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ABSTRACT

The main purpose of this study is to investigate the optimal strategy and the welfare effects of technology improvements in the open economy. The first essay, “Hicks Theorem: Effects of Technological Improvement in the Ricardian Model” studies these questions with the Ricardian model. The essay formally proves Hicks’ (1953) insight into the effects of technological improvement: uniform technological improvement at home benefits all countries (or at least does not hurt); export-biased technological improvement at home benefits the foreign country (or at least does not hurt), but import-biased technological improvement at home can hurt the foreign country if the comparative advantage is not reversed.

The paper then studies optimal strategies of technological improvement and shows that for a small country it is optimal to choose export-biased technological improvement. For a large country, it is optimal to improve technology in both sectors at a rate proportional to the consumers’ expenditure share.

The second essay, “A Two-Sector Eaton and Kortum Model: Technological Changes and International Trade” studies the effects of technological changes with a two-sector Eaton and Kortum model. This paper distinguishes two types of technology changes: changes in the technology levels (technology improvements) and changes in the dispersion of productivity of firms. The paper shows that technology improvements always

increase the total trade. Technology improvements increase inter-industry trade if they originate in the comparative advantage sector, otherwise they decrease inter-industry trade. Increases in the degree of heterogeneity always increase the total trade and inter-industry trade.

The essay also analyzes the welfare effects of technology improvements and yields some new results. It shows that with the Cobb-Douglas utility function technology improvements are always beneficial to the innovator. In agreement with the literature, export-biased improvements benefit the foreign country. In a departure from the literature, however, the paper shows that import-biased improvements could benefit the foreign country. The essay also shows that when the final goods are complements, immiserizing growth may occur.

The theoretical model of the paper shows that the net exports of the comparative advantage sector are positive while those of the other sector are negative. This offers us a testable hypothesis about the Ricardian trade model. Using the OECD STAN databases, the paper conducts some simple tests concerning the prediction and finds strong support for it. The Ricardian model is one of the pillars of the international trade theory, but there have been few empirical tests of it. The results of this work will enrich the literature in this field.

The third essay, "Hicks Path: The Optimal Strategy of Technological Improvement in the open economy" extends the Eaton and Kortum framework into a multi-sector model to analyze the innovation pattern of countries. The

model shows that the R&D activities are determined by sectoral expenditure and research efficiency. The model also shows that the laissez faire R&D input level is less than the socially optimal R&D input level in autarky when there are two sectors. In the open economy the R&D input in an industry depends on the country's advantage in the industry.

Using the OECD STAN database, the empirical analysis finds some support for Hicks' path, a technology improvement strategy for countries advanced by Hicks, but it also indicates that the R&D pattern in the real world might be richer than what Hicks predicted.

Chapter 1 :

INTRODUCTION

1.1. Background

Technological change has always been an important issue in economics. In the fields of economic growth and economic development, researchers have studied how countries improve their technologies and how technical progress affects the economy. Extensive as it is, the literature in these fields did not do justice to international trade. In the real world, though, international trade becomes increasingly important. The export's share in GDP is as high as 129.8% for Singapore and 109.7% for Hong Kong (IMF, 1998), and the growth rate of exports has been around 20% for the last ten years in China, who ranked third in merchandise trade in 2005 (WTO, 2007).

These facts attract economists' attention and they begin to use the trade framework to analyze the issues concerning technological progress. The theoretical work on these issues can be divided into two categories according to the trade theories they use. The first stream is based on the Ricardian model and the second stream is based on the Eaton Kortum framework. There is also a great deal of empirical work on the effects and the strategy of technological progress based on various trade models.

1.1.1. Theoretical Study Based on the Ricardian Model

Theoretical works on technical progress based on the Ricardian model date back to Ricardo himself. However, most papers in this stream of research have appeared in recent decades. Hicks (1958) analyzed how technology improvements in one country affect its trade partners' welfare and payment balance. Dornbusch, Fischer and Samuelson (1977) prove that a uniform technology improvement in the foreign country will improve the home country's welfare in a continuum-good Ricardian model. Choi and Yu (1987) study the welfare effect of Hicks-neutral technical progress under variable returns to scale. They find that for a small country, technology improvement benefits itself under certain circumstances, and the technology improvement may hurt other countries. They also study how technology improvements affect a country's terms of trade. Markusen and Svensson (1985) study how Hicks-neutral technological differences between two similar countries affect them. Krugman (1986) uses a model of "technology gaps" to explain how the technology evolution pattern determines the economy pattern. Grossman and Helpman (1995) study how learning-by-doing, R&D and diffusion determine the technology progress. They also summarize the welfare effects of technical progress, which seems to bring closure to this issue. However, several years later, the issue regains its popularity when people are arguing about the impact of globalization. Samuelson (2004) calls our attention to the fact that developing countries could improve their technologies to the detriment of developed countries. Ruffin and Jones (2007) study some cases omitted in previous literature.

1.1.2. Theoretical Study Based on the Heterogeneous Firms Framework

The second stream of theoretical research is based on the heterogeneous firms framework. As important as it is, "the problem with the (Ricardian model) as a vehicle for discussing technical change is that too many things can happen (Krugman, 1986)." The switches in trade regimes make the analysis quite complicated. Moreover, the Ricardian model makes some strong assumptions, such as perfect competition and homogeneous firms. These assumptions have not been a problem because traditionally trade theory has been aimed at understanding aggregate evidence on topics such as the factor content of trade and industry specialization. These flaws encourage economists to develop new models to study technological progress in the trade framework. On the other hand, economists begin to emphasize the effects of trade on micro issues such as plant sizes and worker productivity. To this end, the trade theory should take into consideration the differences among individual producers within an industry. The new trade theory, which is based on the heterogeneous-firms framework, incorporates these elements and has become a popular model for studying technical change.

The Melitz' (2003) model and the Eaton and Kortum (2002) model are two important frameworks that model the heterogeneity of firms in international trade. The Melitz model allows for imperfect competition and infinite goods varieties. It is often used to analyze intra-industry reallocation. The Eaton-Kortum model assumes perfect competition and a fixed continuum of goods. The core assumption of the Eaton-Kortum model is that the productivity of a firm in a country is a random draw from a Fréchet distribution, whose parameters represent the country's technology level. The model assumes that the final goods are produced with intermediate goods, which is in turn produced with intermediate goods and labor. The framework also allows for multiple countries and geographical barriers. Overall, the setup is more realistic than the Ricardian model.

1.1.3. Empirical Study

Besides the above two streams of theoretical study, there has been rich literature on the empirical study of the welfare effects and the optimal strategy of technology improvements. Eaton and Kortum's(1999) paper is most relevant to this project. It measures the effects of research on the state of technology of foreign countries. In their model, new ideas diffuse across countries and all countries grow at the same steady-state rate. Research effort is determined by the gains from the world market. They find that research performed in foreign countries is about two-thirds as potent as domestic research. Eaton et al. (1998) study what determines the research efforts of European countries. They find that the size of the domestic markets is more important than the research efficiency. Bernstein and Mohnen (1998) investigate the bilateral link between the U.S. and Japanese economies in terms of how R&D capital formation in one country affects the production structure, physical and R&D capital accumulation, and productivity growth in the other country. Clerides et al. (1998) study how exports affect a country's technology level. Evidence from Colombia, Mexico, and Morocco shows that the positive association between exporting and efficiency can be explained by the self-selection of the more efficient firms into the export market.

1.1.4. Related Literature

Besides the above three streams of research, there are many related papers that help us understand the welfare effects and the optimal strategy of technology improvements. The first group of papers is on the evolution of technology. Kortum (1997) develops a search-theoretic model of technological change. Researchers randomly draw new ideas from a distribution. If the new idea surpasses the state-of-the-art technology, it becomes the new technology frontier. Technology improvements become increasingly difficult as the technological frontier advances. This accounts for the fact that patents grew steadily as the research effort rose sharply in the past century. Kortum shows that if researchers sample from Pareto distributions, the distribution of the productivity of individual firms converge to Fréchet distributions in law. The Fréchet distribution has some nice mathematical properties. It can also be converted into an exponential distribution à la Avarez and Lucas (2007). Eaton, Gutierrez, and Kortum (1998), Eaton and Kortum (2001a) provide further analysis of research indicators across countries and over time.

The second group of related papers studies the welfare effects of patent protection. Deardoff (1992) shows that while the welfare of the innovator increases that of other countries decreases as the protection strengthens. Helpman (1993) studies how the protection of intellectual property rights affects the welfare of each country. He decomposes the effects into four items:

(1) Terms of trade, (2) Production composition, (3) Available products, and (4) Inter-temporal allocation of consumption. He claims that when the imitation rate is low, tighter protection will hurt both parties. Grossman and Lai (2002) study how governments protect intellectual property. They consider two countries that differ in market size, in their capacities for innovation, and in their absolute and comparative advantage in manufacturing. The strength of IPR protection is correlated with the duration of a country's patents. They study why patents are longer in the North. They also show us an efficient global regime of patent protection. The issue has been revisited recently by Gancia (2003) as well as by Dinopoulos and Segerstrom (2005).

1.2. Objectives of the Study

The main purpose of this study is to investigate the optimal strategy and the welfare effects of technology improvements in the open economy. The project is divided into three papers. The first paper endogenizes technology progress in the Ricardian model and investigates its welfare effects. The second paper analyzes the effects of technology changes in a trade framework that incorporates the heterogeneity of firms. The third essay looks at the the optimal strategy of technology improvement.

1.3. Motivation for the Study

Each of these papers addresses some interesting questions and fills in some gaps in the literature. As for the first paper, many economists (e.g., Hicks, Grossman and Helpman) have mentioned the welfare effects of technology improvements in the Ricardian model. However, most of them focus on one or two trade regimes and ignore the switches in trade patterns. For such a benchmark model, I believe, it is worth the effort to consider all the possibilities and to give a complete analysis of the welfare effects of technology improvements. As for the optimal strategy of technology development, there is no literature that endogenizes technology progress in the Ricardian model. Moreover, most of the literature assumes technology progress to be uniform. In the Ricardian, we can model biased technology improvement and it gives us several new results.

The second paper addresses some questions that are of interest to many economists. Recently, economists have been concerned with the assumption of homogeneous firms in trade theories. They point out that this assumption is inconsistent with economic facts (e.g., Melitz, 2002; Bernard et al., 2003). On the other hand, papers based on the assumption of heterogeneous firms show us some new mechanisms through which trade affect countries (e.g., Melitz, 2002; Demidova, 2005). However, some results of this stream of research are contradictory with those of the Ricardian model.

The third paper studies the pattern of R&D of countries. Hicks (1953) argued that "*the first stage in a process of development is very likely to be export-biased*," and then "*… the process passes into its second stage … that are import-biased*." Thus when his analysis "*is put into an historical dress, it suggests as a normal sequence the succession of an export-biased by an import-biased phase*" (Hicks, 1953), a pattern that I refer to as the Hicks path hereafter. Interesting as it is, neither Hicks himself nor other economists have conducted formal empirical tests on the Hicks path. To fill this gap, the third essay provides a theoretical foundation for Hicks path in this paper and study if it exists in the data.

1.4. Results of the Study

The first essay, “Hicks Theorem: Effects of Technological Improvement in the Ricardian Model” studies these questions with the Ricardian model. The paper formally proves Hicks’ (1953) insight into the effects of technological improvement: uniform technological improvement at home benefits all countries (or at least does not hurt); export-biased technological improvement at home benefits the foreign country (or at least does not hurt), but import-biased technological improvement at home can hurt the foreign country as long as the comparative advantage is not reversed.

The paper then studies optimal strategies of technological improvement and shows that for a small country it is optimal to choose export-biased technological improvement. For a large country, it is optimal to improve technology in both sectors at a rate proportional to the consumers’ expenditure share.

The second essay, “A Two-Sector Eaton and Kortum Model: Technological Changes and International Trade” studies the effects of technological changes with a two-sector Eaton and Kortum model. This paper distinguishes two types of technology changes: changes in the technology levels (technology improvements) and changes in the dispersion of productivity of firms. The paper shows that technology improvements always increase the total trade. They increase inter-industry trade if they originate in the comparative advantage sector, otherwise they decreases inter-industry trade. Increases in the degree of heterogeneity always increase the total trade and inter-industry trade.

The paper also analyzes the welfare effects of technology improvements and yields some new results. It shows that with the Cobb-Douglas utility function technology improvements are always beneficial to the innovator. In agreement to the literature, export-biased improvements benefit the foreign country. In a departure from the literature, however, the paper shows that import-biased improvements could benefit the foreign country. The paper also shows that when the final goods are complements, immiserizing growth may occur.

The theoretical model of the paper shows that the net exports of the comparative advantage sector are positive while those of the other sector are negative. This offers us a testable hypothesis about the Ricardian trade model. Using the OECD STAN databases, the paper conducts some simple tests concerning the prediction and finds strong support for it. The Ricardian model is one of the pillars of the international trade theory, but there have been few empirical tests of it. The results of this work will serve to enrich the literature in this field.

The third essay, "Hicks Path: The Optimal Strategy of Technological Improvement in the open economy" extends the Eaton and Kortum framework into a multi-sector model to analyze the innovation pattern of countries. The model shows that the R&D activities are determined by the sectoral expenditure and the research efficiency. The model also shows that the laissez faire R&D input level is less than the socially optimal level in autarky when there are two sectors. In the open economy the R&D input in an industry depends on the country's advantage in the industry.

Using the OECD STAN database, the empirical analysis finds some support for Hicks' path but it also indicates that the R&D pattern in the real world might be richer than what Hicks predicted. Within each industry, for the majority of countries (whose technology frontier ranks in the top 70%-80% in the industry) the sectoral R&D input of a country first increases with its technological advantage in the industry. When the country moves into the leading group (i.e., its technology frontier ranks among the top 20%-30% in the industry) its sector R&D begins to decrease with its technological advantage. This is consistent with Hicks' claim that countries will first conduct export-biased technology improvements and then import-biased improvement. The empirical study, however, also finds that for the countries whose technological advantage ranks in bottom 20%-30% the sectoral R&D input decreases with their technological advantage. This might arise from the reason that less-developed countries may find it more profitable to rely on technology transfer than on research and development, a hypothesis left for future study.

1.5. Organization of the Study

Chapter 2 presents the first essay "Hicks Theorem: Effects of Technological Improvement in the Ricardian Model". Chapter 3 presents the second essay, “A Two-Sector Eaton and Kortum Model: Technological Changes and International Trade”. Chapter 4 presents the third essay, “Hicks Path: The Optimal Strategy of Technological Improvement in the open economy”. Chapter 5 summarizes the study and suggests possible extensions to this line of research.

Chapter 2 :

HICKS THEOREM: EFFECTS OF TECHNOLOGICAL IMPROVEMENT IN THE RICARDIAN MODEL

2.1. Introduction

There is a great deal of interest in the effects of technological improvement (through either innovation or technology transfer) in developing countries, such as China and India, on the welfare of developed countries, such as the United States. In his recent article, Samuelson (2004) argues that China could improve the technology in its import sector until its post-innovation relative labor productivity is identical to that in the United States, thus eliminating the U.S.'s comparative advantage, and any further gains from free trade. Samuelson's argument, however, is challenged by the technology transfer paradox discussed by Ruffin and Jones (2007) and Jones and Ruffin (2008). They show that the United States will actually gain from technological improvement in China's import sector if such technological improvement is sufficiently large to reverse comparative advantage. Samuelson's argument is also quite different from studies by Eaton and Kortum (2001b, 2002, 2006) and by Alvarez and Lucas (2007), who argue that technological improvement in one country always benefits all other countries.

Hicks (1953) pointed out these varying effects of technological improvement more than half a century ago. In analyzing the effects of increasing productivity in the United States on Britain, Hicks pointed out that: 1) *uniform* technological improvement in one country benefits all countries, which is the case studied by Eaton and Kortum (2001b, 2002, 2006) and Alvarez and Lucas (2007); 2) *export-biased* technological improvement benefits the foreign country, which is emphasized by Ruffin and Jones (2007) and Jones and Ruffin (2008); and 3) *import-biased* technological improvement hurts the foreign country, which is exactly Samuelson's argument. Hicks did not put his insight into a formal model. In this essay I will formally prove Hicks' insight with the Ricardian model.

Even in the simplest two-good, two-country Ricardian model, a formal analysis could be complicated since patterns (regimes) of trade are endogenous. The problem with this model as a vehicle for discussing technical change is that too many things can happen (Krugman, 1986, p. 153). However, we are able to pin down regime switches in a simple diagram by assuming that the utility function is Cobb-Douglas. The analysis then becomes straightforward.

The question that immediately emerges and that is crucial for economic development is: When will a country choose export-biased, and when will it choose import-biased technological improvement? Hicks (1953) proposed two stages of technological improvement: countries start with *export-biased* technological improvement in the first stage, and then move on to *import-biased* technological improvement in the second stage. We call this the *Hicks path*.

The optimal strategy of technological improvement in the Ricardian model is studied here, in order to shed some light on the *Hicks path.* The essay shows that it is optimal for a small country to choose *export-biased* technological improvement, which benefits the partner country. A large country, however, finds it optimal to improve technology in both sectors. Interestingly, the optimal rate of technological improvement in each sector is proportional to the consumers' share of expenditure for that sector. Therefore, if the expenditure share of the import sector is larger than that of the export sector, the large country will choose a relatively *import-biased* technological improvement, which hurts its trade partner. When both countries are fully specialized, the home country may choose either an *export-biased* technological improvement, or a *catching-up* strategy, wherein it also improves the technology in its import sector and becomes self-sufficient in both goods. The catching-up strategy is shown to be optimal if the expenditure share on the importable good is sufficiently large, the country itself is large enough, and the technology gap with the advanced country in the import sector is relatively small.

This paper is related to the theoretical literature that investigates technology and trade. Besides the aforementioned works, Grossman and Helpman (1995) provide an excellent survey of the literature. Helpman (1993) analyzes the welfare effect of intellectual property rights policy and argues that faster diffusion will stimulate the research process in the innovating country. Demidova (2006) shows that technological improvement hurts the innovator's partner in the event that specialization does not occur.

2.2. Welfare Effects of Technological Improvement

The analysis of this paper is based upon the standard Ricardian model, which has two goods and one factor (labor). I assume that only the home country improves its technology.

The goods market is perfectly competitive, and labor is perfectly mobile between industries in each country but immobile across countries[1]. In this essay, foreign variables are denoted by the superscript *. Let $a_i(a_i^*)$ be the amount of labor needed to produce a unit of good i $(i = 1, 2)$ in the home (foreign) country before the technological change. Suppose the home country has comparative advantage is sector 1:

$$a_1/a_2 \;< a_1^* /a_2^*$$

Thus, the home country has a comparative advantage in producing good 1 before the technological change. The total labor force at home (abroad) is $L\ (L^*)$ Let $p^a\ (p^{a*})$ denote the autarky price of good 1 relative to good 2 in the home (foreign) country. Perfect competition implies that $p^a = a_1/a_2$ and $p^{a*} = a_1^* /a_2^*$.

Now suppose that the home country and the foreign country open up to trade. Let p_i be the free trade price of each good, and $p = p_1/p_2$ be the

[1] The assumptions of perfect competition in the good market and homogeneity of the final goods give rise to some sharp predictions concerning the trade pattern. For example, the supply elasticity of a good could be zero or infinity, a country either entirely depends on imports in a sector or does not import any good of that sector. The next essay will introduce heterogeneity to address some of these problems.

relative price of good 1. Output in sector i is denoted by y_i. Let good 2 be the numéraire good, so that $p_2 = 1$. The world relative supply curve has a stepped shape, and is depicted in Figure 2-1. The vertical and horizontal axes represent relative price p and relative supply of good 1, $y = (y_1 + y_1^*)/(y_2 + y_2^*)$ respectively. For the world relative price $p < p^a = a_1/a_2 < p^{a*} < a_1^*/a_2^*$ both countries specialize in good 2, so the world relative supply of good 1 is zero. For $p^a < p < p^{a*}$ the home country specializes in good 1, while the foreign country specializes in good 2, and the world relative supply is $(L/a_1)/(L^*/a_2^*)$. Finally, if $p^a > p > p^{a*}$ both countries specialize in good 1, and the world relative supply of good 1 is infinity.

