The assumption that $\frac{L^S}{L^N} > \frac{(1-\alpha-z\alpha)\omega}{z\alpha}$ is satisfied numerically.

$$n_h^S = \frac{\mu_l}{\iota_h} n_l^N \quad (\text{A.34})$$

$$n_l^S + n_h^N = 1 - \left(1 + \frac{\mu_l}{\iota_h}\right) n_l^N \quad (\text{A.35})$$

From equation (A.32) and (A.33), the relative wage ω in this case is calculated in the following quadratic function

$$\begin{aligned} (a_h L^S - c_l L^N - a_l L^S) \omega^2 + [(1 + \lambda_l) c_l L^N - (1 + \kappa) c_h L^N - (1 + \lambda_l) a_h L^S + a_l L^S] \omega \\ + [a_h L^S - c_l L^N + (1 + \kappa) c_h L^N] \lambda_l = 0 \end{aligned} \quad (\text{A.36})$$

In this case, one of the calibrated value of ω is still a negative number. We will use the calculated $\omega = 1.2839$ to do all calibration. Other parameter values remain the same as Case 3. Basic Results are shown in Table B.8.

A.4 Predictions in Lu (2007)

To facilitate comparing my work to Lu (2007), this subsection briefly introduces some basics of her model. Notations are altered a little bit to fit my setup. First of all, Assumption 1 needs to hold in order to arrive at her major predictions². By assuming this, the cutoff functions will intersect with the relative wage within the reasonable range of z between 0 and 1. Hence, it ensures the existence of the cutoff points and their uniqueness. The detailed proof is shown in Lu (2007). To save space, I do not repeat it here.

Assumption 1 (Single Crossing Property) $\lambda(0) < \omega_{t_0} < \omega(1)$, where ω_{t_0} denotes the initial relative Northern wage when FDI is prohibited.

In fact, the framework of Lu (2007) is almost the same as the descriptions in the last two subsections of my paper, except that there is no role of Southern imitation. In her paper, the only

² See Lu (2007) for proof.

way to transfer technology to the South is by means of FDI. Sorted by R&D productivity, industries are categorized into three groups: high-technology, medium-technology, and low-technology. The first cutoff point \bar{z} is to separate high-technology and medium-technology industries. Its solution is now $f(z) \equiv \frac{a_F}{a_N} \left(1 - \frac{1}{\lambda(z)}\right) + \lambda(z) = \omega$. The second cutoff \underline{z} is to distinguish low-technology industries from medium-technology industries. It is the solution to $g(z) \equiv \lambda(z)^2 = \omega$. A similar process of finding out these cutoff functions is elaborated in the next section.

In high-technology industries, Northern firms engaged in innovation continuously and keeps production within the Northern border. In industries with relatively-lower technology, Northern followers shift production to the cheaper South. The difference is that in low-technology industries, production remains there and technology never gets improved. However, in medium-tech industries, there is still incentive for Northern firms to innovate and return production to the North. As a result, medium-technology industries are product-cycle industries.

A.5 Derive the Cutoff Functions

A.5.1 The First Cutoff

The first cutoff is to distinguish high-technology industries and the rest (including low-technology and medium-technology). It is denoted as \bar{z} in Lu (2007)[60]. To make a distinction, I denote my first cutoff as \bar{z}' .

I call any industry $z_H \in [\bar{z}', 1]$ as the high-technology industries. In these industries, technology advantage defeats cost advantage; therefore, the nearest follower $J - 1$ deploys resources in innovation. There is no risk of FDI in all these industries since that would generate negative profits. When investment in R&D is successful, the new industry leader $J + 1$ takes over production and obtains instantaneous profits $\pi_N(z_H) = [1 - 1/\lambda(z)]E^W$, at a price of $p_N(z_H) = \lambda(z)\omega$. Note that there is no competition from the South.

From Taylor (2003)[83] and Lu (2007), we know that in steady state, the expected market value equal to $v_N(z_H) = \pi_N(z_H)dt + (1 - r_N(z_H)dt)[(1 - \iota(z_H)dt)v_N(z_H) + \iota(z_H)dt \cdot 0]$, where

$r_N(z_H)$ is the instantaneous rate of return of the extant Northern leader. $\iota(z_H)$ is the probability of displacement by a even superior generation. Reorganizing the above function, I solve out $r_N(z_H)$:

$$r_N(z_H) = \frac{\pi_N(z_H)}{v_N(z_H)} - \iota(z_H) \quad (\text{A.37})$$

While, in the rest of industries $z_{\bar{H}} \in [0, \bar{z})$, moving-out strategy is preferred to moving-up strategy. Cheap labor force in the South attracts the followers to invest overseas. The quality level of the active MNE leader J^* is one step behind the Northern leader. In Lu (2007)'s paper, the expected market value for J^* in steady state is $v_F(z_{\bar{H}}) = \pi_F(z_{\bar{H}})dt + (1 - r_F(z_{\bar{H}})dt)[(1 - \iota(z_{\bar{H}})dt)v_F(z_{\bar{H}}) + \iota(z_{\bar{H}})dt \cdot 0]$, where $r_F(z_{\bar{H}})$ is the instantaneous rate of return of the MNE leader. $\iota(z_{\bar{H}})$ is the probability of displacement by a superior version faced by J^* . However, by permitting imitation, the $v_F(z_{\bar{H}})$ function is altered to be $v_F(z_{\bar{H}}) = \pi_F(z_{\bar{H}})dt + (1 - r_F(z_{\bar{H}})dt)[(1 - \iota(z_{\bar{H}})dt - M_F(z_{\bar{H}})dt)v_F(z_{\bar{H}}) + \iota(z_{\bar{H}})dt \cdot 0 + M_F(z_{\bar{H}})dt \cdot 0]$. The possibility of displacement by successful imitation of Firm S is added. Solving $r_F(z_{\bar{H}})$ out, I obtain a function different from Lu (2007):

$$r_F(z_{\bar{H}}) = \frac{\pi_F(z_{\bar{H}})}{v_F(z_{\bar{H}})} - \iota(z_{\bar{H}}) - M \quad (\text{A.38})$$

In particular, from Section 3, it is calculated out that $\pi_N(z_H) = [1 - \frac{1}{\lambda(z)}]E^W$, and $\pi_F(z_H) = [1 - \frac{\lambda(z)}{\omega}]E^W$. It is obvious that $\pi_N(z_H)$ is increasing in z_H , and $\pi_F(z_{\bar{H}})$ is decreasing in $z_{\bar{H}}$. In the cutoff industry \bar{z}' , the nearest follower is indifferent between the moving-out strategy and the moving-up strategy. That is to say, the FDI venture and the R&D venture are equally profitable, i.e. $r_N(z_H) = r_F(z_{\bar{H}})$ at \bar{z} . The equal-profit equation for innovation and FDI for the follower $J-1$ at the cutoff industry \bar{z}' is:

$$\frac{\pi_N(\bar{z}')}{v_N(\bar{z}')} - \iota(\bar{z}') = \frac{\pi_F(\bar{z}')}{v_F(\bar{z}')} - \iota(\bar{z}') - M \quad (\text{A.39})$$

$\iota(\bar{z}')$ on both sides cancel out. Then, since the imitation intensity M is taken as given, plugging the profit and value functions (4.6), (4.8), (4.5) and (4.7) into (A.39), it is

$$\frac{[1 - \frac{1}{\lambda(\bar{z}')}]E^W}{\omega a_N} - \iota(\bar{z}') = \frac{[1 - \frac{\xi\lambda(\bar{z}')}{\omega}]E^W}{a_F} - \iota(\bar{z}') - M \quad (\text{A.39}')$$

Further substituting $E^W(t) = LE(t) + L^*E(t)^* = \omega L + L^*$ into the above function and arranging it into a quadratic function of ω , I derive

$$a_N L \omega^2 + [a_N L^* - \lambda(z) a_N L - a_N a_F M - (1 - \frac{1}{\lambda(z)}) a_F L] \omega - \lambda(z) a_N L^* - (1 - \frac{1}{\lambda(z)}) a_F L^* = 0 \quad (\text{A.40})$$

By solving out equation (A.40), there are two possible results. The first cutoff function is

$$F(z) \equiv \frac{-B \pm \sqrt{B^2 - 4AC}}{2A} \quad (\text{A.41})$$

where $A = a_N L$, $B = a_N L^* - \lambda(z) a_N L - a_N a_F M - (1 - 1/\lambda(z)) a_F L$, and $C = -\lambda(z) a_N L^* - (1 - 1/\lambda(z)) a_F L^*$.

It is difficult to prove the existence of solutions and decide which solution to drop. Also, it is very complicated to think the comparative statics here. More discussion will be elaborated in the calibration part.

A.5.2 The Second Cutoff

The second cutoff \underline{z} is used to distinguish the low-technology and medium-technology industries. It is derived by solving out the equation $g(z) = \lambda(z)^2 = \omega$ if the R&D intensity is treated as endogenous. In fact, my function for the second cutoff is the same as [60], though the proof is a little different.

(1) For any low-technology industry $z_L \in [0, \underline{z}]$, $\lambda(z_L)^2 < \omega$. The increment to quality is very low.

- If a non-producing Northern firm succeeds in R&D and creates a new version of product, it will earn instantaneous profits equal to $\pi_N^{NP}(z_L) = (1 - \omega/\lambda(z_L)^2) E^W < 0$. Hence, it is unprofitable to conduct innovation, neither based on multinationals or imitators. These Northern non-producing firms will exit the market.

$$r_N^{NP}(z_L) = \frac{\pi_N^{NP}(z_L)}{v_N^{NP}} - \phi(z_L) < 0$$

- As proved in Proposition 1, moving-out strategy is preferred to moving-up strategy in all non-high-technology industries. Specifically, in low-technology industries, by charging a price of

$\pi_F^{P^*} = \omega/\lambda(z_L)$, the producing MNE leader makes a flow of profits as $\pi_F(z_L) = (1 - \lambda(z)/\omega)E^W$, with the free-entry requirement $v_F^{P^*} - a_F = 0$.

Now I consider whether there is any motivation for these multinational leaders to undertake innovation and return production to the North. The instantaneous profits are $\pi_N^{P^*}(z_L) = (1 - \omega/\lambda(z_L))E^W$, if it leapfrogs the current leading-edge technology. In steady state, the market value equals to $v_N^{P^*}(z_L) = [\pi_N^{P^*}(z_L) - \pi_F^{P^*}(z_L)]dt - (1 - r_N^{P^*}(z_L)dt)\{[1 - \phi^{P^*}(z_L)dt]v_N^{P^*}(z_L) + \phi^{P^*}(z_L)dt \cdot 0\}$, with the probability that the ex-leader shifts production to the South and makes it valueless. Solving out this equation, the instantaneous rate of return is

$$r_N^{P^*}(z_L) = \frac{\pi_N^{P^*}(z_L) - \pi_F^{P^*}(z_L)}{v_N^{P^*}(z_L)} - \phi(z_L) < 0$$

It is because that the incremental profits to innovate for the MNE leader $\pi_N^{P^*}(z_L) - \pi_F^{P^*}(z_L) = (1 - \omega/\lambda(z_L))/\lambda(z_L)E^W - (1 - \lambda(z_L)/\omega)E^W = [\frac{\lambda(z_L)}{\omega} - \frac{\omega}{\lambda(z_L)}]E^W < 0$ is negative. Hence, it makes $r_N^{P^*}(z_L) < 0$, since $\phi(z_L) \geq 0$ by definition.

(2) For any medium-technology industry $z_M \in (z, \bar{z}')$, $\lambda(z_M)^2 \geq \omega$. The increment to quality is moderate.

- The Northern non-production firms are still discussed first. When the Northern leader improves upon the existing leading-edge blueprint, its instantaneous profits $\pi_N^{NP}(z_M) = (1 - \omega/\lambda(z_M)^2)E^W > 0$, with the free-entry condition $v_N^{NP}(z_M) - \omega a_N = 0$. In steady state, $v_N^{NP}(z_M) = \pi_N^{NP}(z_M)dt + (1 - r_N^{NP}(z_M)dt)\{(1 - \phi(z_M)dt)v_N^{NP}(z_M)dt + \phi(z_M)dt \cdot 0\}$. The instantaneous rate of return is figured out as

$$r_N^{NP}(z_M) = \frac{\pi_N^{NP}(z_M)}{v_N^{NP}(z_M)} - \phi(z_M) = \frac{(1 - \omega/\lambda(z_M)^2)E^W}{\omega a_N} - \frac{(1 - \omega/\lambda(z_M)^2)E^W}{\omega a_N} + \rho = \rho > 0$$

where the function of $\phi(z_M)$ comes from equation (4.11). These Northern firms will undertake R&D in order to recapture the leadership.

- For the multinational leader in medium-technology industries, there is no incentive for this firm to innovate, neither. Similar to the low-technology industries, the instantaneous profits for it is $\pi_F^{P^*}(z_M) = (1 - \frac{\omega(z_M)}{\lambda(z_M)})E^W$. After successful R&D, the profits become $\pi_N^{P^*} = (1 - \omega/\lambda(z_M))E^W$.

Combined with free entry condition $v_N(z_M) - \omega a_N = 0$, the potential incremental rate of return equals to

$$r_N^{P^*}(z_M) = \frac{\pi_N^{P^*}(z_M) - \pi_F^{P^*}(z_M)}{v_N^{P^*}(z_M)} - \phi(z_M) = \frac{(1 - \frac{\omega(z_M)}{\lambda(z_M)})E^W - (1 - \frac{\lambda(z_M)}{\omega})E^W}{\omega a_N} - \phi(z_M) < 0$$

Appendix B

Figures and Tables

Figure B.1: Ratio of Exports to the U.S.: China/Germany. Data Source: www.usitc.gov