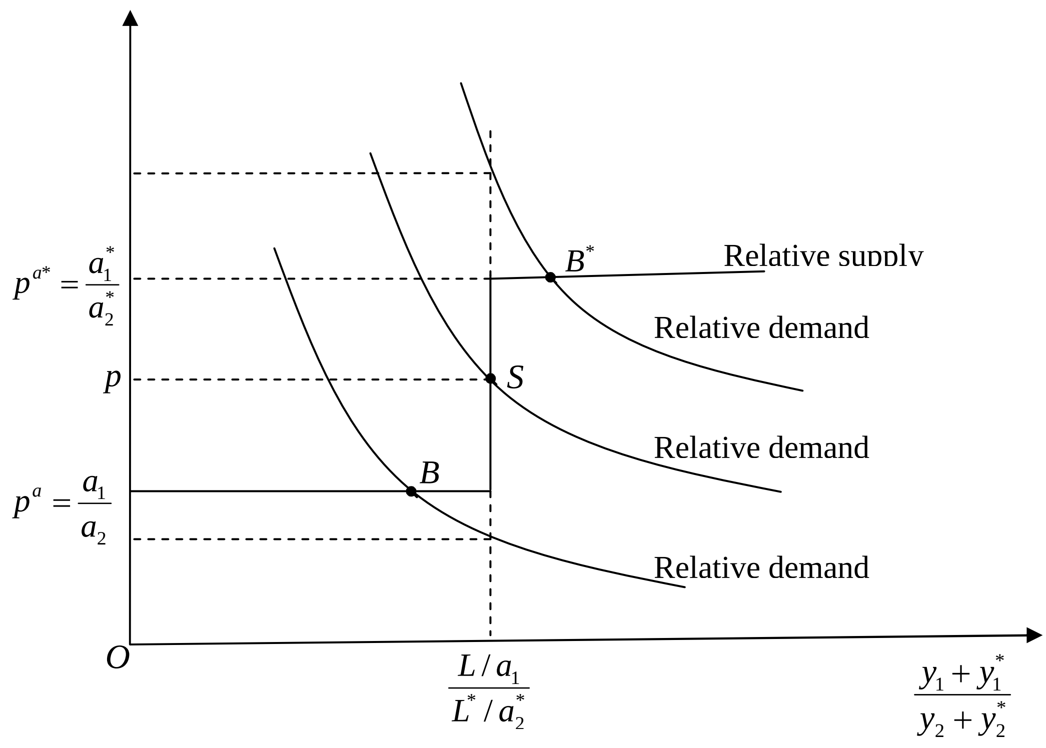

Figure 2-1: Regime Switch

The utility function of the representative consumer in each country is the same, and is represented by

$$u(x_1, x_2) = x_1^{\beta} x_2^{1-\beta}$$

Thus, the world relative demand is

$$x(p) = \frac{x_1}{x_2} = \frac{\beta}{(1-\beta)p} <=> p(x) = \frac{\beta}{(1-\beta)x}$$

The free trade outcome is determined by the relative demand curve, and the relative supply curve. There are three possibilities. The first possibility is that the relative demand curve cuts the lower horizontal segment of the relative supply curve at $p = a_1/a_2$ which is represented by equilibrium B in Figure 2-1. This is referred to as regime B of trade in which the home country produces both goods, and exports good 1. The second possibility is that the demand curve cuts the vertical segment of the supply curve at $y = (y_1 + y_1^*)/(y_2 + y_2^*)$ which is represented by equilibrium S in Figure 2-1. This is referred to as regime S of trade. Both countries are fully specialized in regime S. The third possibility is that the demand curve cuts the upper horizontal segment of the supply curve at $p = a_1^*/a_2^*$ which is represented by equilibrium B^* in Figure 2-1. This is referred to as regime B^* of trade, in which the foreign country produces both goods and exports good 2. It is easily seen that, in Figure 2-1 at $x^s = (L/a_1)/(L^*/\, a_2^*)$ the inverse demand $p(x^s) = \frac{\beta a_1 L^*}{(1-\beta)a_2^* L}$ must be less than a_1/a_2 in regime B, greater than a_1/a_2 but less than a_1^*/a_2^* in regime S, and greater than a_1^*/a_2^* in regime B^*.

Let $E = \frac{\beta L^*}{(1-\beta)L}$ be the relative size of the foreign country. As shown in Figure 2-2, if $0 \leq E < \frac{a_2^*}{a_2} < \frac{a_1^*}{a_1}$, the home country is relatively large, and the two countries are engaged in regime B trade; if $\frac{a_2^*}{a_2} < E < \frac{a_1^*}{a_1}$ the two countries are engaged in regime S trade, and if $E > \frac{a_1^*}{a_1} > \frac{a_2^*}{a_2}$ the foreign country is relatively large, and the two countries are engaged in regime B^* trade. The countries' relative sizes and their productivity determine the trade regime.

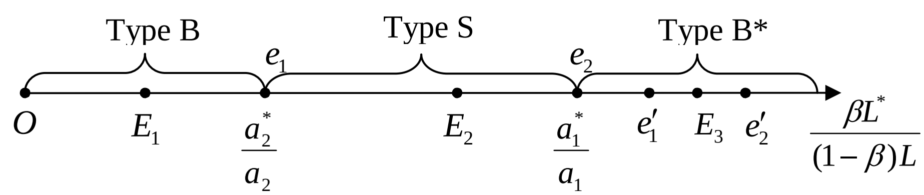

Figure 2-2: Regime Switch and the Relative Country Size

2.2.1. Regime Switch

Changes in technology change the relative productivity of the two countries and thus may switch the trade regime. With the Cobb-Douglas utility function, the regime switch is conveniently determined by the countries' relative sizes.

We analyze how the trade regime changes when the home country adopts *export-biased, import-biased*, or *uniform* technological improvements. In regime B, we have $E_B < \frac{a_2^*}{a_2} < \frac{a_1^*}{a_1}$. The home country is large, produces both goods, and exports good 1. *Export-biased* technological improvement (which reduces a_1) *import-biased* technological improvement (which reduces a_2) and *uniform* technological improvement (which reduces a_1 and a_2 proportionally), all leave the inequality $E_B < \frac{a_2^*}{a_2} < \frac{a_1^*}{a_1}$ unchanged. Hence, technological improvement in regime B does not switch the trade regime.

In regime S, $\frac{a_2^*}{a_2} < E_s < \frac{a_1^*}{a_1}$ and the home country is completely specialized in producing good 1. A reduction in a_1 (*export-biased* technological improvement) does not change the inequality, but a sufficiently large reduction in a_2 (*import-biased* technological improvement) can switch the trade regime from S to B. If proportional reductions in both a_1 and a_2 (*uniform* technological improvement) are sufficiently large, the trade regime can also switch from S to B.

In regime B^*, wherein $E > \frac{a_1^*}{a_1} > \frac{a_2^*}{a_2}$ the home country is small and completely specializes in producing good 1, a sufficiently large *export-biased* technological improvement (reduction in a_1), can switch the trade regime from B^* to S. A sufficiently large import-biased technological improvement (reduction in a_2), can first reverse the comparative advantage, and then switch the trade regime from B^* to S. Finally, a sufficiently large uniform technological improvement (proportional reductions in $a_1$and a_2) can switch the trade regime from B^* to S. Further reductions in a_1 and a_2 can change the trade regime from S to B. The above results for regime switch are summarized in Table 2-1.

Table 2-1: Regime Switch

Starting point	Export-biased technological improvement	Import-biased technological improvement	Uniform technological improvement
Regime B*	Sufficiently large reduction in a_1 can switch the regime from B* to S	Sufficiently large reduction in a_2 can reverse the comparative advantage and then switch the regime from B* to S	Sufficiently large proportional reductions in a_1 and a_2 can switch the regime from B* to S, and then S to B
Regime S	No change	Sufficiently large reduction in a_2 can switch regime from S to B	Sufficiently large proportional reductions in a_1 and a_2 can switch regime from S to B
Regime B	No change	No change	No change

Note:

- Regime B*: Home country is small, specializes in good 1, exports good 1; Foreign country is large, produces both goods, exports good 2
- Regime S: Home country specializes in good 1, exports good 1; Foreign country specializes in good 2, exports good 2

- Regime B: Home country is large, produces both goods, exports good 1; Foreign country is small, specializes in good 2

2.2.2. Welfare Effects

I will first analyze the effects of *export-biased* technological improvement, then the effects of *import-biased* technological improvement, and lastly, the effects of *uniform* technological improvement. For each type of technological improvement, we start from regime B*, where $E \geq \frac{a_1^*}{a_1} > \frac{a_2^*}{a_2}$. The budget lines in the home country and the foreign country are

$$px_1 + x_2 = wL$$

$$px_1^* + x_2^* = w^*L^*$$

Technological improvement changes the terms of trade, p, as well as real income, w/p and w^*/p. The former is denoted as the *terms of trade effect* and the later is denoted as the *real income effect*. In regime B^*, the wage rates are $w = p/a_1$ and $w^* = 1/a_2^*$ and the free trade price is $p = a_1^*/a_2^*$. Consider an *export-biased* technological improvement that reduces a_1 to a_1'. Real income at home increases but the terms of trade are not affected; therefore, the home country budget line shifts out. This change, however, has no effect on the budget line abroad. Thus, under regime B^*, the *export-biased* technological improvement increases welfare at home but has no effect on the foreign country.

Let the reduction in a_1 be sufficiently large so that the trade regime switches from B^* to S ($a_1' < \frac{a_1^*(1-\beta)L}{\beta L^*}$). When both countries are fully specialized, the world relative supply is $y = (L/a_1)/(L^*/a_2^*)$ as indicated by point S in Figure 2-1. From the inverse demand function (1), the world relative price is now $p' = p(y) = \frac{\beta a_1' L^*}{(1-\beta)a_2^* L}$. The terms of trade at home, p, decline. The wage rates in the home country and in the foreign country are $w = p'/a_1' = \frac{\beta L^*}{(1-\beta)a_2^* L}$ and $w^* = 1/a_2^*$ respectively. As a_1 decreases, the real wage at home, $\frac{w}{p} = \frac{1}{a_1}$ increases. Combining the *real income effect* and the *terms of trade effect*, the budget line shifts out as a_1 decreases. This implies that, in the home country, the *real income effect* dominates the *terms of trade effect*, and domestic welfare increases. The reduction in a_1 improves the terms of trade in the foreign country and swivels the foreign budget line out. Therefore, welfare in the foreign country increases as well.

Note that a decrease in a_1 in regime S never switches the trade regime from S to B. On the other hand, if we start from regime B, $p = \frac{a_1}{a_2}$, $w = \frac{p}{a_1} = \frac{1}{a_2}$ and $w^* = \frac{1}{a_2^*}$. The decrease in a_1 swivels both the home and the foreign budget lines out, and therefore increases welfare at home and abroad.[2]

We now turn to *import-biased* technological improvement. Note that in

[2]The above result relies on the assumption of the Cobb-Douglas utility function. If the demand is less elastic, as noted by both Samuelson (2004) and Ruffin and Jones (2005), immiserizing growth may occur.

regimes B^* and S, the reduction in a_2 has no effect on the economy as long as the comparative advantage is not reversed. Once it does, one must have $\frac{a_1^*}{a_1'} < \frac{a_2^*}{a_2'}$. If so, a further reduction in a_2 becomes *export-biased* technological improvement; its welfare effect has been discussed above. In regime B, $p = \frac{a_1}{a_2}$ $w = \frac{p}{a_1} = \frac{1}{a_2}$ and $w^* = \frac{1}{a_2^*}$. *Import-biased* technological improvement increases both the wage rate and the terms of trade at home. The budget line shifts out and therefore improves welfare at home. However, the terms of trade in the foreign country, $1/p$, decline, while the foreign wage rate w^* is not affected by the reduction in a_2 . The budget line for the foreign country shifts in, hence welfare in the foreign country decreases.

Uniform technological improvement is a combination of *export-biased* and *import-biased* technological improvements. From the above analysis we know that welfare in both countries either improves or does not change for all cases except the *import-biased* technological improvement in regime B when foreign welfare declines. When *uniform* technological improvement in regime B takes place, however, p is equal to a_1/a_2 which does not change since a_1 and a_2 decrease proportionally. This implies that welfare in the foreign country does not decline even in this worst case. Therefore, as expected, *uniform* technological improvement improves welfare in both home and foreign countries. The above cases of welfare effects are summarized in Table 2-2, and are also states as the following *Hicks theorem*:

Theorem 1*(Hicks Theorem)*: If the utility function is Cobb-Douglas,

export-biased technological improvement at home benefits the home country, and either benefits the foreign country (or leaves its welfare unchanged). Import-biased technological improvement at home benefits the home country, but can hurt the foreign country as long as the comparative advantage is not reversed. Uniform technological improvement at home benefits all countries (or leaves welfare unchanged).

The above results were first stated by Hicks (1953) while analyzing the effect that increased U.S. productivity had on Britain. His main insight was that, given the terms of trade, the primary effect of technological progress is to increase the growing country's income and leave the foreign one unaffected, an effect summarized as the *real income effect.* When the terms of trade are endogenous, there is a secondary effect, which is labeled as the *terms of trade effect. Export-biased* technological progress lowers the world price of the exported good at home, which hurts the home country but benefits its trading partner. The primary gain to the home country will dominate the secondary loss if demand is sufficiently elastic. The Cobb-Douglas case assumed in this paper is enough to guarantee that the gain is greater than the loss. *Import-biased* technological improvement changes the terms of trade in favor of the home country, so the home country may enjoy further gain, but the foreign country can be hurt.

Fifty years after Hicks, Samuelson (2004) again addresses the unpleasant effect of *import-biased* technological improvement on the foreign country. His argument, however, is challenged by the technology transfer paradox discussed by Ruffin and Jones (2007) and Jones and Ruffin (2008). They show that the United States will, nonetheless, gain from China's technological improvement in its import sector if such technological improvement is sufficiently large to reverse comparative advantage. Jones and Ruffin point out a complication to the formal analysis: trade regimes become endogenous when technology is changing. The paper shows that Hicks' insight still works, provided that the technological improvement is *import-biased* up to the point where comparative advantage is reversed.

Table 2-2: Welfare Effects

Starting point	Export-biased technological improvement	Import-biased technological improvement	Uniform technological improvement
Regime B*	Home welfare improves Foreign welfare is unchanged	Home welfare is unchanged Foreign welfare is unchanged	Home welfare improves Foreign welfare is unchanged
Regime S	Home welfare improves Foreign welfare improves	Home welfare is unchanged Foreign welfare is unchanged	Home welfare improves Foreign welfare improves
Regime B	Home welfare improves Foreign welfare	Home welfare improves Foreign welfare	Home welfare improves Foreign welfare is

	improves	worsens	unchanged

Note:

- Regime B*: Home country is small, specializes in good 1, exports good 1; Foreign country is large, produces both goods, exports good 2
- Regime S: Home country specializes in good 1, exports good 1; Foreign country specializes in good 2, exports good 2
- Regime B: Home country is large, produces both goods, exports good 1; Foreign country is small, specializes in good 2

2.3. Optimal Strategy of Technological Improvement

The effects of *export-biased* versus *import-biased* technological improvements on welfare of the partner country are strikingly opposite. A crucial question that follows is when a country will choose the *export-biased* and when it will choose *import-biased* technological improvement. To answer this question, this section investigates the optimal strategy of technological improvement.

Departing from the assumption of costless technological improvement, I assume that the home country must allocate some labor to improve its technology. After the technological improvement the amount of labor needed to produce one unit of output in sector i is

$$a_i' = \frac{a_i}{1 + \theta d_i}$$

where $d_i > 0$ is the amount of labor used in sector i for technological improvement. $\theta > 0$ measures the efficiency of R&D in sector i, which is assumed, for simplicity, to be the same in both sectors. I start from a social planner's problem in which (d_1, d_2) is chosen to maximize the utility of the representative consumer. The social planner can pay $w(d_1 + d_2)$ to the foreign country for a technology transfer, which is typically the case for developing countries, or she can spend $\frac{d_i}{L}$ share of labor per worker in sector i to improve working efficiency. Either way, the total income left for consumption after technological improvement at home is $w(L - d_1 - d_2)$. It can be shown that the social planner's problem is equivalent to a decentralized market decision when the R&D sector is perfectly competitive (see Appendix 2.A).

2.3.1. The Social Planner's Problem in a Large Country

We start from the regime B equilibrium, where the home country is large and produces both goods, and the world price p equals the autarky price at home, a_1/a_2. Regime B is an important case for us, since it resembles the optimal R&D decision in autarky. It is also a simple one since technological improvement does not change the trade regime in this case. First the representative consumer chooses a consumption bundle (x_1, x_2) given R&D input (d_1, d_2) and prices (p, w); then the social planner chooses the R&D input (d_1, d_2) to maximize utility. Using the envelope theorem, it is straightforward to show that this two-stage maximization problem is equivalent to the social planner's problem of maximizing utility by choosing

(x_1, x_2, d_1, d_2) that is,

$$\max_{x_1,x_2,d_1,d_2} u(x_1, x_2) = x_1^{\beta} x_2^{1-\beta}$$

$$s.t. p_1 x_1 + p_2 x_2 = w(L - d_1 - d_2) and$$

$$p_i = w a_i' = \frac{w a_i}{1 + \theta d_i} \; for \; i = 1,2$$

where the first constraint is the budget constraint, while the second constraint is the equilibrium pricing condition. Substituting the price into the budget constraint, the first-order conditions are then given by

$$\frac{\partial u(x_1, x_2)}{\partial x_i} = \lambda p_i$$

$$w + \frac{w x_i \partial a_i'}{\partial d_i} = 0$$

where λ is the Lagrange multiplier. Note that the social planner is constrained by the market wage rate w and equilibrium price.

The second FOC highlights the costs and benefits of R&D. The first term in it is the marginal cost of R&D, while the second term is the marginal gain. The optimal level of R&D for sector i depends on both the research productivity θ , and the equilibrium output x_i. The higher the research productivity, the larger the marginal gain. Since one unit of ideas benefits x_i units of output, the more the equilibrium output x_i the larger the marginal benefit. If the consumer's expenditure share in sector i is larger, or the country is more specialized in sector i (producing more x_i than the autarky output) in an open economy, the research input for sector i will be greater. It is interesting to note that the above results are very different from the conclusion reached by Eaton and Kortum (2001b, page 15, in their studies of *uniform* technological improvement) that "...*research intensity does not depend on country size, research productivity, or openness*".

Solving the first-order condition gives optimal R&D inputs:[3]

$$d_1^B = \frac{\beta\theta L - 2(1-\beta)}{2\theta}, d_2^B = \frac{(1-\beta)\theta L - 2\beta}{2\theta}$$

Substituting the last two equations into equation $a_i' = \frac{a_i}{1+\theta d_i}$ yields the optimal technology:

$$a_1' = \frac{2a_1}{(\theta L + 2)\beta} \; and \; a_2' = \frac{2a_2}{(\theta L + 2)(1-\beta)}$$

The optimal rates of technological improvement, defined as $(\frac{a_1}{a_1'}, \frac{a_2}{a_2'})$ are proportional to consumers' expenditure share $(\beta, 1-\beta)$. That is, it is optimal to improve technology at a higher rate in the sector on which consumers spend more.

In trade regime B, sector 2 is the import sector at home. If $\beta < \frac{1}{2}$, the

[3]The country size is assumed to be sufficiently large ($L \geq \max\{\frac{2(1-\beta)}{\theta\beta}, \frac{2\beta}{\theta(1-\beta)}\}$), so that R&D input in each sector is nonnegative.

optimal strategy is relatively *import-biased*. The world relative price after technical progress at home is

$$\frac{a_1'}{a_2'} = \frac{a_1}{a_2}\frac{1-\beta}{\beta} > \frac{a_1}{a_2}$$

which implies that the terms of trade in the foreign country deteriorate. Therefore, welfare in the foreign country decreases.