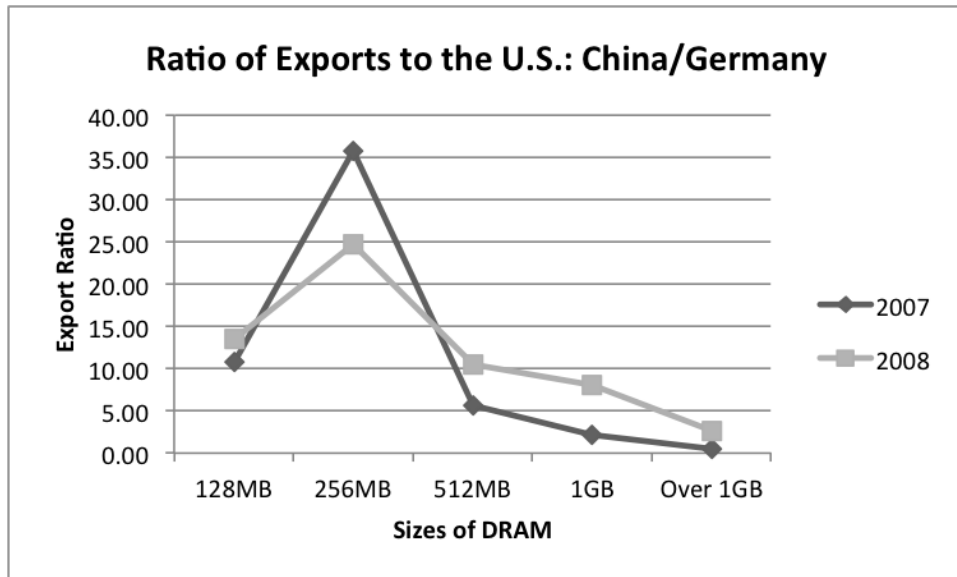


Figure B.2: Measure of Southern Low-tech Plants and Relative Wage

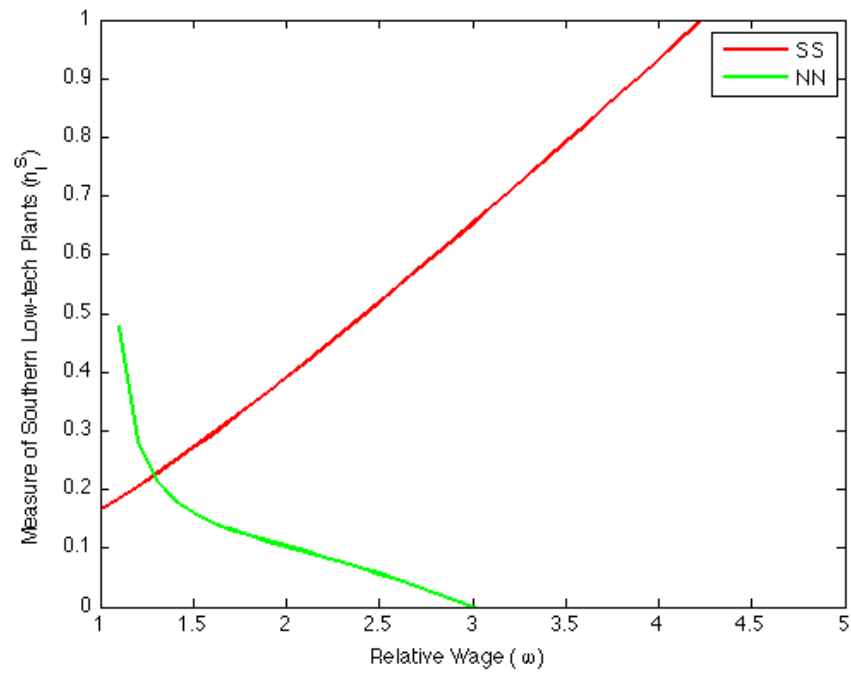


Figure B.3: Quality Increment Ratio and R&D Intensities

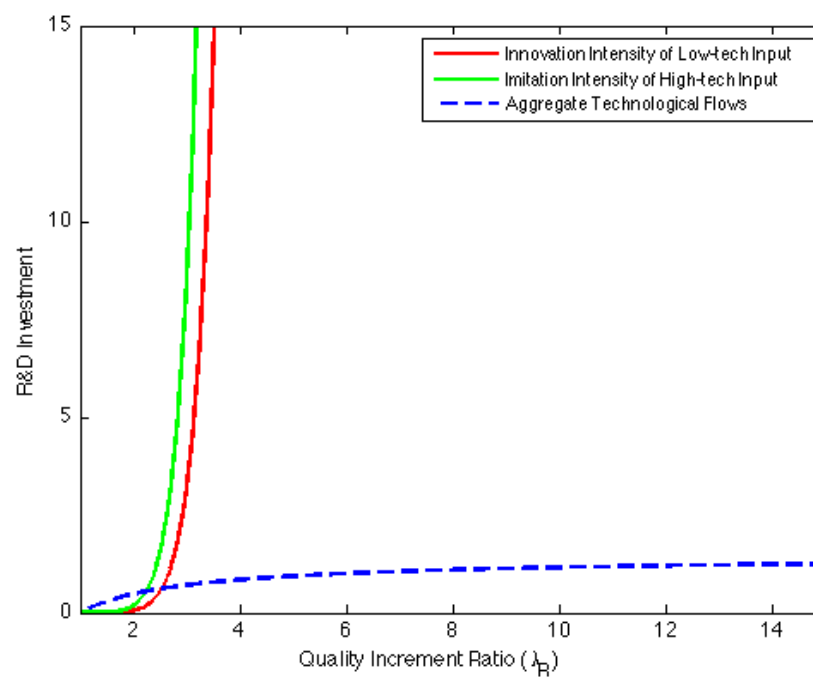


Figure B.4: Quality Increment Ratio and Firm Measures

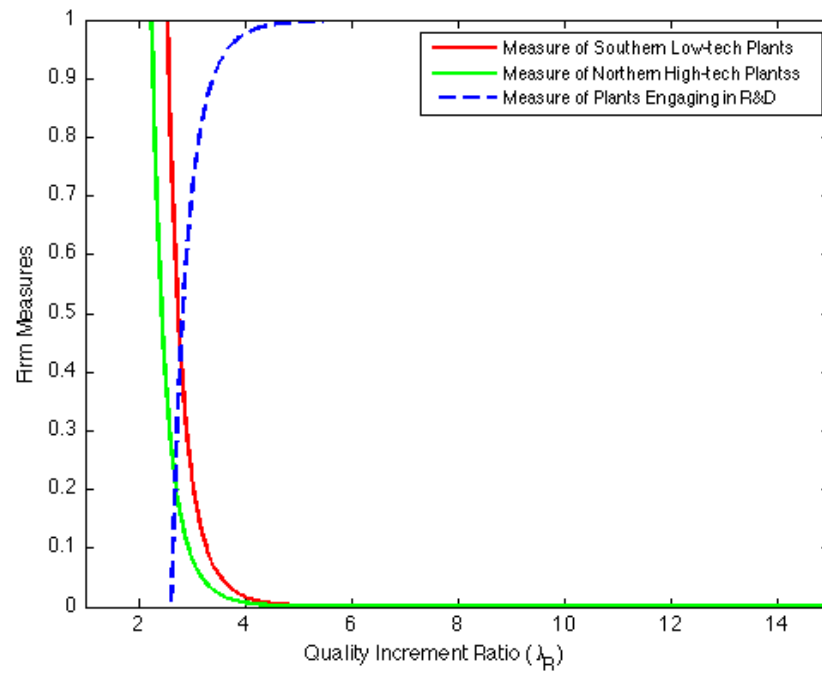


Figure B.5: Share of Low-tech Input and Input Quantities

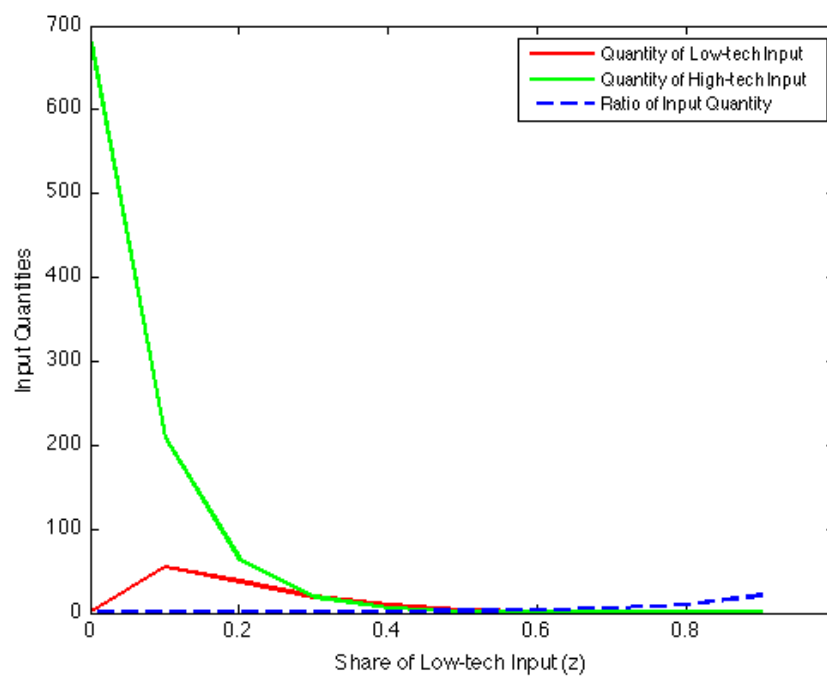


Figure B.6: Share of Low-tech Input and R&D Intensities

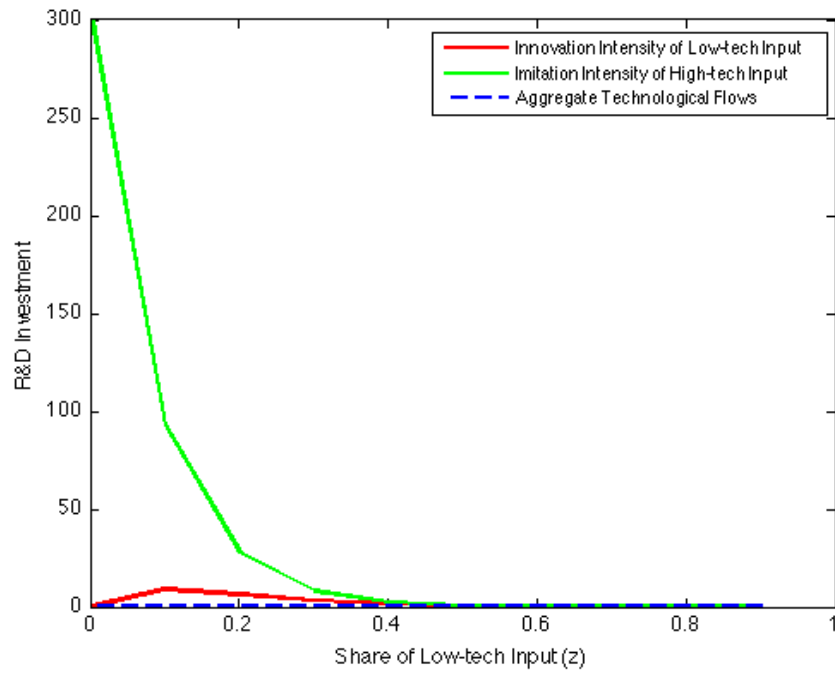


Figure B.7: Share of Low-tech Input and Firm Measures

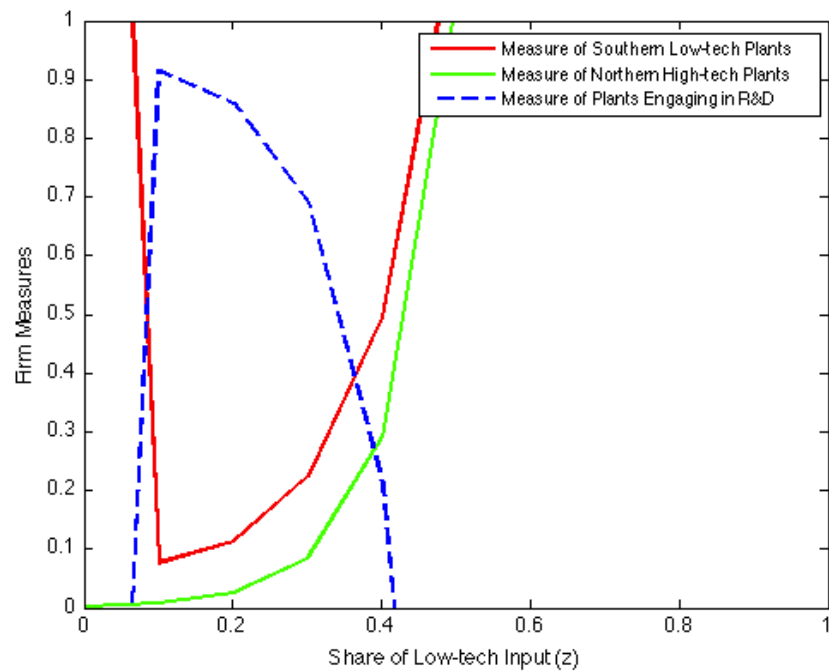


Figure B.8: Degree of Southern IPRs Protection and R&D Intensities

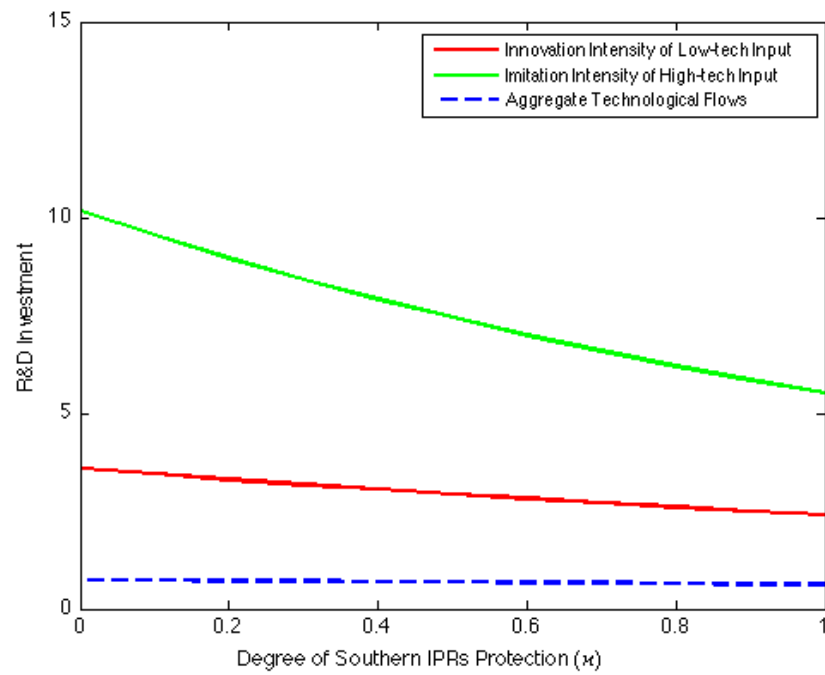


Figure B.9: Degree of Southern IPRs Protection and Firm Measures

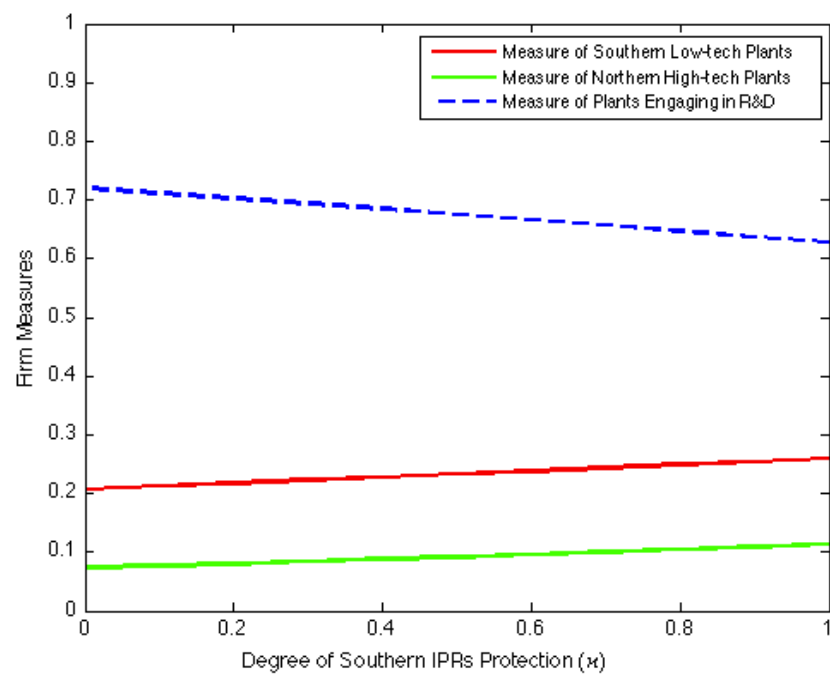


Figure B.10: Labor Endowment and Total World Expenditure

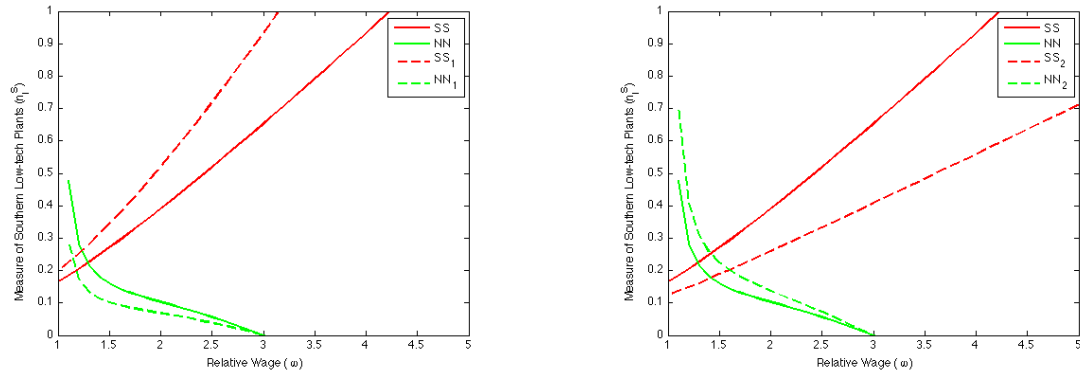


Figure B.11: Labor Endowment and Total World Expenditure

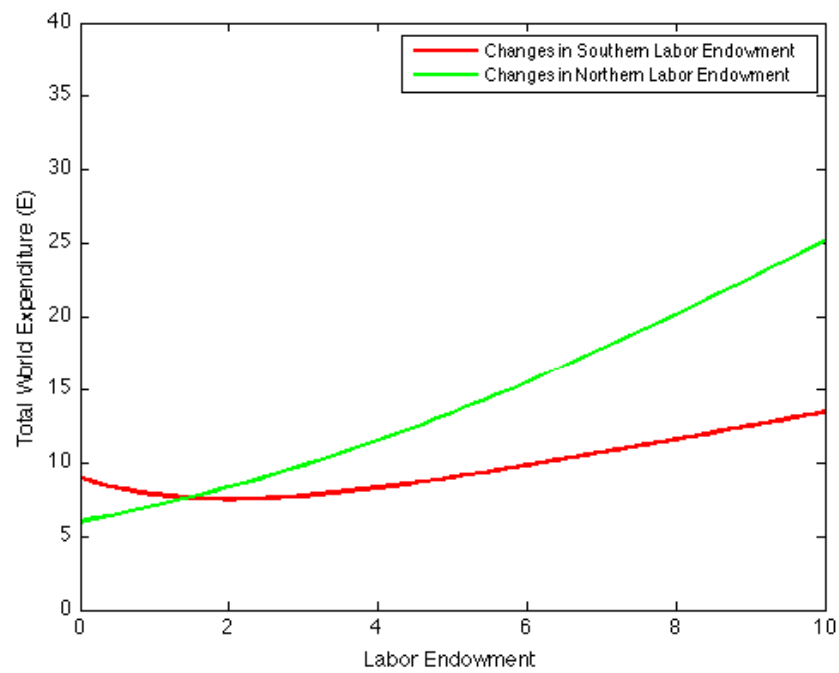


Figure B.12: Labor Endowment and R&D Investment

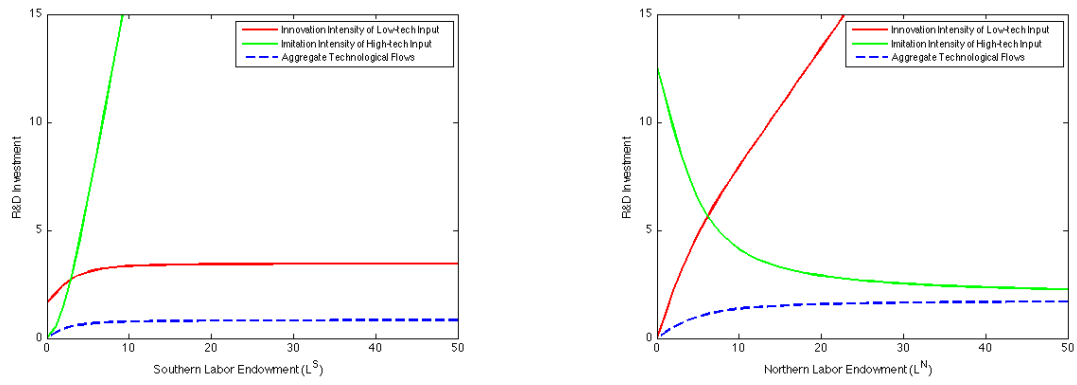


Figure B.13: Labor Endowment and Firm Measures

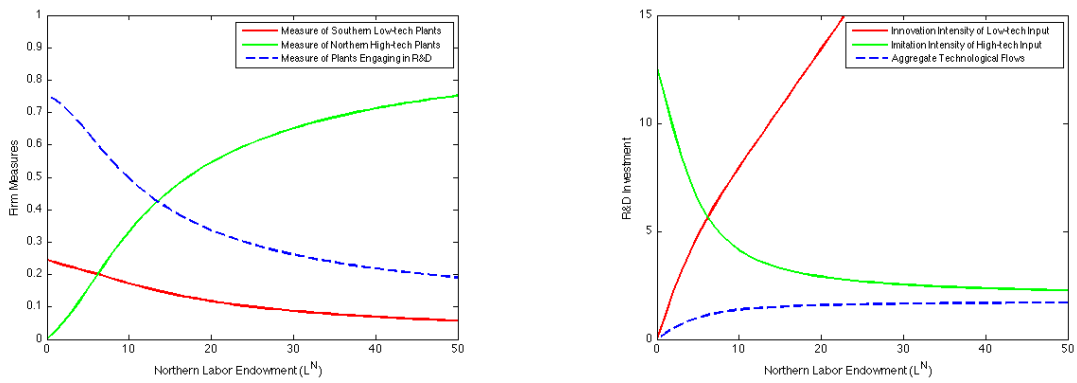


Figure B.14: Unit R&D Cost and Relative Wage

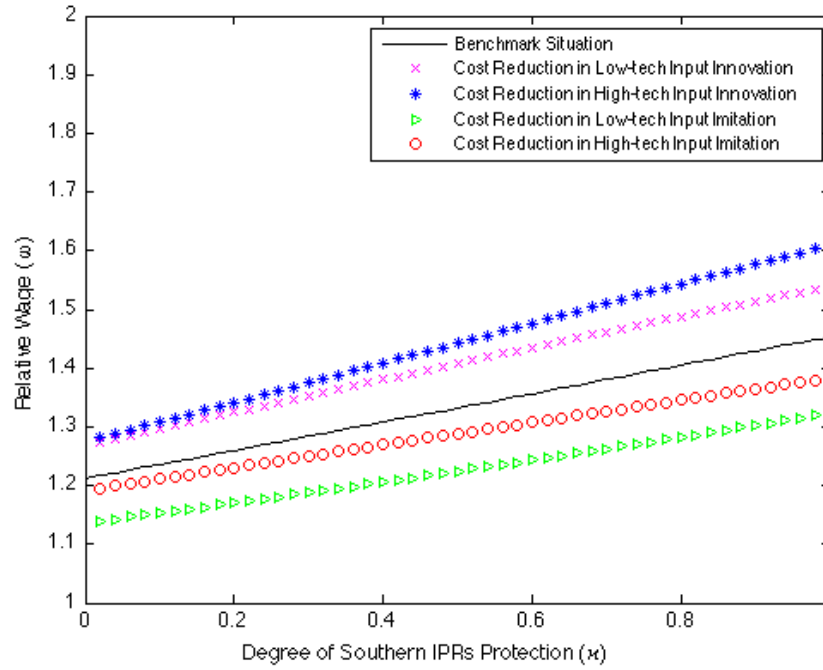


Figure B.15: Unit R&D Cost and R&D Investment

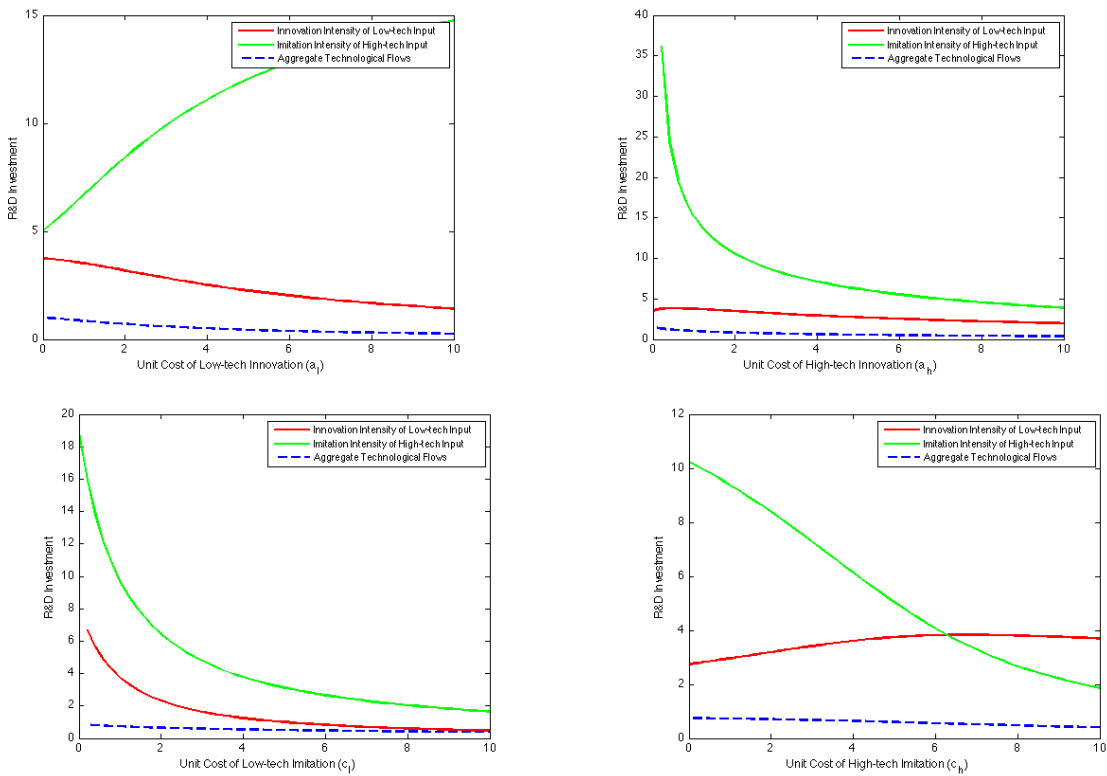


Figure B.16: Unit R&D Cost and Firm Measures

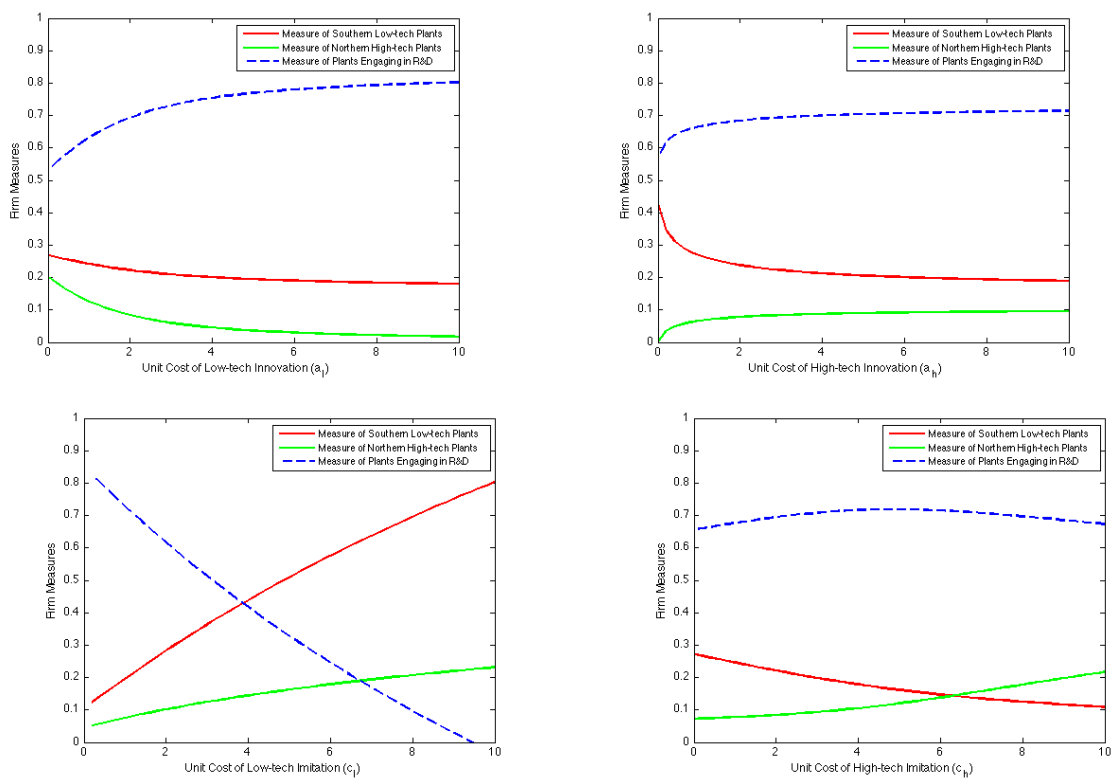


Figure B.17: Example of Unit Value Variation

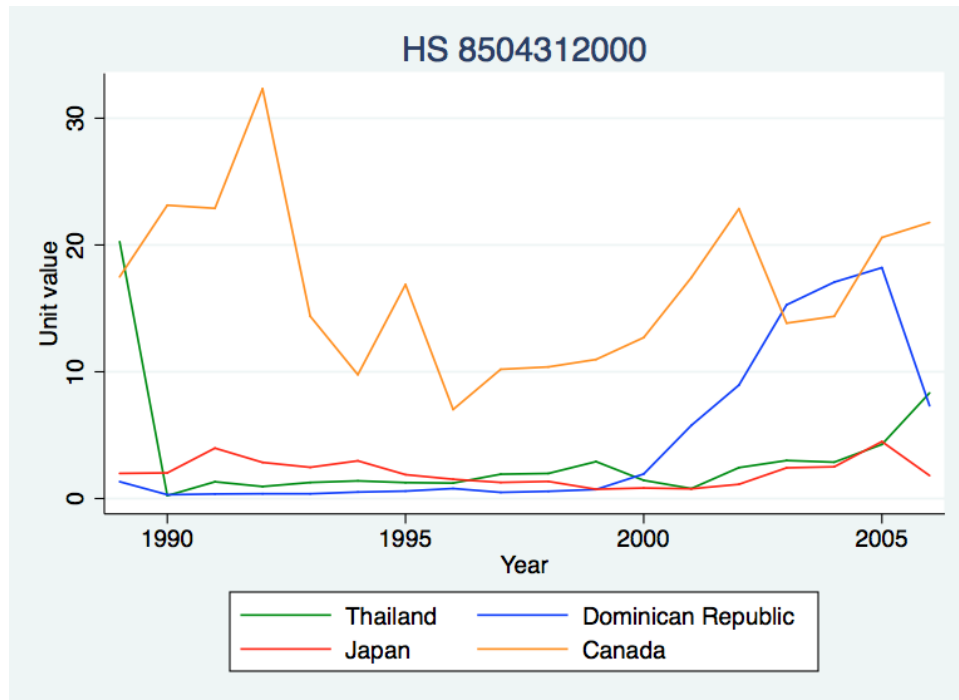


Figure B.18: Histogram of Import Share

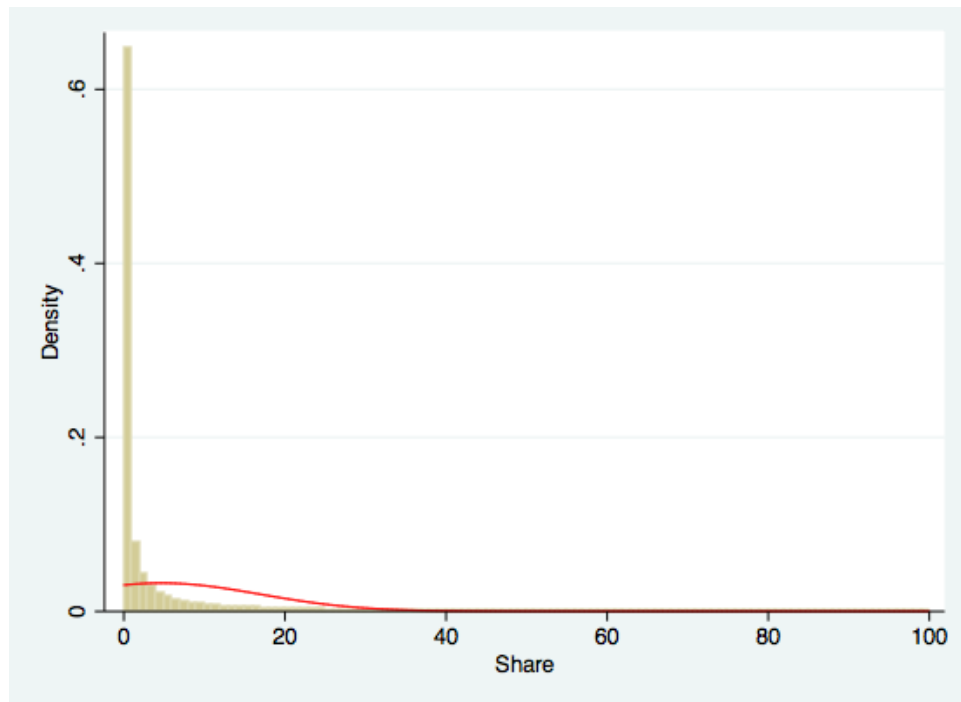


Figure B.19: Fitted Curve of share and GDP per capita

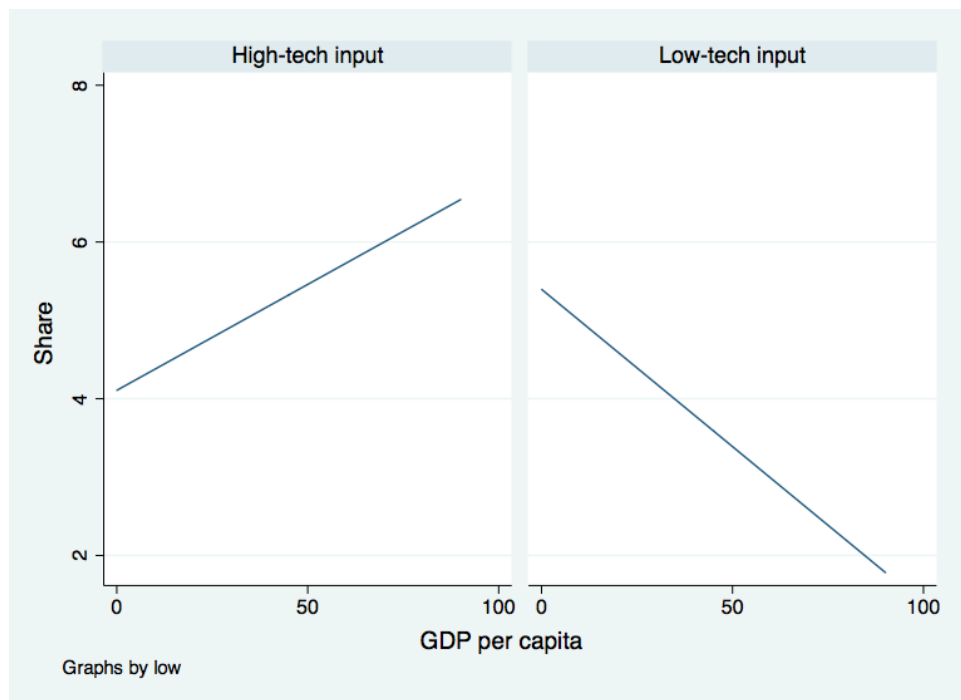


Figure B.20: Histogram of Number of Products Exporting