2.3.2. The Case of a Small Country

We now turn to regime B^*, in which the home country is a small country. Under this regime, technological changes in the home country may lead to regime changes. Also, it is possible for the home country to improve its technology to such an extent that it becomes a large country. If so, the equilibrium moves from regime B^* to regime S, or even regime B. Thus, a complete analysis will require comparing the welfare levels in each possible regime. For simplicity, suppose that the home country remains a small country after the technological improvement. However, it is allowed to reverse its comparative advantage by investing in R&D in the import sector. Such an *import-biased* technological improvement, however, is not optimal, as I will show below.

If *export-biased* technological improvement is chosen, the home country specializes in producing good 1. The budget constraint becomes $p_1x_1 + p_2x_2 = w(L - d_1)$, and the post-improvement technology parameters are $a_1' = \frac{a_1}{1+\theta d_1}$ and $a_2' = a_2$. Solving the first-order conditions gives the optimal

R&D input:

$$d_1^{B^*} = \frac{\theta L - 1}{2\theta}$$

Investment in R&D in the import sector is useless unless it is specialized in sector 2 after technological progress. Assuming it does so, we have $a_2' = \frac{a_2}{1+\theta d_2}$ and $a_1' = a_1$. The optimal solution is

$$d_2^{B^*} = \frac{\theta L - 1}{2\theta}$$

For *import-biased* technological improvement to be effective, the home country must reverse its comparative advantage. If $d_2^{B^*}$ is not sufficiently large to accomplish this, the home country needs to input $d_2 > d_2^{B^*}$ to improve technology in sector 2. Nevertheless, $u(x_1(d_2^{B^*}), x_2(d_2^{B^*})$ is the highest utility that can be reached if *import-biased* technological improvement is chosen.

Substituting $d_1^{B^*}$ and $d_2^{B^*}$ into the indirect utility function, we have

$$\frac{u(x_1(d_1^{B^*}), x_2(d_1^{B^*})}{u(x_1(d_2^{B^*}), x_2(d_2^{B^*})} = \frac{a_2 a_1^*}{a_1 a_2^*} > 1$$

The above inequality comes from the comparative advantage assumption. Thus, *import-biased* technological improvement cannot be optimal for a small country.

A few remarks are in order. First, the optimal R&D input in the large and the small country clearly indicate that the home country should invest more in

R&D if its research productivity is higher. Second, research intensity is related to openness. Consider a thought experiment in which a small home country moves from autarky to free trade. It invests d_1^B in autarky in sector but $d_1^{B^*}$ in free trade. The result indicates that $d_1^{B^*} > d_1^B$, that is, trade openness leads the country to do more research in the sector in which it is more specialized. Finally, d_i^B/L in the large-country case and $d_1^{B^*}/L$ in the small-country case are all increasing in L. Therefore, it is optimal for larger countries to invest more in R&D per capita. Summarizing the above results, we have:

Theorem 2. Research input increases with research efficiency. In an open economy, countries do more research in the sector in which they are more specialized. Larger countries invest more in R&D per capita. B) For a small country, it is optimal to choose export-biased technological improvement, which benefits the foreign country. C) The optimal strategy for a large country, however, is to improve the technology at a higher rate in the sector on which consumers spend more. It hurts the foreign country if consumers at home spend more on the importable good.

R&D per capita is determined by the first-order condition derived above. Dividing both sides of the condition by L, we have

$$\frac{w}{L} = -\frac{wx_i}{L}\frac{\partial a_i'}{\partial d_i} <=> \frac{d_i}{L} = \left(1 - \frac{d_i}{L}\right)\left[\frac{x_i}{(L - d_i)/f(d_i)}\right] a_i \left[-\frac{d_i \partial f(d_i)}{f(d_i)\partial d_i}\right]$$

$$<=> \frac{d_i}{L} = \frac{\bar{x}_i a_i \Phi_i(d_i)}{1 + \bar{x}_i a_i \Phi_i(d_i)}$$

where $f(d_i) = \frac{1}{1+\theta d_i}$ is the production function of R&D, $\bar{x}_i = \frac{x_i}{(L-d_i)/f(d_i)}$ is the output per effective labor in production sectors, and is a constant. $\Phi(d_i) = -\frac{d_i \partial f(d_i)}{f(d_i) \partial d_i}$ is the elasticity of R&D with respect to the labor input. The marginal cost of R&D per capita, $\frac{w}{L}$, reduces proportionally to the increase in country size L. Whether optimal R&D per capita increases depends, therefore, on whether the marginal benefit of R&D increases more than proportionally to the increase in L. As country size L becomes larger, R&D input d_i increases. If $\Phi(d_i)$ increases in d_i which holds in the setup since $\Phi(d_i) = \frac{\theta d_i}{1+\theta d_i}$ R&D per capita, $\frac{d_i}{L}$, must rise as d_i increases.

In summary, R&D elasticity $\Phi(d_i)$ determines R&D per capita. When $\Phi(d_i)$ is an increasing (constant, or decreasing) function of R&D input, the marginal benefit of R&D increases more than proportionally (proportionally, or less than proportionally) to the increase in country size. This implies that optimal R&D per capita increases (remains constant, or decreases) as the country becomes larger. Eaton and Kortum (2001b, 2006) study R&D intensity in steady state growth and conclude that research intensity does not depend on country size. Their result may be viewed as a limit of this static model. Note that, in the limit $(L \to \infty)$, the R&D per capita in this paper also converges to a constant.

2.3.3. When Will a Catching-Up Strategy Be Optimal?

When both countries are specialized, each country produces one good while importing the other good. If a country chooses import-biased improvements so that it will produce both goods in the new equilibrium, then we say that the country is following a *catching-up strategy*(or *import-substitution strategy for growth*).

As we have discussed in Section 2.2.1, $\frac{a_2^*}{a_2} \leq E = \frac{\beta L^*}{(1-\beta)L} < \frac{a_1^*}{a_1}$ in regime S, and the home country is completely specialized in producing good 1. The home country can choose to reduce a_1, which does not change the trade regime. On the other hand, a sufficiently large *import-biased* technological improvement (reduction in a_2) can switch the trade regime from S to B. Within the regime B trade, the R&D input of the home country is that derive in section 2.3.1, which is labeled as a *catching-up* strategy.

Instead of completely relying on imports in sector 2, the home country may want to catch up in the import sector and become self-sufficient in both goods.[4] The *export-biased* strategy has an adverse terms-of-trade effect. Moreover, $w + \frac{w x_i \partial a_i'}{\partial d_i} = 0$ indicates that the marginal benefit of R&D in sector 1 declines. On the other hand, *import-biased* technical progress improves the terms of trade, but the labor spent in filling the gap between $\frac{a_2^*}{a_2}$ and $E = \frac{\beta L}{(1-\beta)L}$ has no

[4]The *catching-up* strategy has been a controversial policy in economic development. On the one hand, implementations of the *catching-up* strategy in 1950s and 1960s by many developing countries are generally not viewed as successful; on the other hand, the success of the *catching-up* strategy used in the automobile industries of Japan and South Korea is impressive.

effect on the economy and is therefore a waste of resources. On the demand side, technological improvement in sector 2 is more desirable if consumer's expenditure share in good 2, $1-\beta$, is larger. A set of sufficient conditions are derived in Appendix 2.B, summarized as follows:

$$\beta < 0.3494$$

$$L > \frac{2(1-\beta)}{\theta\beta}$$

$$a_2 < \bar{a}_2(L)$$

where

$$\bar{a}_2(L) = \frac{(1-\beta)^2 a_2^*}{4\beta L^* \theta}\left[\frac{\beta^\beta (L\theta+2)^2}{(L\theta+1)^{2\beta}}\right]^{1/(1-\beta)}$$

The second and third conditions ensure that the distance between $\frac{a_2^*}{a_2}$ and $E = \frac{\beta L}{(1-\beta)L}$ is not too large, so that the *catching-up* strategy is not too costly, while the first condition requires that the import sector be sufficiently large. Summarizing, we have the following

Theorem 3: When both countries are fully specialized, the *catching-up* strategy is optimal if the expenditure share in the import sector is sufficiently large, the country is relatively large, and the technology in the import sector is relatively advanced.

2.4. Discussion and Conclusion

In analyzing the United States' technological improvement in the nineteenth and twentieth centuries, Hicks proposed two stages of technological improvement: "*countries start with* export-biased *technological improvement, and then ... the process passes into its second stage*"— notice that it is still a stage of development for the world economy, taken as a whole — "*in which the lead is taken by new centers, which are now making improvements that are* import-biased" (Hicks 1953, pp 130). Hicks noticed that Western Europe was not the first metropolis of trade and industry that had suffered from competition from new lands: the same elements were present in the decline of some ancient empires and in the rise of Britain at the expense of the Flemish and Italian centers in the fifteenth and sixteenth centuries. Hicks' two-stage path in technological improvement seems to be not just a historical phenomenon. Are emerging markets like China and India still in Hicks' first stage of development now? Will emerging markets move to the second stage? If so, when will they move? What will be the effect on the existing centers in this globalized age if emerging markets do move on to the second stage? This analysis is only a beginning in the explanation of these extremely important issues.

To simplify the analysis, the essay makes some restrictive assumptions. Although the Cobb-Douglas utility function is not essential to the results of this paper, it helps to keep the analysis tractable. The essay also assumes a simple R&D function and that the efficiency of R&D is identical across sectors. The strategic interactions in R&D between the two countries are not studied. The essay does not consider imperfect competition, firm heterogeneity, or trade costs. The hard part of this analysis is the discrete change of trade regimes. Eaton and Kortum (2002) and Alvarez and Lucas (2007) provide a tractable continuum version of the Ricardian model. It would be worthwhile to investigate the optimal strategy in their version of the Ricardian model. Finally, the model shows that a small country should choose export-biased improvements while many of them choose import-substitution improvements in the real world. This is mainly because the classical model that we use here is a static model that dispenses with the dynamic gains and spillovers that come with import-substitution improvements. In the future research, I will incorporate these factors in my analysis.

2.5. Appendices

2.5.1. Appendix 2.A

This appendix shows that the social planner's optimal strategy for technological improvement is equivalent to the decentralized market decision when the R&D sector is perfectly competitive.

Consider an R&D sector that produces ideas. Firms in the R&D sector sell n_i ideas to manufacturing firms in sector i. Let the production function for ideas be $n_i = \theta d_i$, where θ measures research productivity and is assumed to be identical for sectors 1 and 2. After buying ideas, the technology in sector i becomes

$$a_i' = \frac{a_i}{1 + n_i}$$

The R&D firms charge a royalty of rn_i per unit of output produced in sector i. The total cost for firms in sector i, therefore, becomes

$$c_i = rn_i x_i + wa_i' x_i = (rn_i + wa_i')x_i$$

Firms in sector i choose the number of ideas, n_i, to minimize the marginal cost of production, which gives the first order condition as follows:

$$r + \frac{w\partial a_1'}{\partial n_i} = 0$$

Let there be free entry and exit in the R&D sector so firms earn zero profit; this requires

$$rx_i n_i - wd_i = \left(rx_i - \frac{w}{\theta}\right) n_i = 0$$

Substituting zero-profit condition into the first order condition and noting that $n_i = \theta d_i$, we immediately see that the above equilibrium condition are the same as the one with a social planner are identical. Now, manufacturing firms set the goods price equal to the marginal cost so that

$$\tilde{p}_i = rn_i + wa_i'$$

Applying it to the budget constraint and noting that workers in the R&D sector and manufacturing sectors all earn wage w, we have

$$\tilde{p}_1 x_1 + \tilde{p}_2 x_2 = wL \leq>$$

$$wa_1' x_1 + wa_2' x_2 = w(L - d_1 - d_2)$$

In a decentralized market, the consumer's first-order condition is the same as the one with a social planner. It can be clearly seen, therefore, that the equilibrium conditions in the decentralized market, are identical to that in the social planner's problem.

2.5.2. Appendix 2.B

This appendix derives sufficient conditions for the *catching-up* strategy to be optimal in regime S trade. Conditions under which the *catching-up* strategy is optimal are

$$\frac{a_2^*}{a_2} < \frac{\beta L^*}{(1-\beta)L} < \frac{a_1^*}{a_1}$$

$$a_2 < \frac{(1-\beta)^2 (L\theta + 2)^2 a_2^*}{4\beta L^* \theta}$$

$$L > \max\left\{\frac{2(1-\beta)}{\theta\beta}, \frac{2\beta}{\theta(1-\beta)}\right\}$$

$$u^B(d_1^B, d_2^B) > u^E(d_1^E)$$

The first inequality ensures that the trade regime is S. The second one makes sure that the trade regime switches from S to B. The third one ensures that the country improves technology in both sectors. The last one requires that the utility of the *catching-up* strategy be greater than that of the *export-biased* strategy. The utility of the *export-biased* strategy can be derived as

$$u^E(d_1) = \frac{\beta L^{*(1-\beta)}}{a_1^{\beta} a_2^{*(1-\beta)}}(L - d_1)^{\beta}(1 + \theta d_1)^{\beta}$$

Maximizing $u^E(d_1)$ we obtain the optimal R&D input, $d_1^E = \frac{\theta L - 1}{2\theta}$. With some computations, condition $u^B(d_1^B, d_2^B) > u^E(d_1^E)$can be written as

$$\frac{u^B(d_1^B, d_2^B)}{u^E(d_1^E)} = \frac{\beta^{2\beta-1}(1-\beta)^{(2-2\beta)} a_2^{*(1-\beta)}(L\theta + 2)^2}{(L^*\theta)^{1-\beta} a_2^{1-\beta} 2^{(2-2\beta)}(L\theta + 1)^{2\beta}} > 1$$

The first two conditions and the last condition are combined as

$$\frac{(L-\beta)La_2^*}{\beta L^*} < a_2 < \frac{(1-\beta)^2 a_2^*}{4\beta L^*\theta} \min\left\{(L\theta + 2), \left(\frac{\beta^{\beta}(L\theta + 2)^2}{(L\theta + 1)^{2\beta}}\right)^{\frac{1}{(1-\beta)}}\right\}$$

It can be shown that the first term in the curvy brackets is greater than the second one, so that a sufficient condition for the above inequality is

$$\frac{(L-\beta)La_2^*}{\beta L^*} < a_2 < \frac{(1-\beta)^2 a_2^*}{4\beta L^*\theta}\left(\frac{\beta^{\beta}(L\theta + 2)^2}{(L\theta + 1)^{2\beta}}\right)^{\frac{1}{(1-\beta)}}$$

$$<=> \underline{a}_2(L) < a_2 < \bar{a}_2(L)$$

In order for the above condition to hold, we must have $\underline{a}_2(L) < \bar{a}_2(L)$ Computations reveal that it is so if $\beta < 0.3494$ which proves that the conditions given in section 2.3.3 are sufficient conditions for the conditions at the beginning of this appendix. When $\beta < 0.3494$ it can be easily shown that $\frac{\partial \bar{a}_2(L)}{\partial L} > 0$.

Chapter 3 :

A TWO-SECTOR EATON AND KORTUM MODEL: TECHNOLOGICAL CHANGES AND INTERNATIONAL TRADE

3.1. Introduction

For centuries, trade theorists have assumed that firms in a sector were homogeneous, as seen in the standard Ricardian model, the Heckscher-Ohlin model, and the new trade theory. Beginning with Bernard and Jensen (1995, 1999, 2001) and continuing with other economists (e.g., Clerides, Lach and Tybout 1998; Aw, Chung, and Roberts 2000, Cabral and Mata 2003), recent research nonetheless calls our attention to the existence of large and persistent differences among firms in terms of size as well in terms of productivity and trade behavior. Coupled with other facts, firm heterogeneity breaks down the firms of a sector into a small group of relatively productive exporters and a majority of less productive firms that only serve the domestic markets, leading to many other stylized facts that were neglected in previous trade theories.

In response, the so-called “new new” trade theory has been developed to incorporate the firm level differences (e.g., Eaton and Kortum 2001b, 2002, 2006; Bernard, Eaton, Jensen and Kortum 2003; Melitz 2003; Helpman, Melitz and Yeaple 2004; Yeaple 2005; Baldwin and Robert-Nicoud 2006; Alvarez and Lucas 2007; Melitz and Ottaviano 2008). Papers following Melitz (2003) predict intra-industry reallocation during trade liberalization stemming from firm heterogeneity and fixed trade costs, with Baldwin and Robert-Nicoud (2006) further arguing that the reallocations may affect the growth of economies by changing the marginal cost of R&D. Papers following Eaton and Kortum's framework adopt a realistic yet tractable parameterization of the firm level heterogeneity and are able to carry out more detailed general equilibrium analysis.

Fruitful as it is, "*more recent research on heterogeneous firms … ignores comparative advantage by considering just a single factor and industry*" (Bernard, Redding and Schott 2007, pp. 31). This neglect may prevent us from a complete view of the international trade since comparative advantage is one of the pillars of the traditional trade theory. In response, Bernard, Redding and Schott (2007) extend Melitz's model into a two-sector, two-factor framework. Their paper analyzes how heterogeneity and endowment comparative advantage jointly determines the effects of trade liberalizations and highlights the additional welfare gains arising from the amplification effect of heterogeneity on comparative advantage.

Besides Bernard, Redding and Schott (2007), Costinot and Komunjer (2007), and Fieler (2008) also employ multi-sector heterogeneous-firm models to analyze international trade. Costinot and Komunjer (2007) demonstrate that the Ricardian predictions of trade pattern are empirically relevant if we introduce firm heterogeneity to a multi-sector, multi-country model. Assuming a non-homothetic utility function, Fieler (2008) shows that heterogeneity in technology affects the comparative advantage through the income elasticity and thereby explains the relationship between per capita income, country size, and the trade pattern.

The marriage between firm heterogeneity and comparative advantage opens a door to a better understanding of world trade, yet there are many questions left open. In this paper I analyze how changes in productivity dispersion and average levels affect intra-industry trade and inter-industry trade, total trade volume. To the best of my knowledge, no economists have studied this before. The model also studies the welfare effects of technological improvements.

Based on a two-sector Eaton and Kortum model, this paper shows that technology improvements always increase the total trade. This increase inter-industry trade if they originate in the comparative advantage sector, otherwise it decreases inter-industry trade. Increases in the degree of heterogeneity always increase total trade and inter-industry trade.

The paper also analyzes the welfare effects of technology improvements and yields some new results. It shows that with the Cobb-Douglas utility function technology improvements are always beneficial to the innovator. In agreement with the literature, export-biased improvements benefit the foreign country. In a departure from the literature, however, the paper shows that import-biased improvements could benefit the foreign country. The paper also shows that when the final goods are complements, immiserizing growth may occur.

The theoretical model of the paper shows that the net exports of the comparative advantage sector are positive while those of the other sector are negative. This offers us a testable hypothesis about the Ricardian trade model. Using the OECD STAN databases, the paper conducts some simple tests concerning the prediction and finds strong support for it. The Ricardian model is one of the pillars of the international trade theory. To the best of my knowledge, however, only Bernhofen (2004) and Costinot and Komunjer (2007) successfully test the Ricardian model. The results of this work will greatly enrich the literature in this field.

3.2. The Model

This section extends the model developed by Eaton and Kortum (2002) and Alvarez and Lucas (2007) to a model with two sectors. Following the standard Ricardian model, I assume there are only two countries: the home country (h) and the foreign country (f), whose labor endowments are L_h and L_f respectively. The economies produce two final goods: good 1 and good 2. Consumers in the two countries have the same preferences over the final goods, and their utility function is[5]:

$$U(Q_1, Q_2) = Q_1^{a_1} Q_2^{a_2}$$

where Q_i is the quantity of the final good of sector i $(i = 1,2)$ and a_i is the expenditure share of good i with $a_i \in (0,1)$, $a_1 + a_2 = 1$. Throughout this

[5] It is a strong assumption to assume identical preferences across countries. However, if we are only concerned with developed countries, the assumption may become sensible. In fact, this paper uses a dataset of OECD countries to test the prediction of the theoretical model.

paper, subscripts are used to denote either country or industry. (Please refer to Appendix 3.A for definitions of variables.)