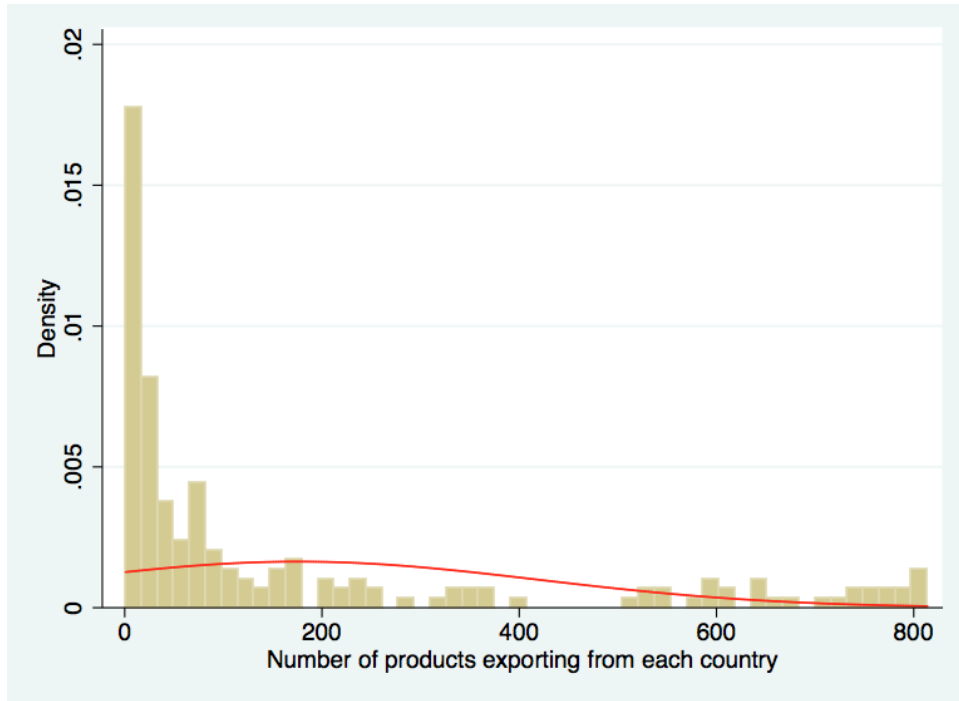


Figure B.21: Number of Products Exporting v.s. GDP Per Capita

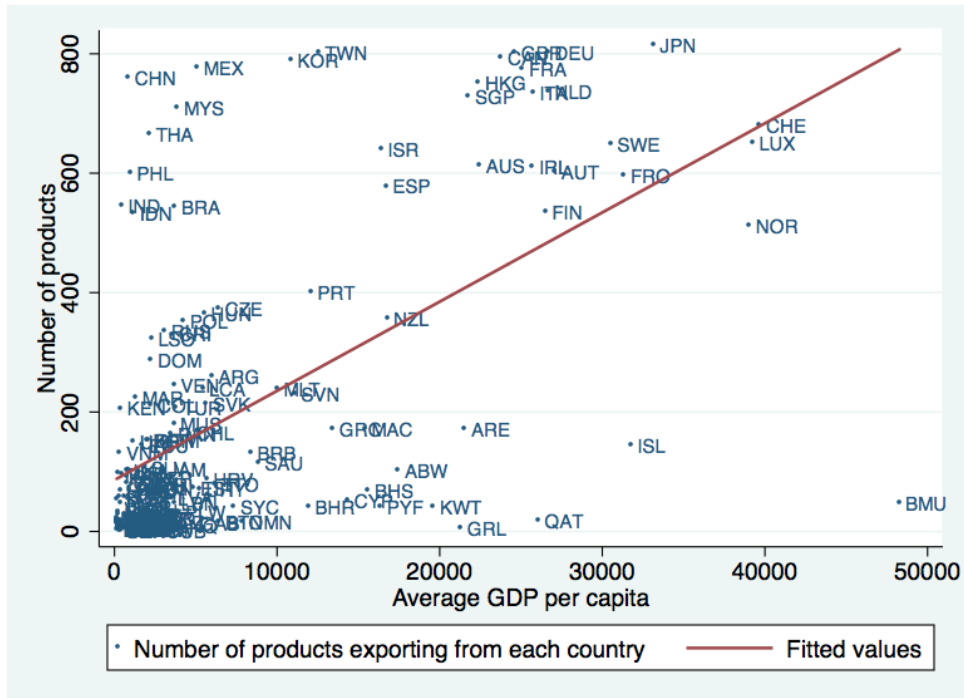


Figure B.22: Change in Exporting Countries by Technology Over Years

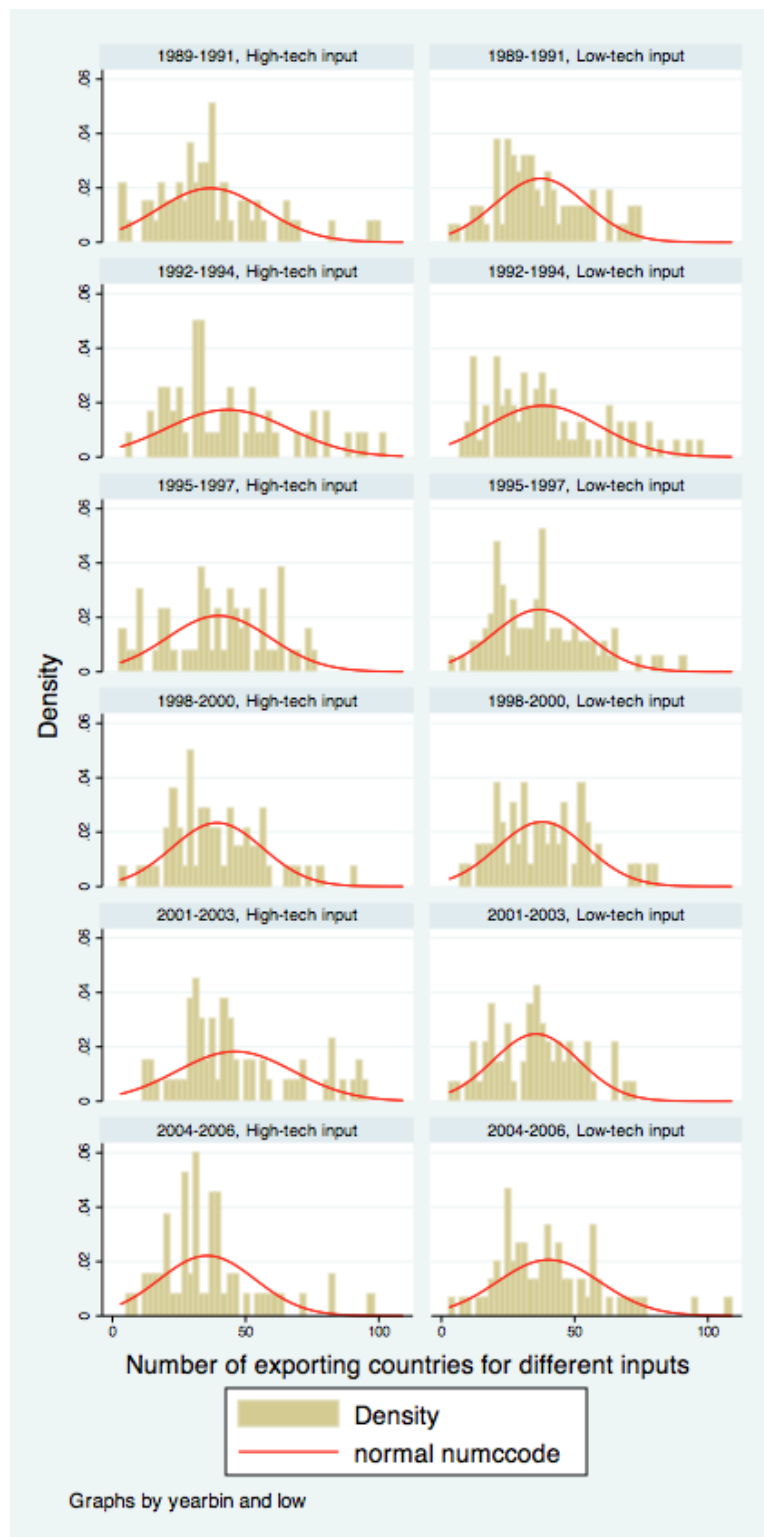
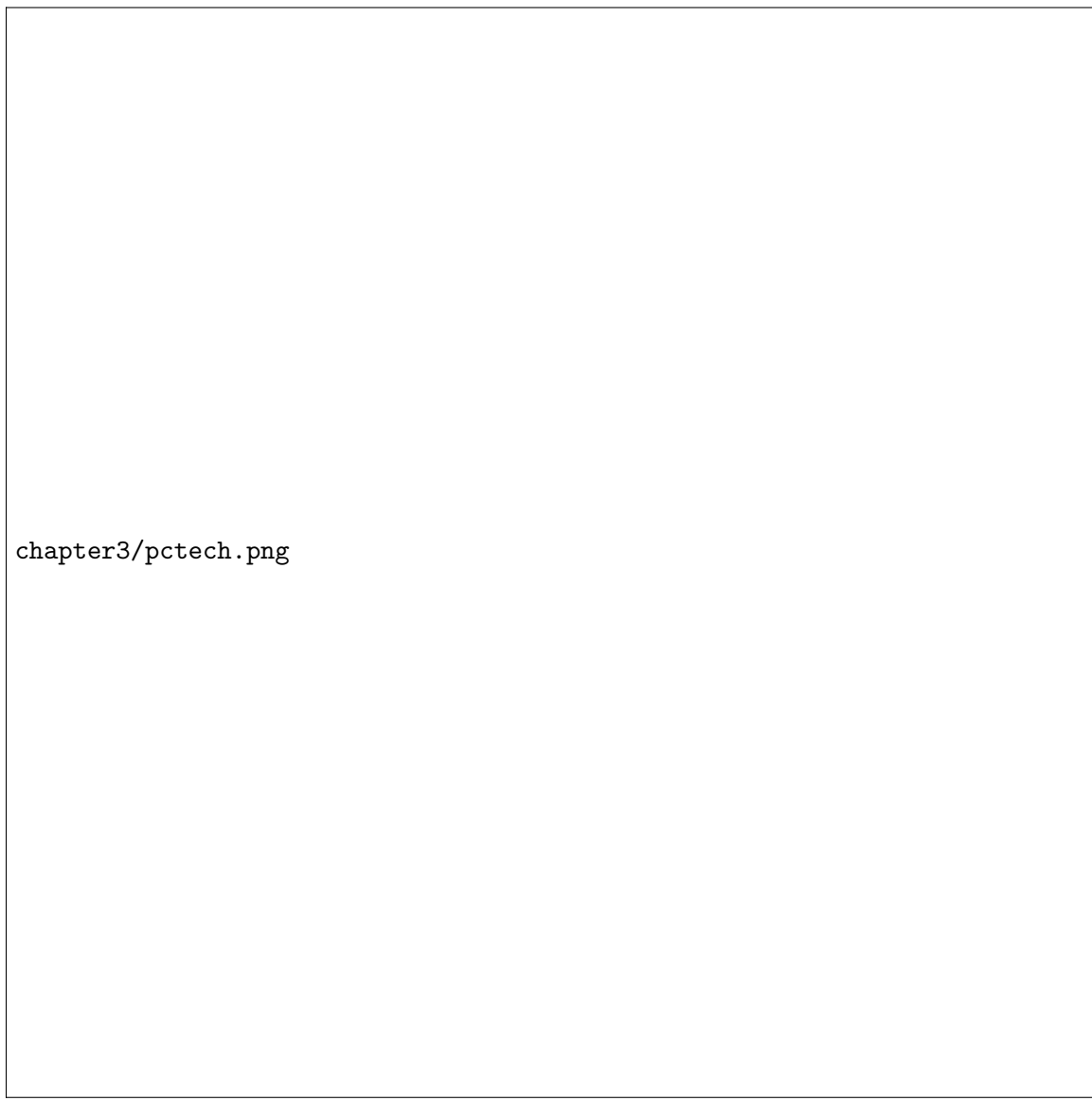


Figure B.23: Product-cycle Measure on R&D Intensity. Here the product-cycle measure is U.S. product cycle imports as a share of total U.S. imports. An observation is an industry-country pair. R&D intensity is the ratio of R&D expenditure to sales in each SIC4 industry, assigning the 3-digit figures to 4-digit industries where there is no record in COMPUSTAT dataset for R&D. I assume that the R&D intensity is the same for all sample countries. A dot means an country-industry observation. The quadratic line is regressed with OLS using the interval sample, conditional on country, industry and year fixed effects.



chapter3/pctech.png

Figure B.24: Product Cycle Composition

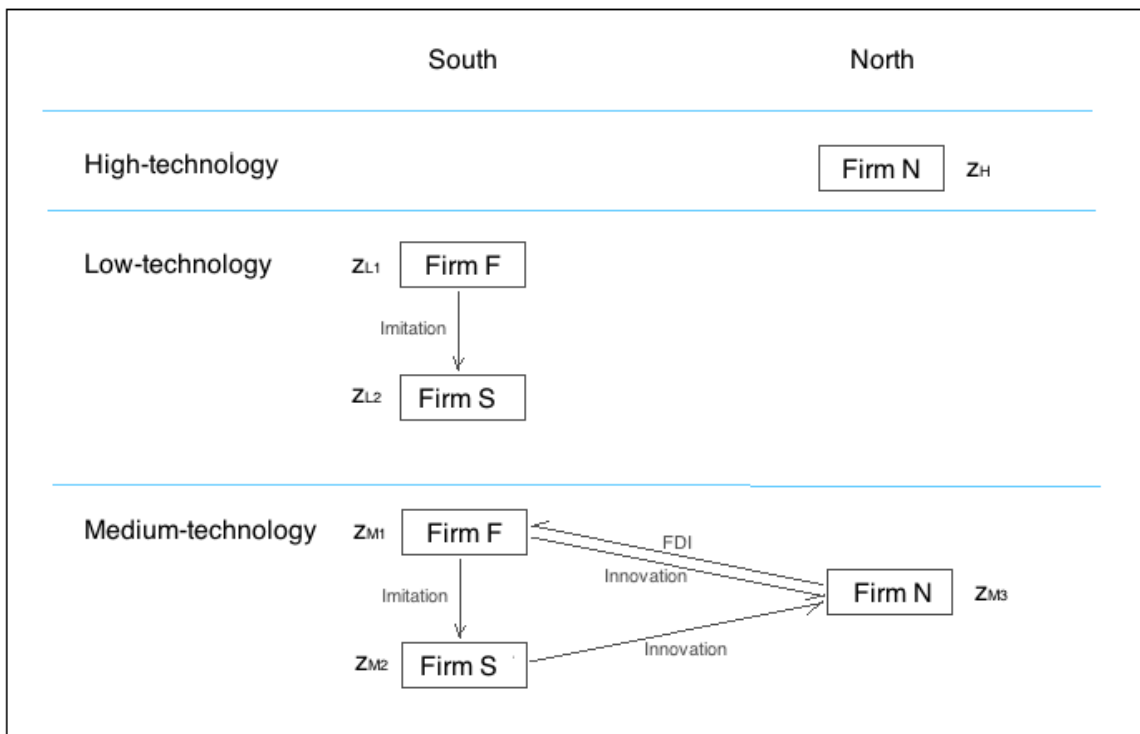


Figure B.25: Cutoff Shift with Southern Imitation

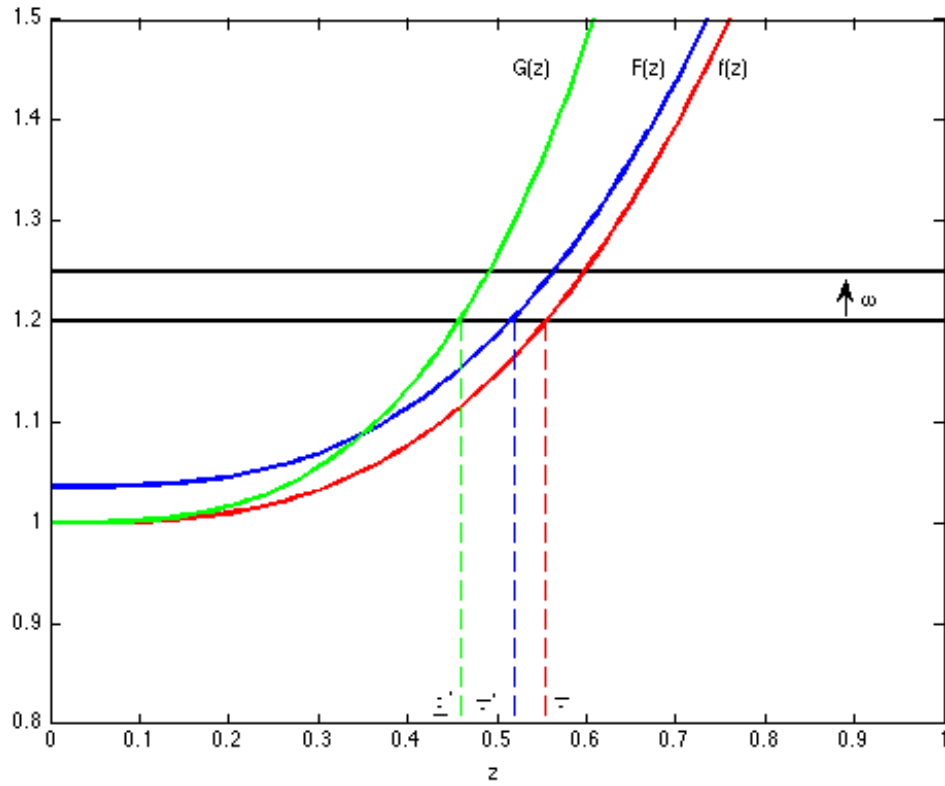


Figure B.26: The Effect of Higher Quality Increment on Cutoffs

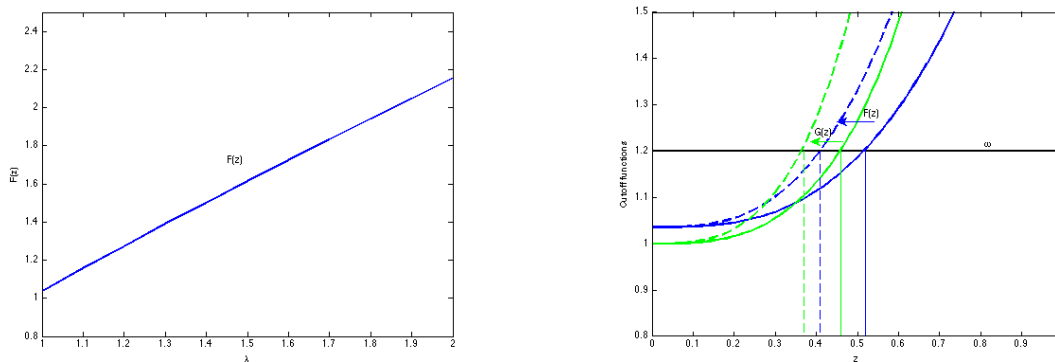


Figure B.27: The Effect of Innovation Cost on Cutoffs

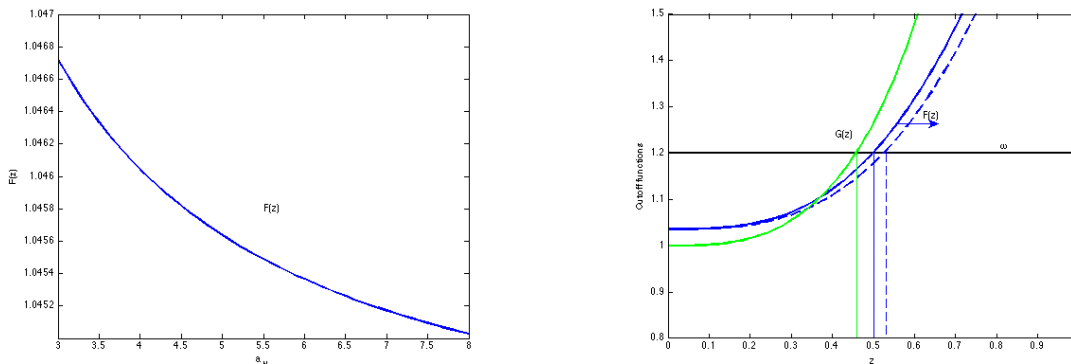


Figure B.28: The Effect of Adaptation Cost on Cutoffs

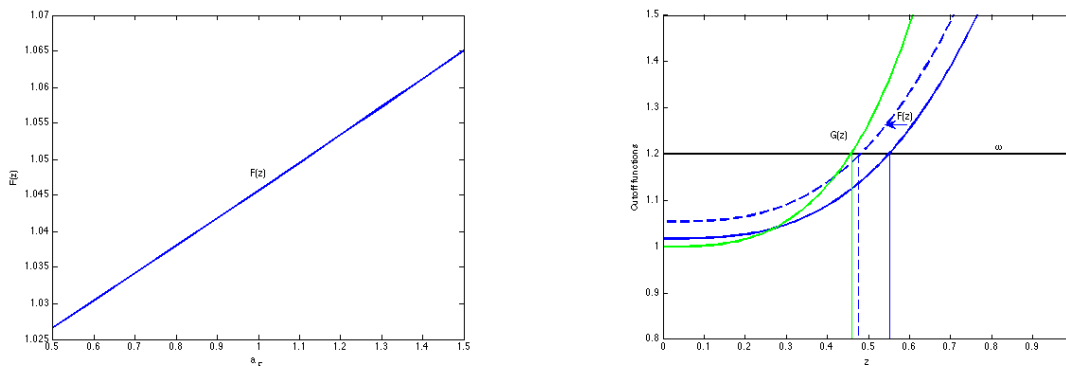


Figure B.29: The Effect of Larger Labor Endowment in the North

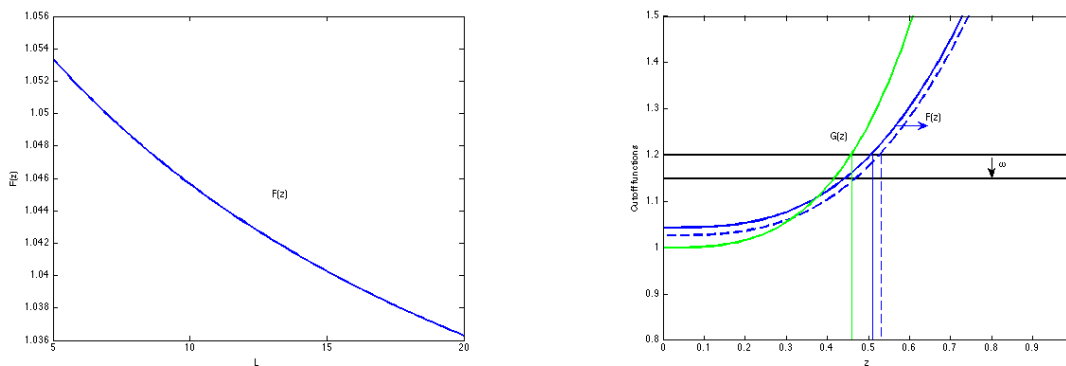


Figure B.30: The Effect of Larger Labor Endowment in the South

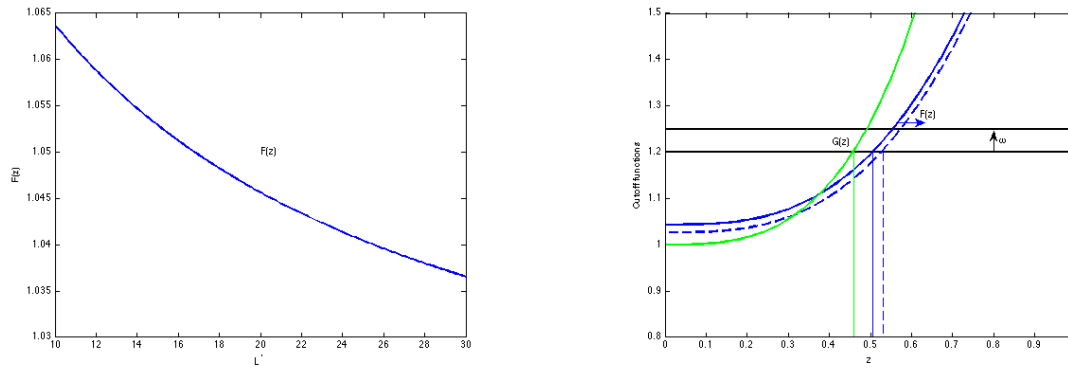


Figure B.31: The Effect of Stronger Southern IPP on Cutoffs

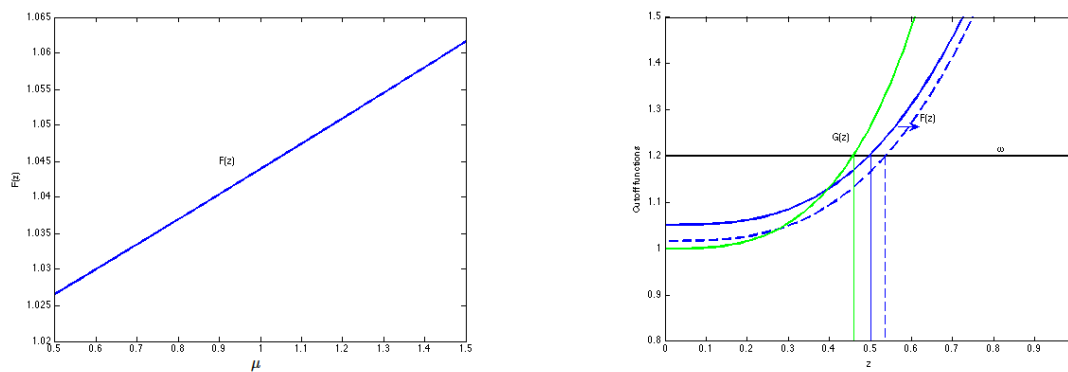


Figure B.32: The Relationship between PCGDP and IPP

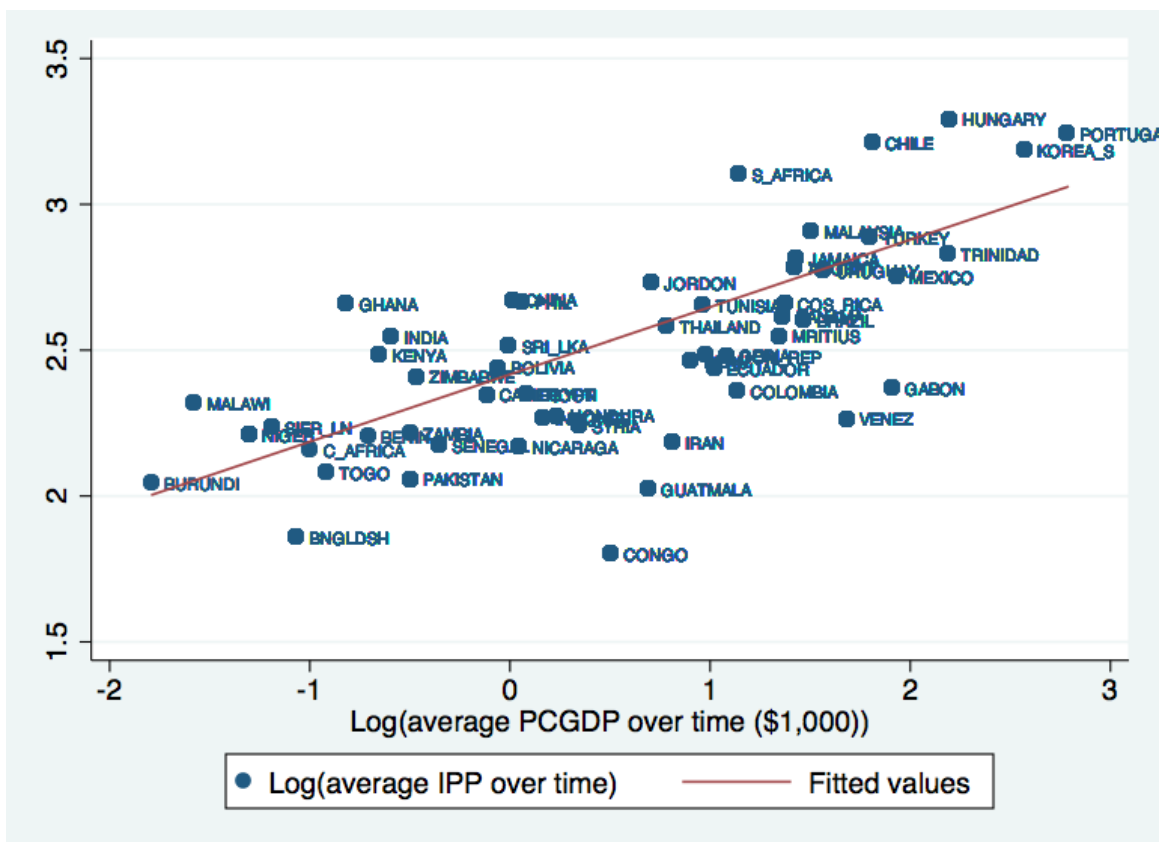


Table B.17: Firm Characteristics

Firm	Quality	Price ^a	Unit production cost	Unit R&D cost	R&D intensity	Stock value
N	J	$\lambda(z)^{J-J^*} \omega$ or $\lambda(z)^{J-J^*}$	$\omega > 1$	ωa_N	$\iota(z)$	v_N
F	J^*	$\frac{\omega}{\lambda(z)^{J-J^*}}$	1	a_F	$\phi(z)$	v_F
S	J^*	1	1	—	μ	-

^a Prices are calculated when profits are positive.

Table B.18: Parameter Values for Simulation

Economic meaning	Notation	Benchmark	Low	High
Relative wage	ω	1.2	-	1.25
Labor endowment in the North	L	10	5	20
Labor endowment in the South	L^*	20	10	30
Resource requirement in innovation	a_N	5	3	8
Resource requirement in adaptation	a_F	1	0.5	1.5
Subjective discount rate	ρ	0.05	0.01	0.1
Quality increment ^a	λ	$\lambda(z) = 1 + z^3$	1	2
Imitation intensity	μ	1.05	0.5	1.5

^a The new $F(z)$ curve in Figure B.26 is calibrated when $\lambda(z) = 1 + 2z^3$. The calibrated results are robust when I change to other $\lambda(z)$ functions.