The final good of each sector is produced with intermediate goods that can only be used in that sector. Following Dornbusch, Fischer, and Samuelson (1977) I assume that in each sector there is a continuum of intermediate goods indexed by $u \in [0,1]$. Firms in both countries can use the intermediate goods to produce the final goods with the following technology:

$$Q_i = \left(\int_0^1 q_i(u)^{1-1/\eta} du\right)^{\eta/(\eta-1)}, i = 1,2$$

where $q_i(u)$ is the amount of intermediate good u of sector i and η is the elasticity of substitution.

Intermediate goods are produced by labor with constant-returns-to-scale technology. All firms in a country have access to the best technology available in the country and the productivity varies across varieties. With one unit of labor, the home (foreign) country firms can produce $x_{ih}^{-\theta}\ (u)$ units ($x_{if}^{-\theta}\ (u)$ units) of variety u in industry i, where $x_{ih}^{-\theta}\ (u)$ (or $x_{if}^{-\theta}\ (u)$) as a whole denotes the productivity associated with variety u in the home (foreign) country, where θ is a positive number.

Following Alvarez and Lucas (2007), I assume that $x_{ih}\ (u)$ is distributed independently and exponentially with parameter λ_{ih} in the home country (λ_{if} in the foreign country).

$$F(x_{ih}) = 1 - e^{-\lambda_{ih}x_{ih}}, E(x_{ih}) = 1/\lambda_{ih}$$

This is equivalent to a Fréchet distribution in Eaton and Kortum (2002).

I assume that the intermediate goods are tradable. For simplicity, I assume that trade is costless. The final good is not tradable. The labor is immobile across countries, but perfectly mobile within a country and across industries.

3.3. Equilibrium

This section solves the equilibrium of the world economy. Given the technology levels and trade barriers, whether a country produces a variety is determined by the relative wage. The exports and the imports of a country are therefore functions of the relative wage. Assuming trade balance, the relative wage is determined and so are other equilibrium variables.

Since the procedure of solving the equilibrium is similar to that in Alvarez and Lucas (2007), I will relegate most of it to the appendix. Throughout this paper, the wage rate in the home country is assumed to be higher and the labor in the foreign country is used as the numéraire.

3.3.1. Price Indices of the Final Goods

I will use the home country's trade balance condition to solve the equilibrium. It turns out that the imports (M_h) and exports (X_h) of the home country can be conveniently denoted as functions of price indices of the final goods. Appendix 3.B shows that the price index of the final good of sector i is:

$$P_{ih} = A(\chi_{ih})^{-\theta} w_h$$

In the above expression, A is a constant and equals $\left(\int_0^\infty \sigma^{\theta(1-\eta)} e^{-\sigma} d\sigma\right)^{1/(1-\eta)}$, where σ is the variable of integration. Following Alvarez and Lucas (2007), I assume $1 + \theta(1 - \eta) > 0$ to guarantee the integral converges. $\chi_{ih} = \lambda_{ih} + \lambda_{if} w_h^{1/\theta} / (w_f^{1/\theta})$ is a weighted average of the technologies of two countries. It is the world technology perceived by consumers in the home country, and therefore is called the "**consumer-perceived**" technology level of sector i in the home country. For ease in writing, I define, $\omega_h = w_h / w_f$ and $\varphi_h = w_h^{1/\theta} / w_f^{1/\theta}$. Then we have $\chi_{ih} = \lambda_{ih} + \lambda_{if} \varphi_h$ (and $\chi_{if} = \lambda_{if} + \lambda_{ih} / \varphi_h$). Likewise, the price of good i in the foreign country is:

$$P_{if} = A \chi_{if}^{-\theta} w_f$$

3.3.2. Imports and Exports

The value of the final good i consumed in the home country is equal to $P_{ih} Q_{ih}$. Since the market of final goods is perfectly competitive, $P_{ih} Q_{ih}$ equals the value of the intermediate goods used as input. Let m_{ih} denote the share of intermediate goods in sector i that the home country imports from the foreign country. Then the imports of the home country in sector i are:

$$M_{ih} = m_{ih} P_{ih} Q_{ih}$$

In Appendix 3.C, I show that

$$m_{ih} = \frac{\lambda_{if} \varphi_h}{\chi_{ih}}$$

where $\lambda_{if} \varphi_h$ is the foreign country's technology level perceived by consumers in the home country. The higher it is, the greater is m_{ih}.

Given the Cobb-Douglas utility function, we have:

$$M_{ih} = \frac{a_i \lambda_{if} \varphi_h^{\theta+1} L_h w_f}{\lambda_{ih} + \lambda_{if} \varphi_h}$$

For notational clarity, let $\rho_{ih} = \lambda_{ih}/\lambda_{if}$ denote the advantage the home country in sector i. Then we have:

$$M_{ih} = \frac{a_i \varphi_h^{\theta+1} L_h w_f}{\rho_{ih} + \varphi_h}$$

Therefore, the imports of the home country are:

$$M_h = \left(\frac{a_1}{\rho_{1h} + \varphi_h} + \frac{a_2}{\rho_{2h} + \varphi_h}\right) \varphi_h^{\theta+1} L_h w_f$$

Since $\theta > 0$, $M_h$is increasing in φ_h(a monotonic transformation of the relative wage rate), keeping everything else constant (Figure 3-1).

The sector i exports of the home country (X_{ih}) equal the sector i imports of foreign country (M_{if}), so the total exports of the home country are:

$$X_h = \left(\frac{a_1 \rho_{1h}}{\varphi_h + \rho_{1h}} + \frac{a_2 \rho_{2h}}{\varphi_h + \rho_{2h}}\right) L_f w_f$$

The above equation shows that the exports of the home country decrease with the relative wage rate (Figure 3-1).

3.3.3. Equilibrium

Suppose the trade balances in equilibrium:

$$L_f \left(\frac{a_1 \rho_{1h}}{\varphi_h + \rho_{1h}} + \frac{a_2 \rho_{2h}}{\varphi_h + \rho_{2h}}\right) = \left(\frac{a_1}{\rho_{1h} + \varphi_h} + \frac{a_2}{\rho_{2h} + \varphi_h}\right) L_h \varphi_h^{\theta+1}$$

The above condition defines the relative wage rate. The following graph shows that there exists a unique equilibrium relative wage. Since the price indices of final goods, the imports and the exports of both countries are functions of the relative wage rate, the equilibrium is solved.

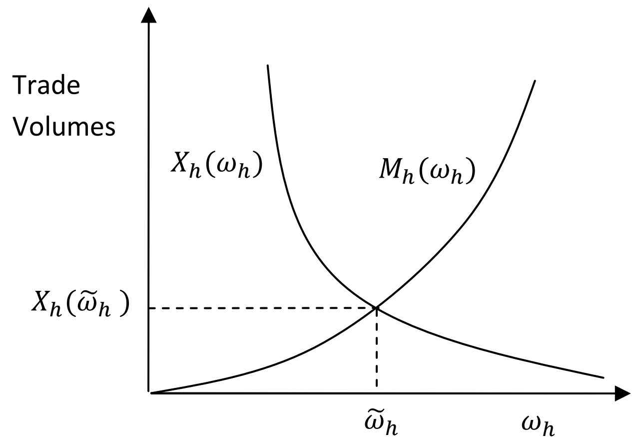

Figure 3-1: Equilibrium

The equilibrium condition shows that *ceteris paribus*, the relative wage rate ($\omega_h = w_h/w_f$) decreases with the size of the home country while it increases with the size of the foreign country.

Given the relative wage rate $\widetilde{\omega}_h$, the price of variety u is determined by the (wage-weighted) best productivity draw in two countries. If the home country has the (wage-weighted) best productivity draw $x_h(u)$ for variety u, that is, $x_{ih}(u) < x_{if}(u)/\widetilde{\omega}_h^{1/\theta}$, , then the price of it is:

$$p_i(u) = \frac{w_h}{x_h^{-\theta}(u)} = \frac{w_f\widetilde{\omega}_h}{x_h^{-\theta}(u)} = w_f\widetilde{\omega}_h x_h^{\theta}(u)$$

Given the CES demand function, the quantity of variety u supplied is:

$$q_i(u) = p_i(u)^{-\eta} P_{ih}^{1-\eta} a_i(L_h w_h + L_f w_f)$$

Write all equilibrium variables in terms of w_f and $\widetilde{\omega}_h$, we have:

$$q_i(u) = \frac{\left(x_h(u)\right)^{-\eta} \mathrm{a_i}\left(L_h + L_f/\widetilde{\omega}_h\right)}{\left(A\left(\lambda_{ih} + \lambda_{if}\widetilde{\omega}_h^{1/\theta}\right)^{-\theta}\right)^{1-\eta}}$$

If the foreign country has the (wage-weighted) best productivity draw $x(u)$ for variety u, that is, $x_{ih}(u) > x_{if}(u)/\widetilde{\omega}_h^{1/\theta}$, then the price of it is:

$$p_i(u) = \frac{w_f}{x_h^{-\theta}(u)} = \frac{w_f}{x_h^{-\theta}(u)} = w_f x_h(u)$$

Likewise, the equilibrium quantity of variety u is:

$$q_i(u) = \frac{\left(x_h(u)\right)^{-\eta} a_i\left(L_h w_f \widetilde{\omega}_h + L_f w_f\right)}{\left(A\left(\lambda_{ih} + \lambda_{if}\widetilde{\omega}_h^{1/\theta}\right)^{-\theta}\right)^{1-\eta}}$$

3.4. Technological Improvements and Trade Patterns

This section analyzes the effects of changes in the levels of technology. Throughout this section I assume that only the technology of sector 1 in the home country increases (λ_{1h} ↑). The technological improvement is assumed to be exogenous, instantaneous and costless.

3.4.1. Effects on Inter-Industry Trade

This section studies the effects of technology improvements on inter-industry trade. Following Grudel and Lloyd (1975), inter-industry trade is defined as absolute value of the net exports of one sector in one country. In this essay, we study the effects on NX_{1h}.

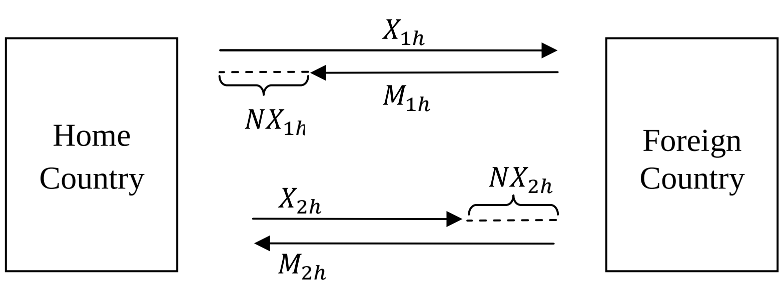

Figure 3-2: Trade Flows

The standard Ricardian model predicts that countries will export goods of one sector and import goods of the other sector. This complete specialization is never observed in the real world (Leamer and Levinsohn 1995), but it does not mean that comparative advantage theory has lost its predictive power altogether. The Ricardian predictions of trade patterns remain sensible if we interpret it as saying that the net exports of the comparative advantage sector are relatively larger while that of the other sector relatively smaller.

Costinot and Komunjer (2007) study a similar question. They prove that total exports of a sector and the sectoral productivity should be positive correlated, which is support by their empirical study. However, they do not check the relationship between comparative advantage and net exports. In this essay, I examine how comparative advantage is related to the direction of net exports here. Note that

$$NX_{1h} = -NX_{2h} = a_2 w_f \frac{\varphi_h^{\theta+1} L_h - \rho_{2h} L_f}{\rho_{2h} + \varphi_h}$$

Consider an increase in λ_{1h}. From the equilibrium condition we know that the relative wage rate (ω_h) increases with ρ_{ih}, so φ_h increases. This implies that NX_{1h} increases with λ_{1h}. Therefore net inter-industry trade increases after a technology improvement if it originates in the comparative advantage sector.

Now let us consider the case in which $\rho_{1h} = \rho_{2h}$. The net exports of sector 1 are:

$$NX_{1h} = a_1 w_f \left(\frac{\rho_{1h} L_f}{\varphi_h + \rho_{1h}} - \frac{\varphi_h^{\theta+1} L_h}{\rho_{1h} + \varphi_h} \right)$$

Substituting this and $\rho_{1h} = \rho_{2h}$ into the trade balance condition ($NX_{1h} = -NX_{2h}$) yields:

$$NX_{1h} = -NX_{2h} = -(a_2/a_1)NX_{1h}$$

This equality must hold for all $a_i \in (0,1)$, so we must have $NX_{1h} = 0$. Since the net export of sector 1 increases with λ_{1h}, the net exports of sector 1 must be positive if $\rho_{1h} > \rho_{2h}$. This gives us clear predictions about inter-industry trade pattern: the cross-country difference in the productivity of two sectors determines inter-industry trade. This corresponds to Krugman and Helpman's (1985) conclusion in a differentiated-product Heckscher-Ohlin model: "*despite the existence of intra-industry trade inter-industry pattern of trade is determined by the cross-country difference in the relative factor endowments, just as in the Heckscher-Ohlin model*". Their result and mine imply that inter-industry trade patterns are determined by the comparative advantage, no matter the comparative advantage arises from the difference in productivity or endowments.

$NX_{1h} < 0$ when sector 1 is has comparative disadvantage ($\rho_{1h} < \rho_{2h}$). Since $\frac{dNX_{1h}}{d\lambda_{1h}} > 0$, that mean the absolute value of NX_{1h} will decrease with λ_{1h}. Likewise, the absolute value of NX_{1h} increases λ_{1h} increases with λ_{1h} when sector 1 is has comparative advantage ($\rho_{1h} > \rho_{2h}$). This means that export-biased technological improvements will increase inter-industry trade and import-biased improvements decrease inter-industry trade.

3.4.2. Effects on Total Trade

This section studies the relationship between technology levels and the total trade volume, which is defined as the total exports of the home country. World trade volume is defined as the exports of the home country, $X_h = \left(\frac{a_1\rho_{1h}}{\varphi_h+\rho_{1h}} + \frac{a_2\rho_{2h}}{\varphi_h+\rho_{2h}}\right) L_f w_f$. Calculations show (Appendix 3.D):

$$\frac{dX_h}{d\rho_{1h}} = \Phi\theta L_h \varphi_h^{\theta} \left(\frac{a_1}{\rho_{1h}+\varphi_h} + \frac{a_2}{\rho_{2h}+\varphi_h}\right) > 0$$

where Φ is a positive constant. The above results do not depend on the relative magnitude of ρ_{1h} and ρ_{2h}, so technology improvements always increase world trade no matter how it changes the comparative advantage pattern.

3.4.3. Effects on Intra-industry Trade

This section analyzes the effect of technological improvements on intra-industry trade. Following Grudel and Lloyd (1975), intra-industry trade is defined as the difference between the gross trade (X_h) and inter-industry trade. Suppose the net exports of sector 1 are positive for the home country ($X_{1h} - M_{1h} > 0$), then the world intra-industry trade is

$$X_h - (X_{1h} - M_{1h}) = X_{2h} + M_{1h} = \frac{a_{j2} L_f \rho_{2h} w_f}{\varphi_h + \rho_{2h}} + \frac{a_1 \varphi_h^{\theta+1} L_h w_f}{\rho_{1h} + \varphi_h}$$

Sector 1is assumed to be the home country's comparative advantage sector. Then increase in λ_{1h} enlarges comparative advantage ($\rho_{1h}/\rho_{2h} \uparrow$). Following the steps used in the previous section, it can be shown show that the derivative of intra-industry trade with respect to ρ_{ih} is:

$$\frac{d(X_{2h}+M_{1h})}{d\rho_{1h}} = \Phi\left(a_1\theta\varphi_h^\theta - a_2\left(\frac{2\varphi_h^\theta + \varphi_h^{2\theta}L_h/L_f + L_f/L_h}{\rho_{2h}+\varphi_h} + \frac{\theta\varphi_h^{2\theta}}{\rho_{2h}}L_h/L_f\right)\right)$$

where Φ is a positive number[6]. Note that only the first term in the parenthesis of the right hand side is positive. Generally speaking, when a_1 is small enough, the first term is dominated by other terms and $\frac{d(X_{2h}+M_{1h})}{d\rho_{1h}}$ will be negative; when a_1 is large enough, it is dominated by other terms and $\frac{d(X_{2h}+M_{1h})}{d\rho_{1h}}$ will be positive. Simulations confirm these conclusions and show that intra-industry trade decreases with comparative advantage in most cases.

Summarizing, we have the following theorem:

Theorem 1. In a two-sector EK model, the net exports of the comparative advantage sector of a country are positive and those of the other sector are negative. The total trade volume always increases with technology improvements. Inter-industry trade increases with export-biased improvements and decreases with import-biased improvement.

3.5. Changes in the Degree of Heterogeneity and Trade Patterns

Trade theorists have been modeling firm heterogeneity for a while, yet there has not been systematic analysis of its effects on trade patterns. A two-

[6] Through out this essay, I use Φ to denote different positive constants. We are note interested in the actual value of these constants so I use the same notation to avoid too many symbols.

sector Eaton and Kortum model differs from the standard Ricardian model by introducing firm level heterogeneity and therefore is a good framework to study the effects of changes in heterogeneity. This section studies how inter-industry trade, the total trade volume and intra-industry trade vary with the degree of firm heterogeneity.

3.5.1. Effects on Inter-Industry Trade

Now let us look at the effect of the degree of heterogeneity on inter-industry trade. Suppose the home country has comparative advantage in sector 1, then inter-industry trade is equal to the net exports of sector 1 of the home country (NX_{1h}):

$$NX_{1h} = a_1 w_f \left(\frac{\rho_{1h} L_f}{\varphi_h + \rho_{1h}} - \frac{\varphi_h^{\theta+1} L_h}{\rho_{1h} + \varphi_h} \right)$$

Consider the trade balance condition:

$$NX_h = \left(\frac{a_1 \rho_{1h}}{\varphi_h + \rho_{1h}} + \frac{a_2 \rho_{2h}}{\varphi_h + \rho_{2h}} \right) L_f w_f - \left(\frac{a_1}{\rho_{1h} + \varphi_h} + \frac{a_2}{\rho_{2h} + \varphi_h} \right) L_h \varphi_h^{\theta+1} w_f = 0$$

Applying the implicit functional theorem on the trade balance condition yields:

$$\frac{d\varphi_h}{d\theta} = - \frac{\left(\frac{a_1}{\rho_{1h} + \varphi_h} + \frac{a_2}{\rho_{2h} + \varphi_h} \right) L_h \varphi_h^{\theta+1} w_f ln\varphi}{\left[\begin{array}{c} \left(\frac{a_1 \rho_{1h}}{(\varphi_h + \rho_{1h})^2} + \frac{a_2 \rho_{2h}}{(\varphi_h + \rho_{2h})^2} \right) (1 + \varphi_h^{\theta}) L_f w_f \\ + \theta \left(\frac{a_1}{\rho_{1h} + \varphi_h} + \frac{a_2}{\rho_{2h} + \varphi_h} \right) L_h \varphi_h^{\theta} w_f \end{array} \right]} < 0$$

Plugging it in $\frac{dNX_{ih}}{d\theta}$ yields:

$$\frac{dNX_{1h}}{d\theta} = \Phi(X_{1h} - M_{1h}) + (M_{2h} - X_{2h})a_1/a_2$$

Due to trade balance, we have $X_{1h} - M_{1h} = M_{2h} - X_{2h}$, therefore we have:

$$\frac{dNX_{1h}}{d\theta} = \Phi(X_{1h} - M_{1h})(1 + a_1/a_2)$$

Sector 1 is assumed to be the comparative advantage sector of the home country, so $X_{1h} - M_{1h} > 0$. Therefore $\frac{dNX_{1h}}{d\theta} > 0$, which implies that inter-industry trade increases with the degree of heterogeneity.