Table B.1: Parameter Values for Simulation

Economic meaning	Notation	Benchmark
Northern working population	L^N	3
Southern working population	L^S	6
Innovation cost of high-tech input	a_h	3
Innovation cost of low-tech input	a_l	2
Imitation cost of high-tech input	c_h	1.95
Imitation cost of low-tech input	c_l	1.3
Quality increment of high-tech input	λ_h	1.5
Quality increment of low-tech input	λ_l	3
Quality jumps of the high-tech input	θ	3
Quality jumps of the low-tech input	η	2
Share of low-tech input in final good production	z	0.3
Elasticity of substitution among final goods	ϵ	6.6
Southern IPRs parameter	κ	0.3

Table B.2: Benchmark Numerical Results

Economic meaning	Notation	Numerical value
Relative wage between the North and the South	ω	1.2839
Total world expenditures	E	9.8516
Quantity of the low-tech input	x_l^S	18.9274
Quantity of the high-tech input	x_h^N	18.9001
Ratio of input quantity	x_R	1.0014
Profits of Southern low-tech plants	π_l^S	5.3727
Profits of Northern high-tech plants	π_h^N	32.4353
Ratio of profits for manufacturing plants	π_R	0.1656
Price of the final good	p^{SN}	0.2139
Quantity of the final good	y^{SN}	446.2287
Profits of the final good assembler	π^{SN}	14.4644
Innovation intensity of the low-tech input	ι_l	3.1791
Imitation intensity of the high-tech input	μ_h	8.4213
Measure of low-tech manufacturers in the South	n_l^S	0.2223
Measure of high-tech manufacturers in the North	n_h^N	0.0839
Ratio of plants engaging in manufacturing	n_R	2.6489
Aggregate measure of plants engaging in manufacturing	n_1	0.3062
Aggregate measure of plants engaging in R&D activities	n_2	0.6937
Ratio of aggregate plant measure	n_{R2}	0.4415
Labor allocated to manufacturing in the South	L_m^S	4.2082
Labor allocated to manufacturing in the North	L_m^N	1.5863
Ratio of labor allocated to manufacturing	L_{R1}	2.6528
Labor allocated to imitative R&D in the South	L_c^S	1.7918
Labor allocated to imitative R&D in the North	L_a^N	1.4137
Ratio of labor allocated to R&D activities	L_{R2}	0.4415
Aggregate technological flows across borders	$\iota = \mu$	0.7068

Table B.3: Comparative Static for Change in Quality Ladder Parameters

	Endogenous Variables						
	$\partial\omega$	$\partial\pi_l^S$	$\partial\pi_h^N$	$\partial\pi^{SN}$	$\partial\iota_l$	$\partial\mu_h$	$\partial\iota(=\partial\mu)$
$\partial\lambda_l$	No effect	+	+	+	+	+	No effect
$\partial\lambda_h (= \partial\lambda_R)$	+	+	+	+	+	+	+
$\partial\eta$	No effect	+	+	+	+	+	No effect
$\partial\theta$	No effect	+	+	+	+	+	No effect

Equilibrium comparative statics are obtained by taking derivatives of the endogenous variables in the first column in Table 1 with respect to the exogenous variables in the second row. “+” is used when the derivative result is positive. It means that an increase in the specific exogenous variable leads to an increase of the endogenous variable. “-” has the opposite effect.

Table B.4: Comparative Static for Change in the Share of the Low-tech Input

	Endogenous Variables						
	$\partial\omega$	$\partial\pi_l^S$	$\partial\pi_h^N$	$\partial\pi^{SN}$	$\partial\iota_l$	$\partial\mu_h$	$\partial\iota(=\partial\mu)$
∂z	No effect	Inverse-U	-	-	Inverse-U	-	No effect

Equilibrium comparative statics are obtained by taking derivatives of the endogenous variables in the first column in Table 1 with respect to the exogenous variables in the second row. “+” is used when the derivative result is positive. It means that an increase in the specific exogenous variable leads to an increase of the endogenous variable. “-” has the opposite effect.

Table B.5: Comparative Static for Change in Southern IPRs Policy

	Endogenous Variables						
	$\partial\omega$	$\partial\pi_l^S$	$\partial\pi_h^N$	$\partial\pi^{SN}$	$\partial\iota_l$	$\partial\mu_h$	$\partial\iota(=\partial\mu)$
$\partial\kappa$	+	+	-	-	-	-	-

Equilibrium comparative statics are obtained by taking derivatives of the endogenous variables in the first column in Table 1 with respect to the exogenous variables in the second row. “+” is used when the derivative result is positive. It means that an increase in the specific exogenous variable leads to an increase of the endogenous variable. “-” has the opposite effect.

Table B.6: Comparative Static for Change in Labor Endowment

	Endogenous Variables						
	$\partial\omega$	$\partial\pi_l^S$	$\partial\pi_h^N$	$\partial\pi^{SN}$	$\partial\iota_l$	$\partial\mu_h$	$\partial\iota(=\partial\mu)$
∂L^S	-	+	+	+	+	+	+
∂L^N	+	+	-	U-shape	+	-	+

Equilibrium comparative statics are obtained by taking derivatives of the endogenous variables in the first column in Table 1 with respect to the exogenous variables in the second row. “+” is used when the derivative result is positive. It means that an increase in the specific exogenous variable leads to an increase of the endogenous variable. “-” has the opposite effect.

Table B.7: Comparative Static for Change in Unit R&D Costs

	Endogenous Variables						
	$\partial\omega$	$\partial\pi_l^S$	$\partial\pi_h^N$	$\partial\pi^{SN}$	$\partial\iota_l$	$\partial\mu_h$	$\partial\iota(=\partial\mu)$
∂a_l	-	-	+	+	-	+	-
∂a_h	-	-	+	+	-	-	-
∂c_l	+	Inverse-U	-	-	-	-	-
∂c_h	+	Inverse-U	-	-	Inverse-U	-	-

Equilibrium comparative statics are obtained by taking derivatives of the endogenous variables in the first column in Table 1 with respect to the exogenous variables in the second row. “+” is used when the derivative result is positive. It means that an increase in the specific exogenous variable leads to an increase of the endogenous variable. “-” has the opposite effect.

	Exogenous Variables												
	$\partial\lambda_l$	$\partial\lambda_h$	$\partial\lambda_R$	$\partial\eta$	$\partial\theta$	∂z	$\partial\kappa$	∂L^N	∂L^S	∂a_l	∂a_h	∂c_l	∂c_h
∂p^{SN}	-	-	-	-	-	+	+	+	-	-	-	+	+
$\partial\pi^{SN}$	+	+	+	+	+	-	-	-	+	+	+	-	-
$\partial\omega$	+	no effect	no effect	no effect	no effect	no effect	+	+	-	-	-	+	+
$\partial\iota_h$	+	+	+	+	+	-	-	Inverse-U	Inverse-U	-	-	+	-
$\partial\mu_l$	+	+	+	+	+	Inverse-U	-	-	+	-	+	-	-
∂n_l^N	-	-	-	-	-	+	+	+	-	-	-	+	+
∂n_h^S	-	-	-	-	-	+	+	+	+	-	-	+	+
∂n_1	-	-	-	-	-	+	+	+	U-shape	-	-	+	+
∂n_2	+	+	+	+	+	-	-	-	Inverse-U	+	+	-	-
$\partial\iota$	+	no effect	no effect	no effect	no effect	no effect	-	+	+	-	-	+	-
$\partial\mu$	+	no effect	no effect	no effect	no effect	no effect	-	+	+	-	-	+	-

Table B.8: Comparative Statics Results for Case 4

Table B.9: Number of Observations in Each HS4 Industry

HS4 industry	HS10 codes contained	Frequency	Percent	Cumulative percentage
8503	17	869	0.54	0.54
8504	81	18,824	11.61	12.14
8505	11	1,429	0.88	13.02
8506	14	2,256	1.39	14.42
8507	31	4,781	2.95	17.36
8508	22	3,552	2.19	19.55
8509	32	4,431	2.73	22.29
8510	11	726	0.45	22.73
8511	13	4,186	2.58	25.31
8513	4	992	0.61	25.95
8514	18	1,774	1.09	27.05
8515	17	3,272	2.02	29.06
8516	45	6,582	4.06	33.12
8517	63	5,739	3.54	36.66
8518	21	5,965	3.68	40.34
8520	21	3,360	2.07	42.41
8522	14	269	0.17	42.58
8524	41	11,058	6.82	49.40
8529	71	4,263	2.63	52.02
8531	37	2,139	1.32	53.34
8532	31	10,382	6.40	59.75
8533	37	8,246	5.08	64.83
8539	46	10,062	6.20	71.03
8540	76	5,708	3.52	74.55
8541	40	14,812	9.13	83.69
8542	204	22,478	13.86	97.55
8543	66	3,712	2.29	99.84
Total	818	162,177	100.00	-

Note: The statistics of this table is based on the censored panel.

Table B.10: Summary Statistics

Variable	Mean	Std. Dev.	Min.	Max.	N
Unit value	4390.52	62248.238	0.001	5239902	160862
Share	4.633	12.265	0	100	162177
Notzero	0.291	0.454	0	1	832158
OECD dummy	0.434	0.496	0	1	162177
GDP per capita	17.631	13.352	0.064	90.032	161449
t	10.272	4.991	1	18	162177
Contiguity dummy	0.076	0.264	0	1	161449
Language dummy	0.279	0.448	0	1	161449
Colony dummy	0.117	0.321	0	1	161449
Distance	8.43	3.97	0.548	16.18	161449
Real GDP	50.332	166.391	0	1720	161449
IIT index	0.734	0.202	0.078	1	162177
FDI stock	110.805	146.285	0	1139.155	128972
Tariff	0.027	0.024	0	0.15	50587

Note: All summary statistics is based on the censored panel, except *notzero*.

Table B.11: Subsample Mean-comparison Test

Variable	Mean of high-tech inputs	Mean of low-tech inputs	Difference	Standard error
Unit value	8450.569	794.6906	7655.878 ***	310.3929
Share	4.58888	4.671236	-.0823561	.0610287
Notzero	.2952044	.2846124	.010592***	.0010265
OECD dummy	.4451292	.4241752	.0209541***	.0024656
GDP per capita	18.09482	17.22077	.8740485***	.0665494
Contiguity dummy	.0742353	.0766725	-.0024372 *	.0013177
Language dummy	.2778086	.2793855	-.0015769	.0022358
Colony dummy	.1175943	.1158376	.0017566	.0016009
Distance	8.324724	8.522742	-.1980183***	.0197896
Real GDP	49.19133	51.3407	-2.149372 ***	.8297543
IIT index	.7360947	.7318516	.004243 ***	.0010034
FDI stock	113.0647	108.8196	4.245142 ***	.8162925
Tariff	.0247318	.0284253	-.0036935 ***	.0002164

Notes: All group mean-comparison tests are based on the censored sample, except *notzero*.

Difference = mean(High-tech inputs) - mean(Low-tech inputs), conducted by two-sample t-test with equal variances.

Robust standard errors clustered in country-industry level are shown in parentheses.

*Significant at 10-percent level; **significant at 5-percent level; *** significant at 1-percent level.

Table B.12: OLS Model, OECD Dummy Without Interactions, The Whole Sample

VARIABLES	Dependent variable: Share											
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
	Low-tech	High-tech	Low-tech	High-tech	Low-tech	High-tech	Low-tech	High-tech	Low-tech	High-tech	Low-tech	High-tech
OECD dummy	1.369*** (0.0849)	2.915*** (0.0883)	0.461** (0.216)	0.946*** (0.233)	0.880*** (0.235)	1.460*** (0.259)	0.880*** (0.235)	1.465*** (0.259)	0.808*** (0.278)	1.732*** (0.315)	0.468 (0.508)	2.096*** (0.541)
Contiguity dummy					195.2 (204,131)	-4.180 (70,681)	195.2 (204,128)	-4.270 (70,680)	-36.11*** (11.74)	-16.86 (117,090)	-68.20*** (15.36)	7.797 (14.31)
Language dummy					-217.0 (204,131)	0.984 (70,681)	-217.0 (204,128)	0.983 (70,680)	-0.848 (13.92)	3.403 (117,090)	-44.59*** (18.06)	22.50 (18.87)
Colony dummy					5.278 (4.883)	4.687 (6.457)	5.278 (4.883)	4.693 (6.457)	9.983* (5.223)	8.349 (6.760)	14.44 (14.21)	9.206 (14.34)
Distance					-2.668*** (0.292)	-1.861*** (0.347)	-2.668*** (0.292)	-1.866*** (0.347)	-5.233*** (0.348)	-3.565*** (0.405)	-7.487*** (0.892)	-4.599*** (0.951)
Population					0.0471*** (0.00216)	0.0343*** (0.00246)	0.0471*** (0.00216)	0.0343*** (0.00246)	0.0814*** (0.00307)	0.0597*** (0.00352)	0.0925*** (0.00811)	0.0632*** (0.00873)
IIT index							-0.102 (0.385)	0.654 (0.423)	-0.534 (0.449)	0.372 (0.493)	-0.529 (1.021)	0.476 (1.045)
FDI stock									0.00191*** (0.000647)	-0.000272 (0.000690)	0.00257 (0.00271)	-0.00186 (0.00276)
Tariff											16.55*** (6.049)	19.41*** (6.264)
Constant	4.091*** (0.0553)	3.291*** (0.0589)	12.67 (10.78)	17.01 (10.97)	35.51*** (11.30)	14.28 (11.25)	35.52*** (11.31)	14.20 (11.25)	70.43*** (12.17)	24.34** (11.82)	120.8*** (18.05)	14.44 (14.83)
Observations	86,080	76,097	86,080	76,097	84,331	74,431	84,331	74,431	68,638	60,308	21,460	18,083
R-squared	0.003	0.014	0.243	0.201	0.247	0.203	0.247	0.203	0.257	0.217	0.255	0.252
Year FE	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry FE	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country FE	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Chow-test (<i>p</i> -value)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Notes: The regression function is: $share_{ijt} = \alpha_I + \beta_j + \kappa_t + \theta \cdot OECD_{ijt} + X_{ijt} \cdot \phi + \epsilon_{ijt}$. Robust standard errors clustered in country-industry level are shown in parentheses. *Significant at 10-percent level; **significant at 5-percent level; *** significant at 1-percent level. The null hypothesis for the Chow-test is that two subgroups have equal parameters for OECD dummy. *p*-values are reported.

Table B.13: OLS Model, OECD Dummy with Interactions, The Whole Sample

VARIABLES	Dependent variable: Share											
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
	Low-tech	High-tech	Low-tech	High-tech	Low-tech	High-tech	Low-tech	High-tech	Low-tech	High-tech	Low-tech	High-tech
OECD dummy	2.618*** (0.192)	4.487*** (0.209)	2.576*** (0.263)	2.897*** (0.285)	2.420*** (0.277)	2.980*** (0.306)	2.422*** (0.277)	2.975*** (0.306)	3.298*** (0.332)	3.797*** (0.371)	1.525** (0.632)	3.624*** (0.671)
OECD dummy*t	-0.119*** (0.0169)	-0.146*** (0.0180)	-0.220*** (0.0155)	-0.203*** (0.0171)	-0.170*** (0.0160)	-0.171*** (0.0177)	-0.170*** (0.0160)	-0.170*** (0.0177)	-0.280*** (0.0202)	-0.248*** (0.0225)	-0.135*** (0.0516)	-0.206*** (0.0551)
t	-0.0356*** (0.0108)	-0.0466*** (0.0119)	0.0597*** (0.00996)	0.0465*** (0.0114)	-1.75e-05 181.3	0.00520 -2.411	-0.00192 181.2	0.00773 -2.471	-0.0118 -29.05**	0.0163 -13.55	0.0439 -61.37***	0.0259 9.127
Contiguity dummy					(203.920)	(70.636)	(203.908)	(70.635)	(11.73)	(117.002)	(15.54)	(14.30)
Language dummy					-200.9	1.031	-200.8	1.027	0.419	3.559	-40.52**	18.37
Colony dummy					(203.920)	(70.636)	(203.908)	(70.635)	(13.89)	(117.002)	(18.10)	(18.88)
Distance					4.909	3.747	4.900	3.752	8.825*	6.574	13.26	7.399
Population					(4.880)	(6.451)	(4.880)	(6.451)	(5.216)	(6.753)	(14.21)	(14.34)
IIT index					-2.477***	-1.650***	-2.473***	-1.654***	-4.603***	-3.025***	-6.886***	-3.764***
FDI stock					(0.291)	(0.346)	(0.291)	(0.346)	(0.348)	(0.405)	(0.916)	(0.967)
Tariff					0.0428***	0.0297***	0.0428***	0.0297***	0.0703***	0.0493***	0.0842***	0.0508***
Constant	4.441*** (0.120)	3.774*** (0.136)	11.21 (10.76)	15.08 (10.96)	32.77*** (11.30)	11.84 (11.24)	32.94*** (11.30)	11.79 (11.24)	61.72*** (12.15)	19.60* (11.81)	112.7*** (18.29)	10.92 (14.83)
Observations	86,080	76,097	86,080	76,097	84,331	74,431	84,331	74,431	68,638	60,308	21,460	18,083
R-squared	0.005	0.017	0.245	0.203	0.248	0.204	0.248	0.204	0.259	0.218	0.255	0.252
Year FE	No	No	No	No	No	No	No	No	No	No	No	No
Industry FE	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country FE	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Chow-test (<i>p</i> -value)	0.0530		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Notes: The regression function is: $share_{ijt} = \alpha_l + \beta_j + \epsilon_{jt} + \theta \cdot OECD_{jt} + X_{jt} \cdot \phi + \epsilon_{ijt}$. Robust standard errors clustered in country-industry level are shown in parentheses. *Significant at 10-percent level; **significant at 5-percent level; *** significant at 1-percent level. The joint null hypothesis for the Chow-test is that two subgroups have equal parameters for OECD dummy and the interaction term. *p*-values are reported.

Table B.14: OLS Model, OECD Dummy with 3-year Bin Interactions, The Whole Sample

VARIABLES	Dependent variable: Share											
	(1) Low-tech	(2) High-tech	(3) Low-tech	(4) High-tech	(5) Low-tech	(6) High-tech	(7) Low-tech	(8) High-tech	(9) Low-tech	(10) High-tech	(11) Low-tech	(12) High-tech
OECD dummy	0.268 (0.197)	1.807*** (0.198)	-1.110*** (0.267)	-0.517* (0.286)	-0.442 (0.287)	0.108 (0.314)	-0.443 (0.287)	0.113 (0.314)	-1.638*** (0.345)	-0.415 (0.384)	0.824 (0.614)	3.104*** (0.668)
OECD dummy*Year dummy 1989-1991	1.799*** (0.308)	2.420*** (0.334)	3.170*** (0.277)	3.280*** (0.311)	2.403*** (0.284)	2.763*** (0.319)	2.403*** (0.284)	2.758*** (0.319)	3.774*** (0.349)	3.701*** (0.397)		
OECD dummy*Year dummy 1992-1994	1.078*** (0.299)	1.624*** (0.316)	2.749*** (0.268)	2.658*** (0.293)	2.157*** (0.274)	2.261*** (0.300)	2.157*** (0.274)	2.256*** (0.300)	3.713*** (0.335)	3.194*** (0.369)	0.207 (0.528)	-0.225 (0.594)
OECD dummy*Year dummy 1995-1997	2.222*** (0.283)	1.519*** (0.289)	1.957*** (0.250)	1.238*** (0.265)	1.577*** (0.255)	0.998*** (0.270)	1.577*** (0.255)	0.993*** (0.270)	3.045*** (0.310)	1.960*** (0.329)	-0.163 (0.523)	-1.596*** (0.575)
OECD dummy*Year dummy 1998-2000	1.384*** (0.279)	1.289*** (0.280)	1.370*** (0.245)	1.237*** (0.254)	1.206*** (0.249)	1.163*** (0.260)	1.206*** (0.249)	1.164*** (0.260)	2.429*** (0.299)	1.969*** (0.313)	-0.937* (0.542)	-1.494** (0.587)
OECD dummy*Year dummy 2001-2003	0.650*** (0.280)	0.820*** (0.282)	0.530*** (0.244)	0.712*** (0.255)	0.381 (0.250)	0.627*** (0.262)	0.381 (0.250)	0.630*** (0.262)	0.954*** (0.290)	1.107*** (0.304)	-1.537** (0.738)	-2.244*** (0.765)
Year dummy 1989-1991	0.515*** (0.196)	0.643*** (0.219)	-0.810*** (0.178)	-0.769*** (0.206)	0.108 (0.189)	-0.130 (0.220)	0.117 (0.193)	-0.185 (0.224)	0.394 (0.256)	-0.324 (0.303)	0.511 (0.586)	-0.359 (0.616)
Year dummy 1992-1994	0.485*** (0.190)	0.598*** (0.206)	-0.871*** (0.171)	-0.654*** (0.192)	-0.155 (0.180)	-0.154 (0.203)	-0.146 (0.184)	-0.208 (0.207)	-0.130 (0.239)	-0.301 (0.272)	-0.154 (0.567)	-0.505 (0.575)
Year dummy 1995-1997	-0.411** (0.185)	-0.0248 (0.192)	-0.790*** (0.164)	-0.419** (0.176)	-0.313* (0.170)	-0.0979 (0.184)	-0.305* (0.173)	-0.139 (0.186)	-0.439** (0.223)	-0.454* (0.241)	-0.267 (0.520)	-0.304 (0.515)
Year dummy 1998-2000	-0.292 (0.187)	-0.219 (0.190)	-0.615*** (0.164)	-0.497*** (0.173)	-0.384** (0.170)	-0.373** (0.180)	-0.376** (0.173)	-0.417** (0.183)	-0.570*** (0.218)	-0.732*** (0.231)	-0.0766 (0.495)	-0.255 (0.489)
Year dummy 2001-2003	-0.135 (0.186)	-0.127 (0.191)	-0.270* (0.163)	-0.289* (0.173)	-0.0910 (0.170)	-0.185 (0.181)	-0.0867 (0.171)	-0.210 (0.182)	-0.0813 (0.214)	-0.407* (0.229)		
Contiguity dummy												
Language dummy												
Colony dummy												
Distance												
Population												
IIT index												
FDI stock												
Tariff												
Constant	4.087*** (0.131)	3.204*** (0.133)	12.28 (10.76)	16.73 (10.96)	32.74*** (11.29)	11.75 (11.23)	32.79*** (11.29)	11.72 (11.23)	61.97*** (12.14)	19.90* (11.80)		
Observations	86,080	76,097	86,080	76,097	84,331	74,431	84,331	74,431	68,638	60,308	21,460	18,083
R-squared	0.005	0.017	0.245	0.203	0.248	0.204	0.248	0.204	0.259	0.218	0.255	0.253
Year FE	No	No	No	No	No	No	No	No	No	No	No	No
Industry FE	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country FE	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
F-test (<i>p</i> -value)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0717	0.0046
Chow-test (<i>p</i> -value)		0.0337	0.2645	0.2498	0.2498	0.2521	0.2521	0.2521	0.0945	0.6330		

Robust standard errors clustered in country-industry level are shown in parentheses. *Significant at 10-percent level; **Significant at 5-percent level; *** significant at 1-percent level.

The null hypothesis for the F-test is that all the coefficients related to OECD dummy are the same.

The joint null hypothesis for the Chow-test is that two subgroups have equal parameters for OECD dummy and the interaction term. *p*-values are reported.

Table B.15: Heckman Selection Model, OECD Dummy with Interaction

VARIABLES	Panel A: Low-tech Inputs			Panel B: High-tech Inputs			Panel C: Low-tech Inputs			Panel D: High-tech Inputs		
	(1) share	(2) notzero	(3) mills	(4) share	(5) notzero	(6) mills	(7) share	(8) notzero	(9) mills	(10) share	(11) notzero	(12) mills
OECD dummy	1.617*** (0.197)	0.289*** (0.0183)		3.318*** (0.211)	0.292*** (0.0193)		4.349*** (0.190)	0.300*** (0.0194)		5.077*** (0.210)	0.312*** (0.0205)	
OECD dummy*t	-0.0956*** (0.0174)	-0.0119*** (0.00108)		-0.117*** (0.0180)	-0.0125*** (0.00114)		-0.184*** (0.0165)	-0.0124*** (0.00110)		-0.199*** (0.0177)	-0.0130*** (0.00117)	
t	-0.0983*** (0.0112)	0.0226*** (0.000654)		-0.152*** (0.0120)	0.0424*** (0.000701)		-0.0591*** (0.0107)	0.0225*** (0.000705)		-0.0841*** (0.0120)	0.0423*** (0.000756)	
Contiguity dummy							10.82*** (0.191)	1.210*** (0.176)		10.37*** (0.202)	1.271*** (0.166)	
Language dummy							-3.920*** (0.0986)	-0.200 (0.360)		-2.991*** (0.103)	0.143 (0.523)	
Colony dummy							0.513*** (0.138)	0.118 (0.314)		1.603*** (0.143)	-0.210 (0.303)	
Distance							0.572*** (0.0134)	0.00143 (0.0193)		0.459*** (0.0140)	0.0300 (0.0209)	
Population							0.0102*** (0.000160)	0.00108*** (0.000152)		0.00552*** (0.000171)	0.00125*** (0.000163)	
Constant	11.81*** (0.189)	-2.552*** (0.313)		10.50*** (0.205)	-2.482*** (0.496)		1.695*** (0.249)	-2.373*** (0.215)		2.817*** (0.267)	-3.012*** (0.216)	
λ			-6.161*** (0.119)			-5.234*** (0.118)						-3.168*** (0.123)
Observations	298,926	298,926	298,926	271,170	271,170	271,170	289,765	289,765	289,765	262,722	262,722	262,722
Year FE	No	No	No	No	No	No	No	No	No	No	No	No
Industry FE	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes
Country FE	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes

Robust standard errors clustered in country-industry level are shown in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Table B.16: Heckman Selection Model, OECD Dummy with 3-year-bin Interaction

VARIABLES	Panel A: Low-tech Inputs		Panel B: High-tech Inputs		Panel C: Low-tech Inputs		Panel D: High-tech Inputs					
	(1) share	(2) notzero	(3) mills	(4) share	(5) notzero	(6) mills	(7) share	(8) notzero	(9) mills	(10) share	(11) notzero	(12) mills
OECD dummy	-0.327 (0.204)	0.0827** (0.0188)		1.143** (0.198)	0.0658*** (0.0196)		0.843** (0.198)	0.316*** (0.0175)		1.266*** (0.200)	0.491*** (0.0184)	
OECD dummy*Yeardummy 1989-1991	1.446*** (0.317)	0.173*** (0.0192)		2.033*** (0.334)	0.169*** (0.0206)		3.278*** (0.299)	-0.166*** (0.0152)		4.461*** (0.329)	-0.457*** (0.0161)	
OECD dummy*Yeardummy 1992-1994	0.949*** (0.308)	0.133*** (0.0189)		1.325*** (0.315)	0.143*** (0.0200)		2.816*** (0.290)	-0.103*** (0.0149)		3.518*** (0.308)	-0.317*** (0.0157)	
OECD dummy*Yeardummy 1995-1997	1.954*** (0.293)	0.0997** (0.0182)		1.209*** (0.288)	0.104*** (0.0190)		2.146*** (0.274)	0.0194 (0.0142)		1.455*** (0.279)	-0.0448*** (0.0148)	
OECD dummy*Yeardummy 1998-2000	1.189*** (0.290)	0.0801*** (0.0179)		1.082*** (0.279)	0.0653*** (0.0185)		1.479*** (0.272)	0.0204 (0.0136)		1.267*** (0.271)	0.0329** (0.0141)	
OECD dummy*Yeardummy 2001-2004	0.556* (0.290)	0.0328* (0.0179)		0.704** (0.281)	0.0398** (0.0185)		0.669** (0.273)	-0.00613 (0.0137)		0.852*** (0.275)	-0.0194 (0.0142)	
Yeardummy 1989-1991	1.466*** (0.202)	-0.348*** (0.0117)		2.210*** (0.221)	-0.639*** (0.0127)		0.297 (0.192)			-0.0225 (0.216)		
Yeardummy 1992-1994	1.102*** (0.196)	-0.243*** (0.0115)		1.734*** (0.207)	-0.469*** (0.0123)		0.00355 (0.185)			-0.0700 (0.201)		
Yeardummy 1995-1997	-0.283 (0.191)	-0.0887*** (0.0114)		0.330* (0.191)	-0.162*** (0.0119)		-0.358** (0.180)			-0.00970 (0.186)		
Yeardummy 1998-2001	-0.222 (0.194)	-0.0642*** (0.0116)		-0.201 (0.189)	-0.0391*** (0.0119)		-0.440** (0.184)			-0.352* (0.186)		
Yeardummy 2002-2004	-0.0875 (0.193)	-0.0406*** (0.0115)		-0.0312 (0.190)	-0.0616*** (0.0119)		-0.224 (0.184)			-0.236 (0.188)		
Contiguity dummy												
Language dummy												
Colony dummy												
Distance												
Population												
Constant	10.55*** (0.185)	-2.207*** (0.312)		8.400*** (0.178)	-1.864*** (0.497)							
λ			-6.153*** (0.119)			-5.227*** (0.118)						
Observations	298,926	298,926	298,926	271,170	271,170	271,170	289,765	289,765	289,765	262,722	262,722	262,722
Year FE	No	No	No	No	No	No	No	No	No	No	No	No
Industry FE	No	Yes	Yes	No	Yes	Yes	No	Yes	No	No	Yes	Yes
Country FE	No	Yes	Yes	No	Yes	Yes	No	Yes	No	No	Yes	Yes

Robust standard errors clustered in country-industry level are shown in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Table B.19: Comparative Statistics for Cutoff Functions^a

Function	First cutoff function		Second cutoff function
	$\partial f(z)$	$\partial F(z)$	$\partial G(z)$
$\partial\lambda(z)$	+	+	+
∂L	unrelated	-	unrelated
∂L^*	unrelated	-	unrelated
∂a_N	-	-	unrelated
∂a_S	unrelated	unrelated	unrelated
∂a_F	+	+	unrelated
$\partial\rho$	unrelated	unrelated	unrelated
$\partial\mu$	unrelated	+	unrelated

^a The terms in the first row are the functions of interest, and parameters are in the first column. I am interested in how functions vary as the value of parameters increase. + indicates a positive correlation. - indicates a negative correlation.

Table B.20: List of Southern Countries by Their Legal Origins

British	French		Socialist	German
Bangladesh	Algeria	Argent	China	South Korea
Ghana	Benin	Bolivia	Hungary	
India	Brazil	Burundi		
Jamaica	Cameroon	Chile		
Kenya	Colombia	Congo		
Malawi	Costa Rica	Central African		
Malaysia	Ecuador	Dominican		
Pakistan	Egypt	Gabon		
Sierra Leone	Guatemala	Honduras		
Sri Lanka	Indonesia	Iran		
South Africa	Jordan	Mexico		
Thailand	Mauritius	Nicaragua		
Trinidad	Niger	Panama		
Zambia	Peru	Philippines		
Zimbabwe	Portugal	Senegal		
	Syria	Togo		
	Tunisia	Turkey		
	Uruguay	Venezuela		

Table B.21: Summary Statistics

Variable	Unit	Mean	Std. Dev.	Min.	Max.	N
PC_{cjt}	ratio	0.191	0.35	0	1	26766
$R\&D_{ct}$	ratio	0.022	0.03	0	0.337	26766
IPP_{ct}	one	11.87	6.459	1.316	30.704	26766
$PCGDP_{ct}$	thousand	4.163	3.906	0.144	18.186	26639
$Population_{ct}$	billion	0.134	0.309	0	1.304	26766
$Distance_{ct}$	thousand km	8.413	3.986	2.509	16.18	26766
$Finance_{ct}$	ratio	0.427	0.33	0.024	1.358	24004
$Corruption_{ct}$	one	-0.166	0.612	-1.41	1.54	14533
Law_{ct}	one	-0.15	0.673	-1.77	1.27	14533
$Capital_{ct}$	thousand	20.573	17.184	0.89	82.561	23185
$Skill_{ct}$	ratio	0.438	0.381	0.026	2.236	23185

^a The subscript c denotes country, j denotes industry, and t denotes year.