3.5.2. Effects on the Total Trade Volume

This section studies the relationship between firm heterogeneity and the total trade volume of the world. World trade volume is the exports of the home country ($X_h = \left(\frac{a_1\rho_{1h}}{\varphi_h+\rho_{1h}} + \frac{a_2\rho_{2h}}{\varphi_h+\rho_{2h}}\right) L_f w_f$). Heterogeneity ($\theta$) affects the total trade volume solely through the relative wage rate since it is not an explicit argument of X_h.

$$\frac{dX_h}{d\theta} = \frac{dX_h}{d\varphi_h} \cdot \frac{d\varphi_h}{d\theta}$$

It can be shown that

$$\frac{dX_h}{d\varphi_h} = -\left(\frac{a_1\rho_{1h}}{(\varphi_h + \rho_{1h})^2} + \frac{a_2\rho_{2h}}{(\varphi_h + \rho_{2h})^2}\right) L_f w_f < 0$$

In the previous section I showed that $\frac{d\varphi_h}{d\theta} < 0$, therefore

$$\frac{dX_h}{d\theta} = \frac{dX_h}{d\varphi_h} \cdot \frac{d\varphi_h}{d\theta} > 0$$

which implies that world trade volume increases with the degree of heterogeneity.

3.5.3. Effects on Intra-Industry Trade

Due to the homogeneity in the standard Ricardian model, a country either produces all the goods of a sector on its own or completely relies on imports from the foreign country. This sharp prediction excludes the possibility of intra-industry trade altogether, a phenomenon that is actually prevalent in the real world.

Krugman (1979) explains intra-industry trade with increasing returns to scale. Due to increasing returns to scale, it is optimal for each firm to produce a differentiated variety even though they have access to the same technology. Each country imports the varieties produced abroad because of consumers' love of variety. In a two-sector Eaton and Kortum model the returns to scale are constant and the mass of variety is fixed. A country's productivity varies across varieties in a sector. As a result, the country is competitive enough on some varieties and exports them, and for other varieties the home country is less competitive and imports them. Put differently, intra-industry trade in the two-sector Eaton and Kortum model is due to intra-industry comparative advantage that arises from firm heterogeneity.

Eaton and Korgum (2002) define the degree of heterogeneity (θ in this paper) as the level of comparative advantage in their one sector model. In this two-sector version of their model, heterogeneity should be explained as the degree of intra-industry comparative advantage. In what follows, I will study how changes in heterogeneity affect intra-industry trade.

The derivative of intra-industry trade with respect to the degree of heterogeneity is:

$$\frac{d(X_{2h}+M_{1h})}{d\theta}=\frac{a_1\varphi_h^{\theta+1}L_h w_f}{\rho_{1h}+\varphi_h}ln\varphi_h+\frac{\partial(X_{2h}+M_{1h})}{\partial\varphi_h}\frac{d\varphi_h}{d\theta}$$

Since $\varphi_h > 1$, the direct effect is positive ($\frac{a_1\varphi_h^{\theta+1}L_h w_f}{\rho_{1h}+\varphi_h}ln\varphi_h$). The indirect effect functions through the relative wage rate and it could be positive or negative. Calculations show that:

$$\frac{d(X_{2h}+M_{1h})}{d\theta}=\Phi\left(\frac{a_1L_fw_f}{\rho_{1h}+\varphi_h}\frac{a_1\rho_{1h}}{(\varphi_h+\rho_{1h})^2}+\frac{a_2(2\rho_{2h}-\rho_{1h})}{(\varphi_h+\rho_{2h})^2}\frac{a_iL_fw_f}{\varphi_h+\rho_{ih}}+\frac{a_2(X_{1h}-M_{1h})}{(\varphi_h+\rho_{2h})^2}+\left(\frac{a_2L_f\rho_{2h}w_f}{(\varphi_h+\rho_{2h})^2}+\frac{a_1\varphi_h^{\theta+1}L_hw_f}{(\rho_{1h}+\varphi_h)^2}\right)\frac{a_2}{\rho_{2h}+\varphi_h}\right)$$

where Φ is a positive number. Suppose the home country has comparative advantage in sector 1. Then among all the terms in the parenthesis on the right hand side of the equation, only the second could possibly be negative (note that $X_{1h}-M_{1h}$>0). A condition to guarantee $\frac{d(X_{2h}+M_{1h})}{d\theta}>0$ is $\rho_{1h}<2\rho_{2h}$.

Simulations also show that increases in the degree of heterogeneity tend to increase intra-industry trade in most cases[7]. This means that the increase in the heterogeneity normally leads to higher intra-industry comparative advantage.

Summarizing the above results, we have the following theorem:

[7] For example, when the two countries are of similar size have their technology levels in sector 2 are close, intraindustry trade decreases with θ only if ρ_{1h} is as high as 40.

Theorem 2. In the two-sector Eaton and Kortum model, inter-industry trade and world trade volume increases with the degree of heterogeneity; intra-industry trade, however, may increase or decrease with it.

3.6. Technological Improvements and Social Welfare

This section studies how the changes in the technology levels of industries affect the welfare of trade participants in a two-sector Eaton and Kortum model. There has been a rich literature on the welfare effects of technology improvements in the Ricardian model. Hicks (1953) pointed out that although technology improvements benefit the innovator, their effect on the foreign country depends on whether the improvements are import-biased or export-biased. Uniform and export-biased technology improvements benefit foreign countries, while import-biased technology improvements hurt the foreign country by worsening its terms of trade. Grossman and Helpman (1995), Samuelson (2004), Ruffin and Jones (2007) revisit the question and refine Hicks' argument.

The Ricardian model, however, does not consider firm heterogeneity and intra-industry trade. It remains an open question whether Hicks' argument carries over to a model that incorporates these features. To fill this gap, I analyze the welfare effects of changes in technology levels in the two-sector Eaton and Kortum model.

3.6.1. Welfare Effects on the Home Country

The welfare effects of technology improvements can be decomposed into changes in the price indices relative to the wage rate. The price of the final good in sector i is $P_{ih} = A\chi_{ih}^{-\theta} w_h$ in the home country. For people in the home country, the price of good i divided by the wage rate is:

$$P_{ih}/\, w_h = A\chi_{ih}^{-\theta}$$

where $\chi_{ih} = \lambda_{ih} + \lambda_{if}\varphi_h$ is the consumer-perceived technology level of sector i in the home country. The intuition is clear: when the perceived technology level increases, goods become cheaper relative to people's income. When λ_{1h} increases, the relative wage rate of the home country increases, which means that φ_h will increase. Consequently, it leads to an increase in χ_{ih} and makes goods cheaper relative to the home country wage rate.

The above results amount to saying that the home country must be better off after the technological improvement since the prices of both goods decrease relative to the wage rate in the home country. [8]

The effects on the home country can also be decomposed into a direct effect ($\frac{\partial U_h}{\partial \lambda_{1h}}$) and an indirect effect through the relative wage rate ($\frac{\partial U_h}{\partial \varphi_h}\frac{d\varphi_h}{d\lambda_{1h}}$):

$$\begin{aligned}\frac{dU_h}{d\lambda_{1h}} &= \frac{\partial U_h}{\partial \lambda_{1h}} + \frac{\partial U_h}{\partial \varphi_h}\frac{d\varphi_h}{d\lambda_{1h}} \\ &= \theta U_h \frac{a_1}{(\lambda_{1h} + \lambda_{1f}\varphi_h)} + \theta U_h \left(\frac{\lambda_{1f} a_1}{(\lambda_{1h} + \lambda_{1f}\varphi_h)} + \frac{a_2 \lambda_{2f}}{(\lambda_{2h} + \lambda_{2f}\varphi_h)}\right)\frac{d\varphi_h}{d\lambda_{1h}}\end{aligned}$$

[8] This also implies that a uniform technology improvement must benefit the home country.

Both effects are positive, so the technological improvements always benefit the home country. Simulations show that the marginal effect on of technological improvements on the home country is diminishing, with both the direct and the indirect effects deceasing. The following is an example of simulation:

$$a_1 = 0.5, \theta = 0.15; L_h = 1; L_f = 1; \lambda_{2h} = 1; \lambda_{1f} = 1; \lambda_{2f} = 2; \eta = 4$$

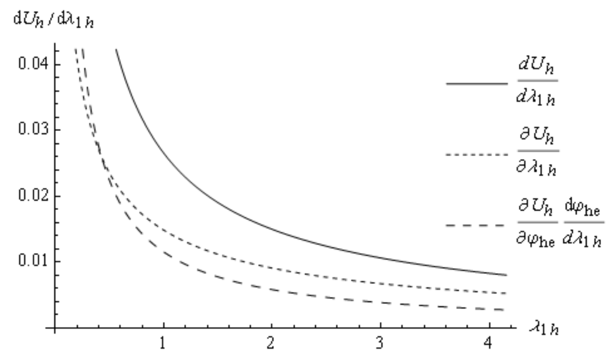

Figure 3-3: The Welfare Effects on the Home Country (1)

$$a_1 = 0.5, \theta = 0.15; L_h = 1.5; L_f = 1; \lambda_{2h} = 1; \lambda_{1f} = 1; \lambda_{2f} = 2; \eta = 4$$

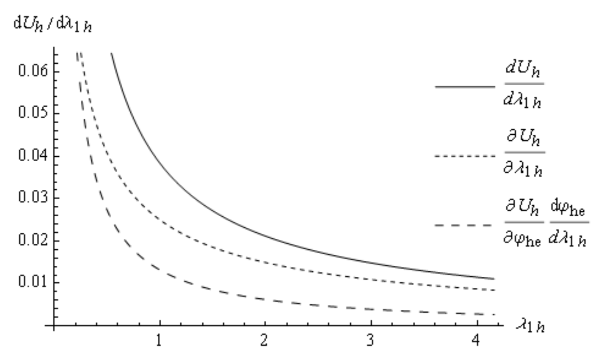

Figure 3-4: The Welfare Effects on the Home Country (2)

$$a_1 = 0.5, \theta = 0.15; L_h = 1; L_f = 1; \lambda_{2h} = 1; \lambda_{1f} = 0.5; \lambda_{2f} = 2; \eta = 4$$

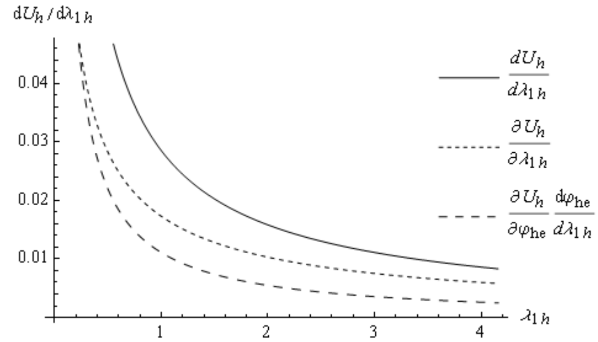

Figure 3-5: The Welfare Effects on the Home Country (3)

Note: In these simulations, the expenditure share of sector 1 is 0.5; that of the other is 0.5. The degree of heterogeneity is 0.15. The labor endowments of two countries are both 1. The horizontal axis represents the home country's technology frontier in sector 1. $\lambda_{2h}, \lambda_{1f}$ *and* λ_{2f} *are other technology frontier parameters of two countries.* $\eta = 4$ *is the elasticity of substitution. The dotted curve represents the direct effect of the effect of technological improvements on the welfare of the home country; the dashed curve represents the indirect effect; the solid curve represents the total effect.*

3.6.2. Welfare Effects on the Foreign Country

In the foreign country, the price of the final good in sector i divided by the wage rate is:

$$P_{if}/\, w_f = A\chi_{if}^{-\theta}$$

where $\chi_{if} = \lambda_{if} + \lambda_{ih}/\varphi_h$. For sector 1 we have $\chi_{1f} = \lambda_{1f} + \lambda_{1h}/\varphi_h$. In Appendix 3.E, I prove that $d(\lambda_{ih}/\varphi_h)/d\lambda_{ih} > 0$. Therefore the consumer perceived technology of sector 1 (λ_{1h}) increases in the foreign country, leading to decreases in $P_{1f}/\ w_f$. For sector 2 we have $\chi_{2f} = \lambda_{2f} + \lambda_{2h}/\varphi_h$. Since the relative wage rate of the home country increases after the technology improvement ($d\varphi_h/d\lambda_{ih} > 0$), the consumer perceived technology of sector 2 (λ_{2h}) decreases in the foreign country, leading to increases in $P_{2f}/\ w_f$. The overall effect of technological improvements on the foreign country depends on the relative magnitude of these two effects[9].

In Appendix 3.F, I show that export-biased technological improvements generally benefit the foreign country, which is in line with the prediction of the standard Ricardian model. The difference between the two models, however, is highlighted by the effects of import-biased technological improvements. In Appendix 3.F I show that the welfare effect on the foreign country could be negative when ρ_{1h} is small enough[10]. The two-sector Eaton and Kortum model, however, also argues that an import-biased technology improvement

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[9] Given a uniform technological improvement, λ_{ih}/φ_hincreases as I proves in Appendix D. Since λ_{ih} increases, the perceived technology in the foreign country($\chi_{if} = \lambda_{if} + \lambda_{ih}/\varphi_h$.) increases. Therefore $P_{if}/\ w_f = A\chi_{if}^{-\theta}$decreases in both sectors, which amounts to saying that a uniform technological improvement always benefits the foreign country.

[10] An example where an import-biased technological improvement deteriorates the foreign country can be found in Appendix I.

may benefit the foreign country, as shown in Appendix 3.F[11]. This contradicts the conclusion of the Ricardian model that import-biased technological improvements will never benefit the foreign country, as argued by Hicks (1958) "*Whatever are the monetary arrangements, whatever the course of money incomes, an improvement in A-productivity that is import-biased must make B worse off.*"

The effects on the home country can also be decomposed into a direct effect ($\frac{\partial U_f}{\partial \lambda_{1h}}$) and an indirect effect through the relative wage rate ($\frac{\partial U_f}{\partial \varphi_h}\frac{d\varphi_h}{d\lambda_{1h}}$):

$$\frac{dU_f}{d\lambda_{1h}} = \frac{\partial U_f}{\partial \lambda_{1h}} + \frac{\partial U_f}{\partial \varphi_h}\frac{d\varphi_h}{d\lambda_{1h}}$$

$$= \theta U_f \frac{a_i}{(\lambda_{if}\varphi_h + \lambda_{ih})} - \frac{\theta U_f}{\varphi_h}\left(\frac{a_i\lambda_{ih}}{(\lambda_{if}\varphi_h + \lambda_{ih})} + \frac{a_j\lambda_{jh}}{(\lambda_{jf}\varphi_h + \lambda_{jh})}\right)\frac{d\varphi_h}{d\lambda_{1h}}$$

$$a_1 = 0.5, \theta = 0.15; L_h = 1; L_f = 1; \lambda_{2h} = 1; \lambda_{1f} = 1; \lambda_{2f} = 2; \eta = 4$$

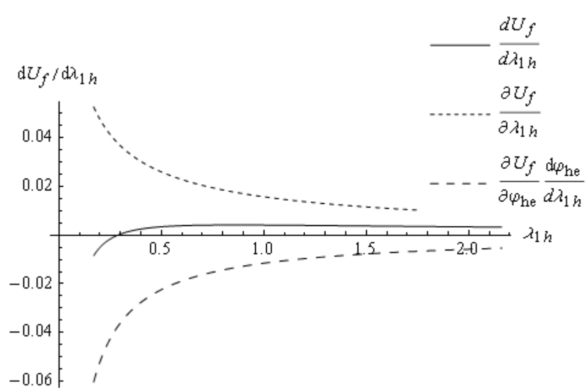

Figure 3-6: The Welfare Effects on the Foreign Country (1)

$$a_1 = 0.5, \theta = 0.15; L_h = 1.5; L_f = 1; \lambda_{2h} = 1; \lambda_{1f} = 1; \lambda_{2f} = 2; \eta = 4$$

[11] An example where an import-biased technological improvement benefits the foreign country can be found in Appendix I.

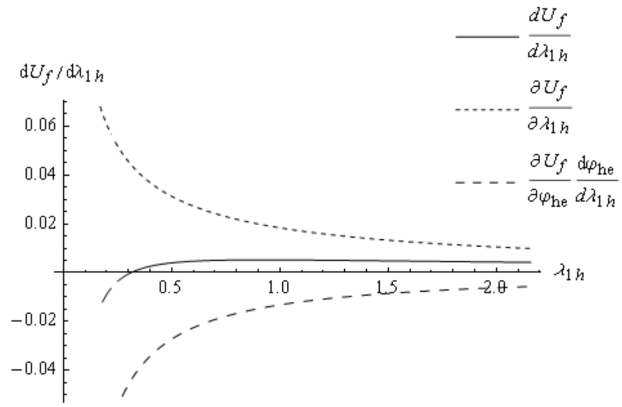

Figure 3-7: The Welfare Effects on the Foreign Country (2)

$a_1 = 0.5, \theta = 0.15; L_h = 1; L_f = 1; \lambda_{2h} = 1; \lambda_{1f} = 0.5; \lambda_{2f} = 2; \eta = 4$

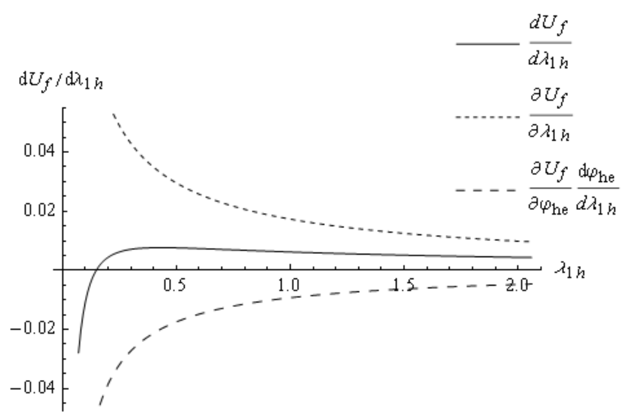

Figure 3-8: The Welfare Effects on the Foreign Country (3)

Note: In this simulation, the expenditure share of sector 1 is 0.5; that of the other is 0.5. The degree of heterogeneity is 0.15. The labor endowments of two countries are both 1. The horizontal axis represents the home country's technology frontier in sector 1. $\lambda_{2h}, \lambda_{1f}$ *and* λ_{2f} *are other technology frontier parameters of two countries.* $\eta = 4$ *is the elasticity of substitution. The dotted curve represents the direct effect of the effect of technological improvements on the welfare of the foreign* *country; the dashed curve represents the indirect effect; the solid curve represents the total effect.*

This discrepancy can be explained by firm heterogeneity. In the standard Ricardian model, import-biased technological improvements substitute home country goods for the foreign country goods altogether. In a two-sector Eaton and Kortum model, however, only inefficient foreign firms are replaced by efficient home country firms when the home country makes an import-biased technology improvement. The replacement process will inflict a negative terms of trade effect on the foreign country, but it also creates a productivity gain arising from intra-industry reallocation. The productivity gain may dominate the terms of trade effect and result in a positive welfare effect given an import-biased technological improvement.

The realization of the productivity gain (increase in the consumer perceived productivity level) depends on heterogeneity of firms. We can say that it helps to spread the benefit of technology improvement. This echoes Bernard, Redding and Schott (2007) point that "*the behavior of heterogenerous firms magnifies countries' comparative advantage and thereby creates a new source of welfare gains from trade*".