Table B.22: Product Cycle Goods for Each Industry

SIC2	Description	1990			2005			
		SIC4 No.	PC No.	Total No.	Aver. PC	PC No.	Total No.	Aver. PC
20	Food & kindred	40	.054	5.54	0.03	0.21	6.46	0.10
21	Tobacco	1	0	1.18	0	0	1.53	0
22	Textile	6	0.01	13.96	0.02	0.22	43.91	0.04
23	Apparel	18	0.01	14.66	0.007	0.03	22.21	0.014
24	Lumber & wood	9	0.03	3.90	0.02	0.11	4.92	0.08
25	Furniture & Fixtures	7	0.05	9.08	0.05	0.27	10.03	0.02
26	Paper	16	0.23	3.30	0.12	0.72	4.31	0.35
27	Printing publishing	8	0.15	5.25	0.11	0.25	7.54	0.14
28	Chemicals	28	0.26	6.63	0.11	1.29	10.63	0.32
29	Petroleum refining	4	0.21	4.32	0.11	0.76	7.54	0.27
30	RubberU	11	0.28	8.77	0.12	0.65	11.44	0.20
31	Leather	4	0	11.06	0.0002	0.03	12.78	0.015
32	Stone clay glass	22	0.12	4.96	0.07	0.50	6.61	0.27
33	Primary metal	15	0.15	8.05	0.06	0.73	13.56	0.22
34	Fabricated metal	30	0.15	7.00	0.08	0.67	8.23	0.19
35	Industrial & commercial merchantry	48	0.38	4.95	0.19	1.23	7.62	0.41
36	Electronic	35	0.32	6.20	0.15	0.95	8.93	0.32
37	Transportation equipment	14	0.30	5.45	0.18	0.78	8.30	0.30
38	Measuring & analyzing instruments	17	0.33	5.62	0.15	0.80	9.13	0.31
39	Miscellaneous manufacturing inds	14	0.08	7.39	0.05	0.53	8.62	0.20
	Total	347	0.19	7.04	0.09	0.72	9.40	0.25

^a SIC4 No. is the number of SIC 4-digit industries within each SIC2 category. PC No. is the number of PC goods within each SIC2 category. Total No. is the number of HS 10 goods within each SIC2 category. Aver. PC is the average PC measures within each SIC2 category.

Table B.23: Enter, Existence, and Quit

Year	Enter	Exist	Quit	Obs.
1990	1365	1658	697	5891
1995	592	2695	696	6341
2000	701	3699	655	6951
2005	422	4343	601	7580

^a Observations are at country-SIC4-year level.

^b “Enter” means that an industry had no product-cycle trade five years ago, but has some this year.

^c “Exist” means that an industry has some product-cycle trade this year.

^d “Quit” means that an industry had some product-cycle trade five years ago, but has null this year.

Table B.24: Correlations Among Key Variables

	PC_{cjt}	$R\&D_{ct}$	$IPP_{c,t-5}$
PC_{cjt}	1		
$R\&D_{ct}$	0.1096	1.0000	
$IPP_{c,t-5}$	0.0429	0.0843	1.0000

Table B.25: Test Hypothesis 1: Interval Sample

	Dependent variable: Product-cycle measure					
	Fractional probit pooled QMLE					
	(1)	(2)	(3)	(4)	(5)	(6)
R&D	3.69 (2.93)	3.65 (2.70)	-15.16*** (4.89)	0.94 (2.38)	1.06 (2.49)	2.75 (3.90)
R&D ²	-10.75 (10.79)	-14.32 (9.14)	46.38** (18.92)	-12.28* (7.23)	-11.37 (7.88)	-20.46** (10.04)
PCGDP		0.04*** (0.01)	0.00 (0.02)		-0.09*** (0.01)	-0.04 (0.03)
Population		1.19*** (0.21)	-2.67*** (0.64)		-1.52*** (0.28)	-3.80*** (0.71)
Distance		-0.02*** (0.00)	-0.03*** (0.00)		-0.03*** (0.00)	-0.04*** (0.01)
Finance			-0.82*** (0.18)			0.44** (0.20)
Corruption			-0.00 (0.07)			0.18* (0.09)
Law			0.49*** (0.09)			0.38*** (0.10)
Capital			-0.00 (0.01)			-0.02** (0.01)
Skill			-1.39*** (0.18)			-1.37*** (0.21)
Constant	-1.15*** (0.05)	-0.85*** (0.06)	-0.58*** (0.08)	-1.20*** (0.15)	-0.68*** (0.13)	-0.34 (0.23)
Observations	26,763	26,637	11,352	26,763	26,637	11,352
Year FE	No	No	No	Yes	Yes	Yes
Industry FE	No	No	No	Yes	Yes	Yes

^a The dependent variable is the product-cycle measure, $PC_{cjt} = X_{cjt}^P / X_{cjt}$, U.S. product cycle imports as a share of total U.S. imports for each industry. An observation is an industry-country-year pair.

^b All regressions include the time averages of all exogenous variables. The estimates of time averages are omitted.

^c Robust errors are clustered by 4-digit industry and appear in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table B.26: Test Hypothesis 2: Interval Sample

	Dependent variable: Product-cycle measure					
	Fractional probit pooled QMLE					
	(1)	(2)	(3)	(4)	(5)	(6)
IPP _{t-5}	0.02*** (0.00)	0.02*** (0.00)	-0.03** (0.01)	-0.04*** (0.01)	-0.02*** (0.00)	-0.05*** (0.01)
PCGDP		0.00 (0.01)	0.07 (0.05)		-0.05*** (0.01)	0.05 (0.04)
Population		0.69** (0.28)	0.40 (1.11)		-1.19*** (0.43)	-2.72** (1.32)
Distance		-0.04*** (0.01)	-0.05*** (0.01)		-0.04*** (0.01)	-0.04*** (0.01)
Finance			-0.54 (0.52)			0.79 (0.70)
Corruption			-0.01 (0.27)			0.11 (0.26)
Law			0.28 (0.19)			0.21 (0.19)
Capital			-0.00 (0.02)			-0.03* (0.02)
Skill			-1.01*** (0.39)			-0.91* (0.47)
Constant	-1.00*** (0.11)	-0.78*** (0.12)	-0.47*** (0.14)	-0.76*** (0.17)	-0.54*** (0.17)	0.00 (0.23)
Observations	26,763	26,637	11,352	26,763	26,637	11,352
Year FE	No	No	No	Yes	Yes	Yes
Industry FE	No	No	No	Yes	Yes	Yes

^a The dependent variable is the product-cycle measure, $PC_{cjt} = X_{cjt}^P / X_{cjt}$, U.S. product cycle imports as a share of total U.S. imports for each industry. An observation is an industry-country-year pair.

^b All regressions include the time averages of all exogenous variables. The estimates of time averages are omitted.

^c Robust errors are clustered by 4-digit industry and appear in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Table B.27: Test Hypothesis 2 with IV Correction: Interval Sample

Dependent variable: Product-cycle measure						
Fractional probit pooled QMLE						
	(1)	(2)	(3)	(4)	(5)	(6)
IPP _{t-5}	-0.07*** (0.01)	-0.01 (0.02)	0.01 (0.02)	-0.09*** (0.02)	-0.01 (0.02)	-0.02 (0.02)
PCGDP		0.06 (0.05)	-0.02 (0.06)		-0.08*** (0.03)	-0.02 (0.04)
Population		1.30** (0.63)	-2.02* (1.14)		-1.57*** (0.51)	-4.40*** (1.71)
Distance		-0.02 (0.01)	-0.04** (0.02)		-0.03** (0.01)	-0.04* (0.02)
Finance			-0.85 (0.55)			0.55 (0.75)
Corruption			0.04 (0.35)			0.14 (0.32)
Law			0.51*** (0.18)			0.39* (0.20)
Capital			0.00 (0.03)			-0.03 (0.03)
Skill			-1.49** (0.62)			-1.24* (0.69)
Constant	-0.12 (0.17)	-0.57*** (0.14)	-0.37** (0.15)	0.39 (0.34)	-0.47* (0.26)	0.05 (0.29)
Observations	26,763	26,637	11,352	26,763	26,637	11,352
Year FE	No	No	No	Yes	Yes	Yes
Industry FE	No	No	No	Yes	Yes	Yes

^a The dependent variable is the product-cycle measure, $PC_{cjt} = X_{cjt}^P / X_{cjt}$, U.S. product cycle imports as a share of total U.S. imports for each industry. An observation is an industry-country-year pair.

^b All regressions include the time averages of all exogenous variables. The estimates of first stage and time averages are omitted. Robust errors are clustered by 4-digit industry and appear in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Table B.28: Test Hypothesis 3, the Probability of Entry: Interval Sample

	Dependent variable: Dummy of entry					
	Probit					
	(1)	(2)	(3)	(4)	(5)	(6)
IPP _{t-5}	-0.00 (0.00)	-0.02** (0.01)	-0.00 (0.00)	0.01*** (0.00)	0.01 (0.00)	0.01 (0.00)
IPP _{t-5} *R&D	-0.85*** (0.16)	-0.84*** (0.15)	-0.37** (0.16)	-0.70*** (0.15)	-0.71*** (0.15)	-0.40** (0.17)
IPP _{t-5} *R&D ²	4.76*** (1.06)	4.65*** (1.02)	1.38* (0.72)	2.93*** (0.79)	2.94*** (0.78)	1.41* (0.76)
R&D	19.26*** (2.62)	19.06*** (2.52)	6.77** (2.75)	7.50** (3.49)	7.56** (3.46)	5.02 (4.41)
R&D ²	-108.77*** (21.00)	-105.61*** (20.12)	-23.73* (13.07)	-38.95** (16.91)	-38.81** (16.76)	-45.16*** (17.48)
PCGDP		0.03*** (0.01)	-0.00 (0.02)		0.01* (0.01)	-0.00 (0.02)
Population		0.02 (0.06)	-0.39*** (0.06)		0.06 (0.04)	-0.42*** (0.06)
Distance		-0.00 (0.01)	-0.02*** (0.01)		-0.01** (0.01)	-0.02*** (0.01)
Finance			0.17* (0.09)			0.17* (0.09)
Corruption			0.00 (0.07)			-0.03 (0.09)
Law			0.09 (0.07)			0.09 (0.07)
Capital			-0.00 (0.00)			-0.00 (0.00)
Skill			-0.02 (0.07)			-0.02 (0.07)
Constant	-1.26*** (0.06)	-1.24*** (0.06)	-1.08*** (0.11)	-1.25*** (0.13)	-1.15*** (0.14)	-1.08*** (0.23)
Observations	26,763	26,637	11,352	24,939	24,776	9,899
Year FE	No	No	No	Yes	Yes	Yes
Industry FE	No	No	No	Yes	Yes	Yes

^a The dependent variable is the product-cycle measure, $PC_{cjt} = X_{cjt}^P / X_{cjt}$, U.S. product cycle imports as a share of total U.S. imports for each industry. An observation is an industry-country-year pair.

^b All regressions include the time averages of all exogenous variables. The estimates of time averages are omitted.

^c Robust errors are clustered by 4-digit industry and appear in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Table B.29: Test Hypothesis 3, the Probability of Existence: Interval Sample

	Dependent variable: Dummy of existence					
	Probit					
	(1)	(2)	(3)	(4)	(5)	(6)
IPP _{t-5}	-0.01** (0.00)	-0.00 (0.01)	0.00 (0.01)	-0.01 (0.01)	0.01 (0.01)	0.01 (0.01)
IPP _{t-5} *R&D	-0.33* (0.18)	-0.34* (0.18)	-0.28 (0.31)	-0.30 (0.19)	-0.30 (0.20)	-0.33 (0.33)
IPP _{t-5} *R&D ²	1.57* (0.85)	1.63* (0.88)	1.07 (1.36)	1.29 (0.86)	1.24 (0.89)	1.16 (1.26)
R&D	5.68** (2.21)	5.82** (2.28)	4.38 (4.37)	3.14 (3.51)	2.91 (3.61)	-2.53 (8.95)
R&D ²	-23.90* (13.61)	-25.10* (14.36)	-14.20 (21.30)	-13.43 (16.16)	-12.03 (16.71)	3.12 (31.39)
PCGDP		-0.03** (0.01)	-0.04 (0.03)		-0.05*** (0.02)	-0.05 (0.03)
Population		-0.70*** (0.09)	-0.42*** (0.07)		-0.77*** (0.10)	-0.48*** (0.07)
Distance		-0.01 (0.01)	-0.03*** (0.01)		-0.01 (0.01)	-0.03*** (0.01)
Finance			0.12 (0.10)			0.12 (0.12)
Corruption			-0.04 (0.07)			-0.07 (0.08)
Law			0.09 (0.06)			0.12 (0.08)
Capital			0.00 (0.01)			0.00 (0.01)
Skill			-0.08 (0.09)			-0.09 (0.10)
Constant	-1.21*** (0.07)	-1.05*** (0.10)	-1.11*** (0.11)	-1.68*** (0.23)	-1.61*** (0.23)	-1.42*** (0.40)
Observations	26,763	26,637	11,352	26,337	26,211	10,190
Year FE	No	No	No	Yes	Yes	Yes
Industry FE	No	No	No	Yes	Yes	Yes

^a The dependent variable is the product-cycle measure, $PC_{cjt} = X_{cjt}^P / X_{cjt}$, U.S. product cycle imports as a share of total U.S. imports for each industry. An observation is an industry-country-year pair.

^b All regressions include the time averages of all exogenous variables. The estimates of time averages are omitted.

^c Robust errors are clustered by 4-digit industry and appear in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Table B.30: Test Hypothesis 3: Interval Sample

	Dependent variable: Dummy of exit					
	Probit					
	(1)	(2)	(3)	(4)	(5)	(6)
IPP _{t-5}	0.03*** (0.01)	0.04*** (0.01)	0.01 (0.01)	0.01 (0.01)	0.00 (0.01)	-0.01 (0.01)
IPP _{t-5} *R&D	0.04 (0.13)	0.03 (0.13)	0.27 (0.20)	0.33** (0.14)	0.33** (0.14)	0.42** (0.19)
IPP _{t-5} *R&D ²	0.57 (0.87)	0.69 (0.87)	-1.17 (1.25)	-1.42** (0.64)	-1.37** (0.65)	-1.88** (0.94)
R&D	21.48*** (1.97)	22.07*** (1.90)	19.24*** (2.86)	-1.44 (2.57)	-1.09 (2.60)	0.97 (4.83)
R&D ²	-100.66*** (16.80)	-104.75*** (16.29)	-75.35*** (18.41)	7.49 (11.03)	5.94 (11.21)	3.08 (21.00)
PCGDP		-0.01 (0.02)	-0.02 (0.04)		0.02 (0.02)	-0.02 (0.05)
Population		0.50*** (0.12)	0.46*** (0.10)		0.58*** (0.11)	0.63*** (0.12)
Distance		-0.02 (0.02)	-0.00 (0.01)		-0.01 (0.02)	-0.00 (0.02)
Finance			-0.12 (0.15)			-0.14 (0.19)
Corruption			0.24 (0.15)			0.36* (0.21)
Law			-0.17 (0.12)			-0.23 (0.16)
Capital			0.01 (0.01)			0.01 (0.01)
Skill			-0.02 (0.12)			-0.01 (0.16)
Constant	-0.81*** (0.07)	-0.77*** (0.12)	-0.29* (0.15)	0.44* (0.23)	0.47** (0.23)	1.19*** (0.38)
Observations	26,763	26,637	11,352	25,951	25,830	10,817
Year FE	No	No	No	Yes	Yes	Yes
Industry FE	No	No	No	Yes	Yes	Yes

^a The dependent variable is the product-cycle measure, $PC_{cjt} = X_{cjt}^P / X_{cjt}$, U.S. product cycle imports as a share of total U.S. imports for each industry. An observation is an industry-country-year pair.

^b All regressions include the time averages of all exogenous variables. The estimates of time averages are omitted.

^c Robust errors are clustered by 4-digit industry and appear in parentheses. *** p<0.01, ** p<0.05, * p<0.1.