3.6.3. Remarks

The above analysis shows that when the top tier utility function takes the Cobb-Douglas form, the marginal effect on the innovator are always positive and that on the foreign country is negative at first (strongly import-biased) while positive later on (weakly import-biased or export-biased). The results are show in the following graph of simulation:

$$a_1 = 0.5, \theta = 0.15; L_h = 1; L_f = 1; \lambda_{2h} = 1; \lambda_{1f} = 1; \lambda_{2f} = 2; \eta = 4$$

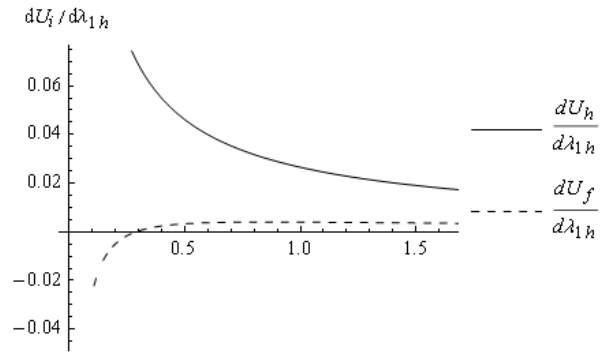

Figure 3-9: The Welfare Effects Given Cobb-Douglas Utility Function

As mentioned in the literature, countries may encounter immiserizing growth when improving their technology. The setup in this paper, however, does not yield this phenomenon. A possible reason is that Cobb-Douglas utility function does not give us a demand function that is sufficiently inelastic. To check if this is the reason and also to complete the analysis, I assume that two final goods are complements:

$$U(Q_1, Q_2) = (Q_1^a + Q_2^a)^{1/a}, a < 0$$

We can prove that the above utility function converges to a Cobb-Douglas function when a approaches zero and when it tends to infinity it becomes a Leontief function. Appendix 3.G solves the equilibrium given this utility function.

Simulations show that when λ_{2h} is positive, the new utility function generates the same patterns as those generated by the Cobb-Douglas function. The following is a typical graph.

$$a_1 = -1, \theta = 0.15; L_h = 1; L_f = 1; \lambda_{2h} = 1; \lambda_{1f} = 1; \lambda_{2f} = 2; \eta = 4$$

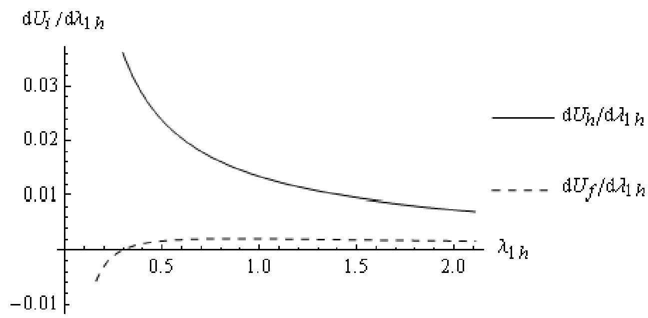

Figure 3-10: The Welfare Effects When Goods Are Complements (1)

However, when λ_{2h} is very close to zero technological improvements may hurt the innovator, as shown in the following example:

$$a_1 = -1, \theta = 0.15; L_h = 1; L_f = 0; \lambda_{2h} = 1; \lambda_{1f} = 1; \lambda_{2f} = 2; \eta = 4$$

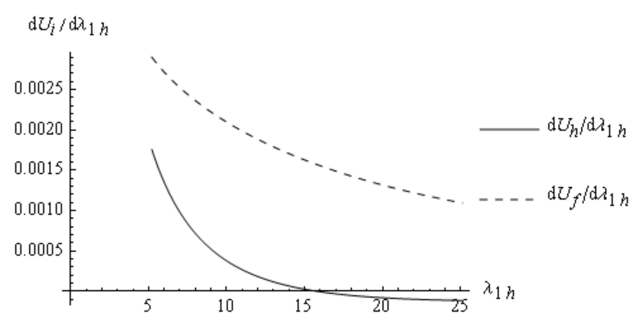

Figure 3-11: The Welfare Effects When Goods Are Complements (2)

The effects on the foreign country are always positive, which is consistent with the fact that all technological improvements are export-biased for the home country. The effects on the foreign country, however, could eventually turn into negative. Simulations show the following pattern:

- A smaller λ_{2f} makes the negative effects come sooner.
- A smallerλ_{2f} or λ_{1f} makes the negative effects come sooner.
- A larger home country or a smaller foreign country makes the negative effects come sooner.

When λ_{1h} increases, inelastic demand will cause the return to sector 1 producers to decrease. A small λ_{2h}, however, implies that very little endowment can be reallocated to sector 2. Therefore, the intense competition cannot be relieved through inter-industry reallocation and the innovator is hurt. Simulations show that existence and the timing of immiserizing growth is very sensitive to the magnitude of λ_{2h}, i.e., the ability that the country reallocation its endowments. Therefore, I propose that factor immobility may be one of the conditions that are necessary for immiserizing growth.

3.7. Empirical Analysis of Comparative Advantage and Net Exports

According to section 3.4.1, the net exports of sector i (NX_{ih}) increase with the advantage of sector i (ρ_{ih}) and decrease with the advantage of the other sector. This implies that NX_{ih} is positively correlated the ratio of ρ_{ih} to ρ_{jh} (ρ_{ih}/ρ_{ih}, $COMPADVr_{ih}$ thereafter) or the difference between them ($\rho_{ih} - \rho_{ih}$, $COMPADVd_{ih}$ thereafter), which can be taken as measures of the strength of comparative advantage. This section investigates whether the positive correlation between net exports and comparative advantage exists in data.

3.7.1. Econometric Model

The theoretical model shows that the absolute value of net exports of a country increases with the country size[12]. To control for the effect of country size, the net exports of a sector are divided by the country's GDP to construct the dependent variable ($NXG_{ih} = \frac{NX_{ih}}{GDP_h}$). Theoretically, NXG_{ih} is positively correlated with $COMPADVr_i$ or $COMPADVd_i$. For tractability, the model in this paper assumes there are no trade barriers. However, they do exist in the real world and exercise substantial effects on trade volumes. Let T denote the trade barriers, then we have the following econometric model:

$$NXG_{iht} = \beta_0 + \beta_1 COMPADV_{iht} + \beta_2 * sign(COMPADVd_{iht}) * T_t + sign(COMPADVd_{iht}) * FE_h + \epsilon_{iht}$$

In the above model, FE_h denotes the country, time and industry group dummies. The tariff is multiplied by the sign of $COMPADVd_{iht}$ because when the country has comparative advantage in sector i, the net exports decreases with trade barriers while decreases with trade barriers when sector i is the comparatively disadvantage sector. For the same reason, the dummies are multiplied by the sign of $COMPADVd_{iht}$.

The model assumes balanced trade. In the real world, however, a country's trade balances only rarely. To mitigate the noise stemming from trade

[12] A caveat is that in the real world the size of net exports also depends on the size of the domestic market and the type of economy.

imbalance, I calculate the imbalance-adjusted trade volume of each sector and construct dependent variables based on them. I first calculate the total trade surplus. Then I calculate the trade volume share of each sector. Finally, I multiply the total trade surplus by the trade volume share of a sector and subtract it from the net exports of that sect. The imbalance-adjusted net exports is denoted as NXa. Accordingly, we have the following econometric model:

$$NXGa_{iht} = \beta_0 + \beta_1 COMPADV_{iht} + \beta_2 * sign(COMPADVd_{iht}) * T_t + sign(COMPADVd_{iht}) * FE_h + \epsilon_{iht}$$

where $NXGa_{iht} = NXa_{hit}/GDP_{ht}$.

When $COMPADV_{iht}$ increases, NX_{iht} should increase and NX_{jht} should decrease. That means $NX_{iht} - NX_{jht}$ should increase with $COMPADV_{iht}$. Define $NXT_{ht} = NX_{iht} - NX_{jht}$ and $NXTG_{ht} = NXT_{ht}/GDP_{ht}$ and have the follow econometric model.

$$NXTG_{iht} = \beta_0 + \beta_1 COMPADV_{iht} + \beta_2 * sign(COMPADVd_{iht}) * T_t + sign(COMPADVd_{iht}) * FE_h + \epsilon_{iht}$$

Likewise, we have the imbalance-adjusted version of the above model:

$$NXTGa_{iht} = \beta_0 + \beta_1 COMPADV_{iht} + \beta_2 * sign(COMPADVd_{iht}) * T_t + sign(COMPADVd_{iht}) * FE_h + \epsilon_{iht}$$

For all above econometric models, the theoretical model predicts that the coefficient of $COMPADV_{iht}$ should be positive.

3.7.2. Data and Measurements

I use OECD STAN (STructural ANalysis) databases for this inquiry since they provide the needed information on the industry level with a relatively large number of observations. In this paper, I use STAN Industry Analysis (ed. 2008) to calculate the productivity of each sector. I use the bilateral trade databases STAN BTD 2000 and STAN BTD 2008 to calculate the net exports of each sector. STAN BTD 2000 covers years 1980-2000 and STAN BTD 2008 covers years 1988-2007. Since STAN BTD 2008 corrected some errors in previous editions, use all its information. STAN BTD 2000 is only used for years prior 1988.

This study focuses on the manufacture industry. I divide the manufacture industry into the high-tech group and the low-tech group following the definition of STAN database[13] . To measure the technology frontier of each industry group, I take each two-digit sector as a variety in the EK model. The observed productivity ($PRODTY_{ih}(u)$) of sector u in industry group i in country h equals the value added ($VA_{ih}(u)$) of sector i divided by the total employment of the sector ($EMPN_{ih}(u)$).

$$PRODTY_{ih}(u) = \frac{VA_{ih}(u)}{EMPN_{ih}(u)}$$

[13] STAN BTD 2008 breaks the manufacturing sectors into four groups: high-tech manufactures (ISIC 3: 2423+30+32+33+353), medium-high tech manufactures (ISIC 3.0: 24x+29+31+34+352+359), medium-low tech manufactures (ISIC 3: 23+25+26+27+28+351) and low-tech manufactures (ISIC 3: 15-16+17-19+20+21-22+36-37). STAN BTD 2000 is in ISIC 2.0. We categorize the industries following the conversion table between two versions of ISIC code systems. Then we divide the four groups into two broad groups: high-tech group and low tech group.

For simplicity, the time period subscriptions are suppressed here. According the EK model, $PRODTY_{ih}(u) = x^{-\theta}\ (u)$, so $x_{ih}(u) = \left(PRODTY_{ih}(u)\right)^{-1/\theta}$. We know that $x_{ih}(u)$~exp (λ_{ih}), so $E(x_{ih}) = 1/\lambda_{ih}$, where λ_i denotes the technology frontier of industry group i in a country. A natural estimator of the technology frontier of industry i ($HLambda_{ih}$) is:

$$HLambda_{ih} = (\overline{x}_i)^{-1} = \left(\frac{1}{N_{ih}}\sum_{u=1}^{N_{ih}}\left(PRODTY_{ih}(u)\right)^{-1/\theta}\ \right)^{-1}$$

where N_{ih} is the number of industries in group i. Due to missing data, the number of industries in an industry group may be different from country to country.

According to the EK model, the technology frontiers of different countries are additive. That is, the combined technology frontier of a group of countries is the sum of their technology frontier weighted by wage and trade barriers. In this essay the world is divided into the home country(h) and the rest of the world, so the technology frontier of the rest of the world ($ROWLambda_{hit}$) should be measured as the sum of the weighted technology frontier for all other countries. However, only the information for the OECD countries is available and it is not easy to get complete information on wages and pair-wise trade barriers. As an alternative, I measure the technology frontier as the sum of the (un-weighted) technology frontier of all OECD countries except the country taken as the home country. This does not follow the theoretical setup closely, but it is still a reasonable measure. First, the OECD countries include majority of the most productive countries. The technology frontier calculated based on them should be a good measure of the world technology frontier. Second, OECD countries bear substantial resemblance and their mutual tariffs are low and close, so the variation of the weight on their technology frontier should not be large. Therefore the technology frontier of the rest of the world is approximated by $ROWLambda_{ih} = \sum_{c \neq h} HLambda_{ic}$.

The comparative advantage measures are defined as mentioned in the previous section, where:

$$COMPADVr_{ih} = \frac{HLambda_{ih}}{ROWLambda_{ih}} \Big/ \frac{HLambda_{jh}}{ROWLambda_{jh}}$$

$$COMPADVrl_{ih} = \log\left(COMPADVr_{ih}\right)$$

and

$$COMPADVd_{ih} = \frac{HLambda_{ih}}{ROWLambda_{ih}} - \frac{HLambda_{jh}}{ROWLambda_{jh}}$$

The final dataset set contains 26 countries for years 1980-2006[14]. All the trade volumes are in 2006 PPP dollars.

3.7.3. Empirical Results

3.7.3.1. Regressions

Table 3-1 reports the OLS results when the percentage share of the net exports of each sector in GDP (NXG_i) is the dependent variable. The results are in line with the predictions of the theoretical model. The estimated coefficients of all comparative advantage measures are positive and most of

[14] A problem of using this sample is that for the majority of countries the trade is not balanced. In a subsequent section, I tried to adjust the variables of the econometric model for trade imbalance in a bid to mitigate this problem.

them are significant. I use the simple world average tariff to measure trade barriers (World Bank). For all specifications, the estimated coefficients of T are negative. The results also show that regressions with imbalance-adjusted measures yield higher R-square and higher significance level for T.

Table 3-1: Results of Regressions (Dependent Variable: $\boldsymbol{NXG}$)

Dependent Variable	NXG_i			Imbalance-Adjusted NXG_i		
COMPADVr	0.00032			0.00004		
	2.177**			0.507		
COMPADVrl		0.00263			0.00287	
		1.962*			3.994***	
COMPADVd			0.01339			0.01468
			0.988			2.011**
T	-0.00009	-0.00039	-0.00047	-0.00056	-0.00068	-0.00076
	-0.087	-0.387	-0.459	-0.995	-1.248	-1.387
N	1024	1060	1060	1024	1060	1060
R^2	0.17259	0.16591	0.16355	0.37489	0.38166	0.37443

Note:

- The t-ratios are reported below the corresponding coefficients.
- *: significant at 10% level; **: significant at 5% level ; ***: significant at 1% level.

Table 3-2 reports the OLS results when $NXTG_i$ and $NXTGa_i$ are the dependent variable. The results are similar for comparative advantage measures. However, the signs of tariffs become positive for some regressions.

Table 3-2: Results of Regressions (Dependent Variable: $\boldsymbol{NXTG}$)

Dependent Variable	$NXTG_i$			Imbalance-Adjusted $NXTG_i$		
COMPADVr	0.00068			0.00058		
	2.210**			2.267**		
COMPADVrl		0.00445			0.00461	
		1.957*			2.462**	
COMPADVd			0.03052			0.03461
			1.329			1.831*
T	0.00078	0.00005	-0.00006	0.00034	-0.00018	-0.0003
	0.443	0.029	-0.035	0.234	-0.127	-0.21
N	512	530	530	512	530	530
R^2	0.33629	0.33235	0.32952	0.37111	0.37102	0.36753

Note:

- The t-ratios are reported below the corresponding coefficients.
- *: significant at 10% level; **: significant at 5% level ; ***: significant at 1% level.

3.7.3.2. Sign Tests

Another approach to examine the prediction concerning the net exports is to conduct sign tests. The model predicts that the net exports of a sector should be positive if the country has comparative advantage in that sector. We can test the null that that the sign of the net exports is completely random (i.e., $P(NX_{hit} * COMPADVd_{hit} > 0) = 0.5$) against the alternative that it is not (i.e., $P(NX_{hit} * COMPADVd_{hit} > 0) > 0.5$).

The dataset contains 1122 valid ($NX_{hit}, COMPADVd_{hit}$) pairs. $NX_{hit} * COMPADVd_{hit}$ is negative for 488 pairs and positive for the other 634 pairs. The p-value of the sign test is 0.000006, so the null is rejected.

I then consider the imbalance-adjusted net exports. For the 1122

($NXa_{hit}, COMPADVd_{hit}$) pairs. $NXa_{hit} * COMPADVd_{hit}$ is negative for 450 pairs and positive for the other 672 pairs. The p-value of the sign test is very close to zero, so the null is again rejected.

Therefore, the sign tests provide further support for the prediction concerning net exports.

3.8. Conclusion

Recent trade literature has begun to model firm level heterogeneity since it is large and persistent in the data. Few papers, however, have combined it with comparative advantage. This paper tries to fill this gap by studying how heterogeneity and comparative advantage work in a perfect-competition model. Based on a two-sector Eaton and Kortum model, this paper shows that technology improvements always increase the total trade. They increase inter-industry trade if they originate in the comparative advantage sector, otherwise they decreases inter-industry trade. Increases in the degree of heterogeneity always increase the total trade and inter-industry trade.

The paper also analyzes the welfare effects of technology improvements and yields some new results. It shows that with the Cobb-Douglas utility function technology improvements are always beneficial to the innovator. In agreement to the literature, export-biased improvements benefit the foreign country. In a departure from the literature, however, the paper shows that import-biased improvements could benefit the foreign country. The paper also shows that when the final goods are complements, immiserizing growth may occur.

The theoretical model of the paper shows that the net exports of the comparative advantage sector are positive while those of the other sector are negative. Using the OECD STAN databases, the paper conducts a simple test concerning the prediction and finds strong support for it.

Although the model provides a framework to explain the effects of technology changes in the open economy, a caveat should be borne in mind that it does not incorporate some important mechanisms. The perfect competition assumption in the model precludes the analysis of trade facts that arise from imperfect competition. Differences in the endowments across countries, which is assumed away in this work, can play an important role in the determining the effects of technological changes.

The model does not consider dynamics of international trade, which has become increasingly important in economic studies (e.g., Matsuyama, 1991; Ventura, 1997, 2005; Galor and Mountford, 2006). A dynamic extension of this model to further study the endogenous technological change may be fruitful.

3.9. Appendices

3.9.1. Appendix 3.A: Definitions of Variables

Note: Through out this essay subscripts are either country or industry identifiers while superscripts are all exponents.

Table 3-3: Definitions of Variables

Definition	Description
L_h, L_f	Labor endowments of the home country and the foreign country
$a_1 \in (0,1)$	Expenditure share on sector 1
$a_2 = 1 - a_1$	Expenditure share on sector 2
w_h, w_f	Wage rates of the home country and the foreign country
$\lambda_{ih}, \lambda_{if}$	Technology frontiers of sector i of the home country and the foreign country
u	Variety identifier
$x_{ih}(u), x_{if}(u)$	Random draws of the productivity index for variety u in sector i for the home country and the foreign country
θ	Degree of productivity heterogeneity
η	Elasticity of substitution between varieties
$i, j = 1,2$	Sector indices
$q_i(u)$	Quantity of variety u of sector i
$Q_i = \left(\int_0^1 q_i(u)^{1-1/\eta} du\right)^{\eta/(\eta-1)}$	The quantity of sector i final good
$\omega_h = w_h / w_f$	The relative wage of the home country
$\varphi_h = w_h^{1/\theta} / w_f^{1/\theta}$	A function of the home country relative wage
$\chi_{ih} = \lambda_{ih} + \lambda_{if}\varphi_h$	The consumer perceived technology level of sector i in the home country

$\chi_{if} = \lambda_{if} + \lambda_{ih}/\varphi_h$	The consumer perceived technology level of sector i in the foreign country
$A = \Gamma(1 + \theta(1 - \eta)$	A constant
$P_{ih} = A\chi_{ih}^{-\theta} w_h$	The price index of sector i final good in the home country
$P_{if} = A\chi_{if}^{-\theta} w_f$	The price index of sector i final good in the foreign country
$m_{ih} = \frac{\lambda_{if}\varphi_h}{\chi_{ih}}$	The import share of sector i intermediate goods of the home country
$m_{if} = \frac{\lambda_{ih}/\varphi_h}{\chi_{if}}$	The import share of sector i intermediate goods of the foreign country
$M_{ih} = \frac{a_i \varphi_h^{\theta+1} L_h w_f}{\rho_{ih} + \varphi_h}$	The total imports of sector i intermediate goods of the home country
$X_{ih} = \frac{a_i L_f \rho_{ih} w_f}{\varphi_h + \rho_{ih}}$	The total exports of sector i intermediate goods of the home country
$M_h = \left(\frac{a_1}{\rho_{1h} + \varphi_h} + \frac{a_2}{\rho_{2h} + \varphi_h}\right) \varphi_h^{\theta+1} L_h w_f$	The total imports of the home country
$X_h = \left(\frac{a_1 \rho_{1h}}{\varphi_h + \rho_{1h}} + \frac{a_2 \rho_{2h}}{\varphi_h + \rho_{2h}}\right) L_f w_f$	The total exports of the home country
$\rho_{ih} = \lambda_{ih}/\lambda_{if}$	The ration of the home country technology level of sector i to that of the foreign country
$NX_{ih} = a_i w_f \left(\frac{\rho_{ih} L_f}{\varphi_h + \rho_{ih}} - \frac{\varphi_h^{\theta+1} L_h}{\rho_{ih} + \varphi_h}\right)$	The net export of sector i of the home country
$\epsilon_{\varphi_h \rho_{ih}}$	The elasticity of φ_h with respect to ρ_{ih}

Φ	A positive number, whose value is different in different expressions

3.9.2. Appendix 3.B: The Price Indices of the Final Goods

Consider sector *i*, let $x_i = (x_{ih}, x_{if})$ denote the draws productivity for intermediate goods in two countries. Assume that these draws are independent across countries, so the joint density of *x* is:

$$\phi_i(x_i) = \phi_{ih}(x_i)\phi_{if}(x_i) = \lambda_{ih}\lambda_{if}\exp(-\lambda_{ih}x_{ih} - \lambda_{if}x_{if})$$

Let u follow the above distribution, then the quantity of the final good is:

$$Q_i = \left(\int_{R_+^2} \phi(x)q_i(x)^{1-1/\eta}dx\right)^{\eta/(\eta-1)}$$

We put all the intermediate goods with productivity x_i into to the same group. Following Alvarez and Lucas, we label the group of goods with the associated productivity and call them “good x”.

Consider the home country. The price of final goods in each sector is:

$$P_{ih} = \left(\int_{R_+^2} p_{ih}^{1-\eta}(x)\,\phi(x)dx\right)^{1/(1-\eta)}$$

The demand function of intermediate good *x* in the home country is:

$$q_{ih}(x) = p_{ih}^{-\eta}(x)P_i^{\eta}Q_{ih}$$

If the home country producers of the final goods buy intermediate goods from domestic firms, the price is $w_h x_{ih}^{\theta}$; if they buy from foreign firms, the price is $w_f x_{if}^{\theta}$. The buyers will choose the lowest price among $w_h x_{ih}^{\theta}$ and $w_f x_{if}^{\theta}$. The price that prevail in the home country is:

$$p_{ih}(x) = \min\{w_h x_{ih}^{\theta}, w_f x_{if}^{\theta}\} => \\ p_{ih}^{1/\theta} = \min\{w_h^{1/\theta} x_{ih}, w_f^{1/\theta} x_{if}\}$$

where $x_{ih}(u) \sim \exp(\lambda_{ih})$, $x_{if}(u) \sim \exp(\lambda_{if})$. A nice property of the exponential distribution is that (Alvarez and Lucas, 2007):

$$x \sim \exp(\lambda)\ and\ \kappa > 0 => \kappa x \sim \exp\ (\lambda/\kappa)$$

Consequently we have:

$$w_h^{1/\theta} x_{ih} \sim \exp\left(\lambda_{ih}/w_h^{1/\theta}\right)$$

Another property of the exponential distribution is that (Alvarez and Lucas, 2007):

$$x \sim \exp(\lambda_1), y \sim \exp(\lambda_2), cov(x,y) = 0, \xi = \min(x,y) => \xi \sim (\lambda_1 + \lambda_2)$$

Therefore $p_{ih}^{1/\theta}(x)$ has the following distribution:

$$p_{ih}^{1/\theta}(x) \sim \exp\left(\left(\lambda_{ih} + \lambda_{if} w_h^{1/\theta}/(w_f^{1/\theta})\right)/w_h^{1/\theta}\right)$$

Let $\chi_{ih} = \lambda_{ih} + \lambda_{if} w_h^{1/\theta}/(w_l^{1/\theta})$, then we have:

$$p_{ik}^{1/\theta}(x) \sim \exp\left(\chi_{ik}/w_k^{1/\theta}\right)$$

χ_{ih} is the "**consumer-perceived**" sector i technology level in the home country. For ease in writing, define $\omega_h = w_h/w_f$, $\varphi_h = w_h^{1/\theta}/w_f^{1/\theta}$. Throughout this paper, the wage rate in the foreign country is taken as the numéraire. Then we have:

$$\chi_{ih} = \lambda_{ih} + \lambda_{if}\varphi_h$$

Consider $\int_{R_+^2} p_{ih}(x)^{1-\eta}\,\phi(x)dx$. Since $\phi(x)$ is the probability distribution function of *x*, so the integral can be taken as the expectation of $p_{ih}^{1-\eta}(x)$ in the technology spaceR_+^2. $p_{ih}^{1-\eta}(x)$ with $x \sim \phi(x)$ in R_+^2 corresponds to $p_{ih}^{1-\eta}(x) = p_{ih}^{(1/\theta)\theta(1-\eta)} = v^{\theta(1-\eta)}$ with $v\sim \exp\left(\chi_{ih}/w_h^{1/\theta}\right)$ in R_+^1. Here v is the projection of $p_{ih}^{1/\theta}$ on R_+^1. Therefore, the expectation of $p_{ih}^{1-\eta}(x)$ in the technology space is equivalent to the expectation of $v^{\theta(1-\eta)}$ in R_+^1. This implies that

$$P_{ih} = \left(\int_0^\infty v^{\theta(1-\eta)}\chi_{ih}/w_h^{1/\theta} e^{-v\chi_{ih}/w_h^{1/\theta}}dv\right)^{1/(1-\eta)}$$

Let $\sigma = v\chi_{ih}/w_h^{1/\theta}$, we have that:

$$P_{ih} = \left(\chi_{ih}/w_h^{1/\theta}\right)^{-\theta}\left(\int_0^\infty \sigma^{\theta(1-\eta)}e^{-\sigma}d\sigma\right)^{1/(1-\eta)}$$

Let $A = \left(\int_0^\infty \sigma^{\theta(1-\eta)}e^{-\sigma}d\sigma\right)^{1/(1-\eta)}$, which is value of the Gamma function $\Gamma(\gamma)$ at $\gamma = 1 + \theta(1-\eta)$ raised to $1/(1-\eta)$ power. Following Alvarez and Lucas (2007), I assume $1 + \theta(1-\eta) > 0$ so as to guarantee the integral converges. Henceforth, I will take A as a constant. So we have:

$$P_{ih} = A(\chi_{ih})^{-\theta}w_h$$

Likewise, the price of good i in the foreign country is:

$$P_{if} = A\chi_{if}^{-\theta}w_f$$

3.9.3. Appendix 3.C: Imports and Exports

The imports of the home country in sector i are:

$$\begin{aligned} M_{ih} &= m_{ih} P_{ih} Q_{ih} \\ &= m_{ih} \int_{R_+^2} p_{ih}(x)\, q(x)\, \phi(x) dx \\ &= \int_{B_{if}} p_{ih}(x)\, q(x)\, \phi(x) dx \end{aligned}$$

where B_{if} denotes the set on which the foreign country offers the lowest price (transportation costs inclusive) for goods *x* of sector *i* in the home country. Alvarez and Lucas argue that m_{ih} is equal to $\Pr(x \in B_{if})$ where $x \sim \phi(x)$ is the vector of productivity in two countries (Alvarez and Lucas). Therefore, we have:

$$\begin{aligned} m_{ih} &= \Pr(x \in B_{if}) \\ &= \Pr\left(\left(w_f^{1/\theta}\right) x_{if} = \min\left\{w_h^{1/\theta} x_{ih}, w_f^{1/\theta} x_{if}\right\}\right) \end{aligned}$$

We know that

$$w_h^{1/\theta} x_{ih}(u) \sim \exp\left(\lambda_{ih} / w_h^{1/\theta}\right)$$

and the property of the exponential distribution:

$$x \sim \exp(\lambda_1)\,, y \sim \exp(\lambda_2)\,, cov(x, y) = 0 \Rightarrow \Pr(x \leq y) = \frac{\lambda_1}{\lambda_1 + \lambda_2}$$

Therefore, we have:

$$m_{ih} = \frac{\lambda_{if} \varphi_h}{\chi_{ih}}$$

Likewise, the share of the sector *i* intermediate goods that the foreign imports from the home country is:

$$m_{if} = \frac{\lambda_{ih} / \varphi_h}{\chi_{if}}$$

3.9.4. Appendix 3.D: Total Trade and Technological Levels

The total trade is:

$$X_h = \left(\frac{a_1\rho_{1h}}{\varphi_h + \rho_{1h}} + \frac{a_2\rho_{2h}}{\varphi_h + \rho_{2h}}\right) L_f w_f$$

To study the effect of technological levels of the home country on total trade, we just need to assume the technology levels of the foreign country do not change calculate $\frac{dX_h}{d\rho_{1h}}$.

$$\frac{dX_h}{d\rho_{1h}} = \Phi\left(\frac{a_1\varphi_h}{(\varphi_h + \rho_{1h})^2} - \left(\frac{a_1\rho_{1h}}{(\varphi_h + \rho_{1h})^2} + \frac{a_2\rho_{2h}}{(\varphi_h + \rho_{2h})^2}\right)\frac{d\varphi_h}{d\rho_{ih}}\right)$$

Note that the equilibrium is defined by:

$$NX_h = \left(\frac{a_1\rho_{1h}}{\varphi_h + \rho_{1h}} + \frac{a_2\rho_{2h}}{\varphi_h + \rho_{2h}}\right) L_f w_f - \left(\frac{a_1}{\rho_{1h} + \varphi_h} + \frac{a_2}{\rho_{2h} + \varphi_h}\right)\varphi_h^{\theta+1} L_h w_f = 0$$

Employing the implicit function theorem, we have:

$$\frac{d\varphi_h}{d\theta} = -\frac{\partial NX_h/\partial\theta}{\partial NX_h/\partial\varphi_h} = \frac{\left(\frac{a_1}{\rho_{1h} + \varphi_h} + \frac{a_2}{\rho_{2h} + \varphi_h}\right) L_h \varphi_h^{\theta+1} w_f ln\varphi}{\partial NX_h/\partial\varphi_h}$$

where $\partial NX_h/\partial\varphi_h$ is:

$$\partial NX_h/\partial\varphi_h = \left(\frac{a_i\rho_{ih}}{(\varphi_h + \rho_{ih})^2} + \frac{a_j\rho_{jh}}{\left(\varphi_h + \rho_{jh}\right)^2}\right) L_f - \left(\frac{a_i}{(\rho_{ih} + \varphi_h)^2} + \frac{a_j}{\left(\rho_{jh} + \varphi_h\right)^2}\right) L_h \varphi_h^{\theta+1} + (\theta + 1)\left(\frac{a_i}{\rho_{ih} + \varphi_h} + \frac{a_j}{\rho_{jh} + \varphi_h}\right) L_h \varphi_h^{\theta}$$

Plug them into $\frac{dX_h}{d\rho_{1h}}$. After tedious calculation, we have:

$$\frac{dX_h}{d\rho_{1h}} = \Phi\theta\frac{a_i L_h \varphi_h^{\theta}}{\rho_{ih} + \varphi_h} + \theta\frac{a_j L_h \varphi_h^{\theta}}{\rho_{jh} + \varphi_h}$$

3.9.5. Appendix 3.E: The Growth Rate of the Relative-Wage

In this section, I show how fast the relative wage growth relative to the technology level. Since the productivity draws are raised to the θ power($x_{ih}^{-\theta}$ (u)), we should compare $\varphi_h = \omega^{1/\theta}$ with λ_{ih}, the technology index that increases.

Consider a uniform technological improvement in the home country. Let ρ'_{ih} $(i = 1,2)$ denote the new value of ρ_{ih} and suppose $\frac{\rho'_{ih}}{\rho_{ih}} = \Lambda > 1$. Let φ'_h the value of φ_h after the technology improvement. Suppose φ_h increases at a rate that is at least equal to the technology improvement, i.e., $\frac{\varphi'_h}{\varphi_h} \geq \Lambda$. Consider the equilibrium condition:

$$L_f\left(\frac{a_1\rho_{1h}}{\varphi_h + \rho_{1h}} + \frac{a_2\rho_{2h}}{\varphi_h + \rho_{2h}}\right) = \left(\frac{a_1}{\rho_{1h} + \varphi_h} + \frac{a_2}{\rho_{2h} + \varphi_h}\right)L_h\varphi_h^{\theta+1}$$

Then LHS of the equilibrium condition after the technology improvement is:

$$L_f\left(\frac{a_1\rho'_{1h}}{\varphi'_h + \rho'_{1h}} + \frac{a_2\rho'_{2h}}{\varphi'_h + \rho'_{2h}}\right) \leq L_f\left(\frac{a_1\rho_{1h}}{\varphi_h + \rho_{1h}} + \frac{a_2\rho_{2h}}{\varphi_h + \rho_{2h}}\right)$$

The RHS of the equilibrium condition after the technology improvement is

$$\left(\frac{a_1\varphi'_h}{\rho_{1h}' + \varphi_h'} + \frac{a_2\varphi_h'}{\rho_{2h}' + \varphi_h'}\right)L_h{\varphi'_h}^{\theta+1} \geq \left(\frac{a_1\varphi_h}{\rho_{1h} + \varphi_h} + \frac{a_2\varphi_h}{\rho_{2h} + \varphi_h}\right)L_h\varphi_h^{\theta}\Lambda^{\theta+1}$$

We can see that the RHS is greater than the LHS after the technology improvement. This contradicts the trade balance condition. Therefore we must have $\frac{\varphi'_h}{\varphi_h} < \Lambda$ given a uniform technological improvement.

Since the relative wage rate increases less given a biased technology improvement ($\frac{\rho'_{ih}}{\rho_{ih}} = \Lambda, \frac{\rho'_{jh}}{\rho_{jh}} = 1$), the relative wage rate must grow even slower. Therefore we must have $d(\rho_{ih}/\varphi_h)/d\rho_{ih} > 0$, (or $d(\lambda_{ih}/\varphi_h)/d\lambda_{ih} > 0$) given a biased technological improvement.

3.9.6. Appendix 3.F: Welfare Effects on the Foreign Country

The welfare of the foreign country is:

$$U_f(\cdot) = a_i^{a_i} a_j^{a_j} \, L_f A^{-1} \left(\left(\lambda_{if} + \lambda_{ih}/\varphi_h\right)^{a_i} \left(\lambda_{jf} + \lambda_{jh}/\varphi_h\right)^{a_j} \right)^{\theta}$$

Consider a monotonic transformation of it:

$$u_f = a_i ln\left(\lambda_{if} + \lambda_{ih}/\varphi_h\right) + a_j ln\left(\lambda_{jf} + \lambda_{jh}/\varphi_h\right)$$

Then we have:

$$\frac{du_f}{d\lambda_{1h}} = \frac{1}{\lambda_{1f}\varphi_h}\left(\frac{a_1\varphi_h}{\varphi_h + \rho_{1h}} - \left(\frac{a_1\rho_{1h}}{\varphi_h + \rho_{1h}} + \frac{a_2\rho_{2h}}{\varphi_h + \rho_{2h}}\right)\frac{d\varphi_h}{d\rho_{1h}}\right)$$

where

$$\frac{d\varphi_h}{d\rho_{1h}} = \frac{\dfrac{a_1 L_f \varphi_h + a_1 L_h \varphi_h^{\theta+1}}{(\varphi_h + \rho_{1h})^2}}{\left[\begin{array}{c}\left(\dfrac{a_1\rho_{1h}}{(\varphi_h + \rho_{1h})^2} + \dfrac{a_2\rho_{2h}}{(\varphi_h + \rho_{2h})^2}\right) L_f - \left(\dfrac{a_1}{(\rho_{1h} + \varphi_h)^2} + \dfrac{a_2}{(\rho_{2h} + \varphi_h)^2}\right) L_h \varphi_h^{\theta+1} \\ +(\theta + 1)\left(\dfrac{a_1}{\rho_{1h} + \varphi_h} + \dfrac{a_2}{\rho_{2h} + \varphi_h}\right) L_h \varphi_h^{\theta}\end{array}\right]}$$

and φ_h is determined by the equilibrium condition:

$$NX_h = 0$$

- **The Welfare Effects of Export-biased Improvements**

Consider the case where $\rho_{1h} > \rho_{2h}$.

$$\begin{aligned}\frac{du_f}{d\lambda_{1h}} &= \frac{1}{\lambda_{1f}\varphi_h}\left(\frac{a_1\varphi_h}{\varphi_h+\rho_{1h}} - \left(\frac{a_1\rho_{1h}}{\varphi_h+\rho_{1h}} + \frac{a_2\rho_{2h}}{\varphi_h+\rho_{2h}}\right)\frac{d\varphi_h}{d\rho_{1h}}\right) \\ &> \frac{1}{\lambda_{1f}\varphi_h}\left(\frac{a_1\varphi_h}{\varphi_h+\rho_{1h}} - \left(\frac{a_1\rho_{1h}}{\varphi_h+\rho_{1h}} + \frac{a_2\rho_{1h}}{\varphi_h+\rho_{1h}}\right)\frac{d\varphi_h}{d\rho_{1h}}\right) \\ &= \frac{1}{\lambda_{1f}\varphi_h^2(\varphi_h+\rho_{1h})}\left(a_1 - \epsilon_{\varphi_h\rho_{1h}}\right)\end{aligned}$$

When $\rho_{1h} = \rho_{2h}$, we have $\epsilon_{\varphi_h\rho_{1h}} < a_1$. Since φ_h is bounded, generally speaking the wage rate increasing at a slower rate than ρ_{1h}, which means that $\epsilon_{\varphi_h\rho_{1h}} < a_1$ when $\rho_{1h} > \rho_{2h}$. This implies that $\frac{du_f}{d\lambda_{1h}} > 0$, which means that technological improvement s increases the welfare of the foreign country.

- **Import-biased Improvements That Hurts the Foreign Country**

Consider the case where $\rho_{1h} < \rho_{2h}$.

$$\begin{aligned}\frac{du_f}{d\lambda_{1h}} &= \frac{1}{\lambda_{1f}\varphi_h}\left(\frac{a_1\varphi_h}{\varphi_h+\rho_{1h}} - \left(\frac{a_1\rho_{1h}}{\varphi_h+\rho_{1h}} + \frac{a_2\rho_{2h}}{\varphi_h+\rho_{2h}}\right)\frac{d\varphi_h}{d\rho_{1h}}\right) \\ &< \frac{1}{\lambda_{1f}\varphi_h}\left(\frac{a_1\varphi_h}{\varphi_h+\rho_{1h}} - \left(\frac{a_1\rho_{1h}}{\varphi_h+\rho_{1h}} + \frac{a_2\rho_{1h}}{\varphi_h+\rho_{1h}}\right)\frac{d\varphi_h}{d\rho_{1h}}\right) \\ &= \Phi\left(a_1 - \epsilon_{\varphi_h\rho_{1h}}\right)\end{aligned}$$

When ρ_{1h} is very small, the wage rate are sensitive to changes in ρ_{1h}, so $\epsilon_{\varphi_h\rho_{1h}}$ could be larger than a_1 and leads to a negative effects on the foreign welfare.

Let us consider an example in which an import-biased technology improvement has negative effects on the foreign country. Suppose $\rho_{1h} = 1/\rho_{2h} < 1, L_h = L_f, T = 1$. In this case, we must have $\varphi_h = 1$. Consequently:

$$\frac{du_f}{d\lambda_{1h}} = \frac{\Phi}{\lambda_{1f}}\left(a_1 - (a_1\rho_{1h} + a_2)\frac{d\varphi_h}{d\rho_{1h}}\right)$$

Since $\frac{d\varphi_h}{d\rho_{ih}} = \frac{2a_i}{2\rho_{ih}+\theta(a_i+a_j\rho_{ih})(1+\rho_{ih})}$, we have:

$$\frac{du_f}{d\lambda_{1h}} = \Phi(2a_2\rho_{1h} + \theta(a_1 + a_2\rho_{1h})(1 + \rho_{1h}) - 2a_2)$$

If θ is small enough we can see that $\frac{du_f}{d\lambda_{1h}} < 0$.

- **Import-biased Improvements That Benefits the Foreign Country**

Suppose $\rho_{1h} = \rho_{2h}$, we have:

$$\frac{du_f}{d\lambda_{1h}} = \frac{1}{\lambda_{1f}(\varphi_h + \rho_{1h})}\left(a_1 - \epsilon_{\varphi_h\rho_{1h}}\right)$$

I proved above that $\epsilon_{\varphi_h\rho_{1h}} < a_1$ when $\rho_{1h} = \rho_{2h}$(refer to the section on changes in total trade volume.), therefore $\frac{du_f}{d\lambda_{1h}} > 0$.

Given the setup in this paper, $\frac{du_f}{d\rho_{1h}}$ is a continuous function. Therefore we have $\frac{du_f}{d\rho_{1h}} > 0$ when ρ_{1h} is in the left vicinity of ρ_{2h}. In other words, we are sure that import-biased technological improvements increases the welfare of the foreign country when it is about to eliminate the comparative advantage.

Consider the symmetric example in “Import-biased Improvements That Hurts the Foreign Country”. If θ is large enough we must have $\frac{du_f}{d\lambda_{1h}} > 0$. This is an example in which export biased technological improvements benefits the foreign country.

3.9.7. Appendix 3.G: Equilibrium When Two Final Goods Are Complements

Suppose that the two final goods are compliments

$$U(Q_1, Q_2) = (Q_1^a + Q_2^a)^{1/a}, a < 0$$

Given income w and price P_1 and P_2 we have:

$$Q_{1h} = \frac{w}{P_{1h} + P_{1h}^{\frac{1}{1-a}} P_{2h}^{\frac{a}{a-1}}}$$

We know that

$$P_{ih} = A(\chi_{ih})^{-\theta} w_h$$

and the import share of the home country in sector i:

$$m_{ih} = \frac{\lambda_{if}\varphi_h}{\chi_{ih}}$$

Therefore the imports of sector i are:

$$M_{ih} = m_{ih} P_{ih} Q_{ih} = \frac{\lambda_{if}\varphi_h}{\chi_{ih}} \frac{L_h w_h}{1 + \left(\frac{\chi_{ih}}{\chi_{jh}}\right)^{\frac{a\theta}{a-1}}}$$

The total import of the home country is:

$$\begin{aligned} M_h &= M_{ih} + M_{jh} \\ &= \varphi_h L_h w_h \left(\frac{\lambda_{if}}{\lambda_{ih} + \lambda_{if}\varphi_h} \left(1 + \left(\frac{\lambda_{ih} + \lambda_{if}\varphi_h}{\lambda_{jh} + \lambda_{jf}\varphi_h} \right)^{\frac{a\theta}{a-1}} \right)^{-1} \right. \\ &\quad \left. + \frac{\lambda_{jf}}{\lambda_{jh} + \lambda_{jf}\varphi_h} \left(1 + \left(\frac{\lambda_{jh} + \lambda_{jf}\varphi_h}{\lambda_{ih} + \lambda_{if}\varphi_h} \right)^{\frac{a\theta}{a-1}} \right)^{-1} \right) \end{aligned}$$

Likewise, the import of the foreign country is:

$$\begin{aligned} M_f = L_f w_f &\left(\frac{\lambda_{ih}}{\lambda_{if}\varphi_h + \lambda_{ih}} \left(1 + \left(\frac{\lambda_{if}\varphi_h + \lambda_{ih}}{\lambda_{jf}\varphi_h + \lambda_{jh}} \right)^{\frac{a\theta}{a-1}} \right)^{-1} \right. \\ &\quad \left. + \frac{\lambda_{jh}}{\lambda_{jf}\varphi_h + \lambda_{jh}} \left(1 + \left(\frac{\lambda_{jf}\varphi_h + \lambda_{jh}}{\lambda_{if}\varphi_h + \lambda_{ih}} \right)^{\frac{a\theta}{a-1}} \right)^{-1} \right) \end{aligned}$$

Therefore the trade balance condition is:

$$\varphi_h^{\theta+1} L_h \left(\frac{\lambda_{if}}{\lambda_{ih} + \lambda_{if}\varphi_h} \left(1 + \left(\frac{\lambda_{ih} + \lambda_{if}\varphi_h}{\lambda_{jh} + \lambda_{jf}\varphi_h} \right)^{\frac{a\theta}{a-1}} \right)^{-1} + \frac{\lambda_{jf}}{\lambda_{jh} + \lambda_{jf}\varphi_h} \left(1 + \left(\frac{\lambda_{jh} + \lambda_{jf}\varphi_h}{\lambda_{ih} + \lambda_{if}\varphi_h} \right)^{\frac{a\theta}{a-1}} \right)^{-1} \right)$$

$$= L_f \left(\frac{\lambda_{ih}}{\lambda_{if}\varphi_h + \lambda_{ih}} \left(1 + \left(\frac{\lambda_{if}\varphi_h + \lambda_{ih}}{\lambda_{jf}\varphi_h + \lambda_{jh}} \right)^{\frac{a\theta}{a-1}} \right)^{-1} + \frac{\lambda_{jh}}{\lambda_{jf}\varphi_h + \lambda_{jh}} \left(1 + \left(\frac{\lambda_{jf}\varphi_h + \lambda_{jh}}{\lambda_{if}\varphi_h + \lambda_{ih}} \right)^{\frac{a\theta}{a-1}} \right)^{-1} \right)$$

Given the equilibrium φ_h, the utility of the home country is:

$$U(Q_1, Q_2) = (Q_1^a + Q_2^a)^{1/a}$$

$$= \frac{L_h}{A} \left(\left(\left(\lambda_{ih} + \lambda_{if}\varphi_h\right)^{-\theta} + \left(\lambda_{ih} + \lambda_{if}\varphi_h\right)^{\frac{\theta}{a-1}} \left(\lambda_{jh} + \lambda_{jf}\varphi_h\right)^{\frac{a\theta}{1-a}} \right)^{-a} + \left(\left(\lambda_{jh} + \lambda_{jf}\varphi_h\right)^{-\theta} + \left(\lambda_{jh} + \lambda_{jf}\varphi_h\right)^{\frac{\theta}{a-1}} \left(\lambda_{ih} + \lambda_{if}\varphi_h\right)^{\frac{a\theta}{1-a}} \right)^{-a} \right)^{1/a}$$

Likewise, we have:

$$U_f = \frac{L_f}{A} \left(\left(\left(\lambda_{if} + \lambda_{ih}/\varphi_h\right)^{-\theta} + \left(\lambda_{if} + \lambda_{ih}/\varphi_h\right)^{\frac{\theta}{a-1}} \left(\lambda_{jf} + \lambda_{jh}/\varphi_h\right)^{\frac{a\theta}{1-a}} \right)^{-a} + \left(\left(\lambda_{jf} + \lambda_{jh}/\varphi_h\right)^{-\theta} + \left(\lambda_{jf} + \lambda_{jh}/\varphi_h\right)^{\frac{\theta}{a-1}} \left(\lambda_{if} + \lambda_{ih}/\varphi_h\right)^{\frac{a\theta}{1-a}} \right)^{-a} \right)^{1/a}$$

Chapter 4 :

HICKS PATH: THE OPTIMAL STRATEGY OF TECHNOLOGICAL IMPROVEMENT IN THE OPEN ECONOMY

4.1. Introduction

In his paper on technological improvements, Hicks (1953) argued that "*the first stage in a process of development is very likely to be export-biased*," and then "*… the process passes into its second stage … that are import-biased*." Thus when his analysis "*is put into an historical dress, it suggests as a normal sequence the succession of an export-biased by an import-biased phase"* (Hicks 1953), a pattern that I refer to as Hicks path hereafter.

Interesting as it is, there have been no theoretical explanations for the pattern. Hicks argued that "*countries, like people, are most likely to make their improvements in those sorts of production which they already do relatively well than in those they do relatively badly*." However, he did not use a model to formally prove the argument, nor did he explain the reason behind it. As for the empirical evidence, Hicks listed some historical facts and argue that "*we see the shadows of such patterns across the face of history*". Neither he nor other economists have conducted formal empirical tests on Hicks path. To fill this gap, this work provides a theoretical foundation for Hicks path in this paper and investigates if it exists in the data.

In order to study the technological improvement pattern, the first step is to model innovation activities. Kortum (1997) develops a R&D framework that proves to be realistic. In his model, each unit of R&D input generates a random amount of new ideas whose productivity is a random draw from a Pareto distribution. Each new idea is applied to a random variety in a continuum of goods. The productivity associated with each good converges to a Fréchet distribution in limit. This model explains some puzzling trends in productivity, patents, and R&D activity in the United States. Kortum's model has been extended to conduct other empirical analysis as well (e.g., Eaton and Kortum, 1999).

Eaton and Kortum (2001b) develop a unified framework of innovation, trade, and growth by combining Kortum (1997) and Dornbush et al. (1977). In their 2002 paper (Eaton and Kortum 2002), they develop a similar model of bilateral trade to study trade and price data among the OECD. Bernard et al. (2003) augment the model to study the export behavior of individual US plants. Alvarez and Lucas (2007) develop an equilibrium analysis to the Eaton and Kortum model to analyze the gains from trade liberalization.

This essay extends the Eaton and Kortum framework into a multi-sector model to analyze the innovation pattern of countries in the open economy. The theoretical model first analyzes the R&D pattern in autarky and shows that sectoral R&D input is proportional to the expenditure share and the research efficiency of each sector. The model also shows that the laissez faire R&D input level is less than the socially optimal R&D input level in autarky.

The above results carry over to the open economy. Moreover, the model shows that in the open economy the total R&D input in a sector of a country depend on the country's advantage. The research efficiency function, which is a function of current technology frontiers of the home and the foreign countries, determines whether the R&D input increases of decreases with a country's advantage in a sector.

Using the OECD STAN database, the empirical analysis finds some support for Hicks' path but it also indicates that the R&D pattern in the real world might be richer than what Hicks predicted. Within each industry, for the majority of countries (whose technology frontier ranks in the top 70%-80% in the industry) the sectoral R&D input of a country first increases with its technological advantage in the industry. When the country moves into the leading group (i.e., its technology frontier ranks among the top 20%-30% in the industry) its sector R&D begins to decrease with its technological advantage. This is consistent with Hicks' claim that countries will first conduct export-biased technology improvements and then import-biased improvement. The empirical study, however, also finds that for the countries whose technological advantage ranks in bottom 20%-30% the sectoral R&D input decreases with their technological advantage. This might arise from the reason that less-developed countries may find it more profitable to rely on technology transfer than on research and development, a hypothesis left for future study. [15]

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[15] Both the theoretical and empirical results are based on the assumption that governments do not intervene the R&D of the business sector. However, in the real world, governments may subsidize business R&D for various reasons (e.g., mercantilism). I defer the analysis of R&D subsidies in future research.

4.2. Setup

There are two countries: the home country (*h*) and the foreign country (*f*), whose labor endowments are $L_h$and L_f respectively. The economies produce N final goods. Consumers in two countries have the same preferences over the final goods, and their utility function takes the Cobb-Douglas form:

$$U(\cdot) = \prod_{i=1}^{N} \left(\frac{Q_i}{a_i}\right)^{a_i}$$

where $Q_i$is the quantity of the final good of sector i and a_i is the expenditure share of good i with $a_i \in (0,1)$ and $\sum_{i=1}^{N} a_i = 1$. Throughout this paper, subscripts are either country identifiers or industry identifiers and superscripts are exponents.

Each type of final good is produced with a different group of intermediate goods. Each group of intermediate goods is indexed from 0 to 1. Firms in both countries can produce final goods with the same technology:

$$Q_i = \left(\int_0^1 q_i(u)^{1-1/\eta} du\right)^{\eta/(\eta-1)}$$

where η is the elasticity of substitution, which is the same for all sectors. The intermediate goods are produced with constant-returns-to-scale technology, the evolution of whose frontier will be described below.

I follow Eaton and Kortum's way of modeling research activities. A unit of labor input on R&D generates ideas at a Poisson rate $r_{ih}(\cdot)$ which indicates research efficiency of sector *i* in the home country. The research efficiency is a function of the home country technology frontier ($r_{ih}(\cdot) = r_{ih}(\lambda_{ih})$). In the open economy, the research efficiency is a function of the technology frontiers in home and foreign countries ($r_{ih}(\cdot) = r_{ih}(\lambda_{ih}, \lambda_{if})$). Suppose there is a fundamental difference between the R&D activities in autarky and in the open economy, so cannot set λ_{if} in $r_{ih}(\lambda_{ih}, \lambda_{if})$ to zero to get the autarky research efficiency function.

The intermediate good to which a sector *i* idea applies has a uniform distribution over the variety continuum [0, 1]. The efficiency of an idea (z) is defined as the quantity of goods that the idea can produce with a unit of labor. Following Eaton and Kortum, I assume *z* has a Pareto distribution $G(z) = 1 - z^{-1/\theta}, z \in (1, \infty)$[16]. With this setup, the distribution of the productivity of a sector will converge to a Fréchet distribution over time (Kortum 1997):

$$H_{ih}(z) = e^{-\lambda_{ih} z^{-1/\theta}}, z > 0$$

where parameter λ_{ih} is the total stock of ideas:

$$\lambda_{ih} = \int_0^t r_{ih} d_{ih}(v) dv$$

and d_{ih} is the flow of R&D input.

Suppose that R&D can only be done at the beginning of each period. The R&D process does not take time, therefore the inventors can utilize the new ideas in the same period they are discovered. Suppose that firms are engaged in Bertrand competition, so the firm with the best idea sets its price equal to the marginal cost of the runner-up. The patent length is normalized to one period, which implies that firms' planning horizon for R&D is one period.

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[16] Through out this paper, we define θ *a la* Alvarez and Lucas (2007). So a larger θ means a higher degree of heterogeneity.

The intermediate goods are traded freely while the final good is not tradable. The labor is immobile across countries, but perfectly mobile within a country and across industries.

4.3. R&D Decisions in Autarky

This section analyzes the technological improvements of the home country in autarky. Suppose that at the beginning of a period the home country technology frontiers are $[\lambda_{1h}, \lambda_{2h}, \ldots \lambda_{Nh}]$. The population, however, becomes L'_h. Suppose that that with the new population it is profitable to do research in both sectors. Suppose d_{ih} units of labor is allocated to do research in sector i. According to Eaton and Kortum's framework, after the innovation the technology level of sector i becomes:

$$\lambda'_{ih} = \lambda_{ih} + r_{ih}(\lambda_{ih})d_{ih}$$

where λ'_{ih} denotes the level of technology after the innovation . In what follows, primes are used to indicate the variables after the innovation.

4.3.1. The Decentralized R&D Decision in Autarky

4.3.1.1. The Expected Value of an Idea

This section calculates the expected value of an idea in autarky. In Appendix 4.A, I show that under perfect competition when all firms have access to the best technology the price of intermediate goods of sector i has the following distribution $p_{ih}^{1/\theta} \sim \exp\left(\chi_{ih}/w_h^{1/\theta}\right)$, where $\chi_{ih} = \lambda_{ih} + \lambda_{if}\varphi_h$ is the consumer-perceived technology level in the home country. In autarky, the foreign goods does not reach the home country so $\chi_{ih} = \lambda_{ih}$. After the innovation, given perfect competition we have

$$p'_{ih}{}^{1/\theta} \sim \exp\left(\chi'_{ih}/w'_h{}^{1/\theta}\right)$$

We can take this as the distribution of the cost after technology improvement. Let us consider a marginal researcher. If her idea associated wtih variety u is competitive in the home country, one must have:

$$w'_h/z(u) < p'_{ih}(u) => z(u) > w'_h/p'_{ih}(u)$$

When this is the case, the optimal price could be the monopolistic price or the second lowest cost in the market. Bernard et al. (2003) consider both possibilities. However, the true distribution of the markup is complicated. Following Grossman and Helpman (1991), Aghion and Howitt (1992), Eaton and Kortum (2001b, 2006), I assume that a successful researcher always sets the price to $p'_{ih}(u)$. Appendix 4.A shows that the price index of the final good in sector i is $P_{ih} = A(\chi_{ih})^{-\theta} w_h$, so the demand of variety u is:

$$q'_{ih}(u) = p'_{ih}{}^{-\eta} A^{\eta-1} \chi'_{ih}{}^{\theta(1-\eta)} a_i L'_h w'_h{}^{\eta}$$

The profit that a successful idea earns in the home country is:

$$\pi_{ihh}(z,u) = (p'_{ih}(u) - w'_h/z)\, p'_{ih}{}^{-\eta} A^{\eta-1} \chi'_{ih}{}^{\theta(1-\eta)} a_i L'_h w'_h{}^{\eta}$$

Appendix 4.B shows that the expectation of $\pi_{ihh}(z,u)$ is:

$$E\big(\pi_{ihh}(z,u)\big) = \frac{\theta\big(1+\theta(1-\eta)\big)}{(1+\theta)\chi'_{ih}} a_i L'_h w'_h$$

4.3.2. Equilibrium R&D Input

In equilibrium, the return to labor input in production and that to R&D should be equalized:

$$r_{ih}(\lambda_{ih})E\big(\pi_{ihh}(z,u)\big) = w'_h$$

Solving this equation, we have:

$$\lambda'_{ih} = \frac{1+\theta(1-\eta)}{1+\theta}\theta a_i r_{ih}(\lambda_{ih})L'_h$$

The R&D input is:

$$d_{ih} = \frac{1+\theta(1-\eta)}{1+\theta}\theta a_i r_{ih}(\lambda_{ih})L'_h - \lambda_{ih}/r_{ih}(\lambda_{ih})$$

Suppose that the new population is sufficiently large so that the R&D input is non-negative.The ratio of the two post-innovation technology levels is:

$$\frac{\lambda'_{ih}}{\lambda'_{jh}} = \frac{a_i r_{ih}(\lambda_{ih})}{a_j r_{jh}(\lambda_{jh})}$$

The research intensity of the country is:

$$\frac{\sum_{i=1}^{N} d_{ih}}{L'_h} = \frac{1+\theta(1-\eta)}{1+\theta}\sum_{i=1}^{N}\theta a_i r_{ih}(\lambda_{ih}) - \frac{1}{L'_h}\sum_{i=1}^{N}\frac{\lambda_h}{r_{1h}(\lambda_{ih})}$$

which is increasing in L_h. This means that the research intensity increases with the country size.

When L'_h goes to infinity, the research intensity $\frac{\sum_{i=1}^{N} d_{ih}}{L'_h}$ tends to a constant $\frac{1+\theta(1-\eta)}{1+\theta}\sum_{i=1}^{N}\theta a_i r_{ih}(\lambda_{ih})$ since that λ_{ih} is exogenous to L'_h. Eaton and Kortum(2001b) consider a steady state in which a constant share of the labor force in a country engages in research. The model in this essay is extended to a dynamic version, this type of steady state will be the only possible steady state since λ'_{ih} is proportional to L'_h.

4.3.3. The Social Planner's R&D Decision in Autarky

Now let us assume that a social planner chooses R&D input to maximize social welfare. Suppose the R&D input in a sector is d_{ih}, then after the technological improvement the new welfare level is:

$$U_h'(\cdot) = A^{-1}\left(L_h' - \sum_{i=1}^{N} d_{ih}\right)\prod_{i=1}^{N} {\lambda_{ih}'}^{\theta a_i}$$

The solution to the above maximization problem is defined by N first order conditions:

$$\sum_{j=1}^{N} d_{jh} + \frac{d_{ih}}{a_i\theta} = L_h' - \frac{\lambda_{ih}}{a_i\theta r_{ih}}, i \in (1, 2, \dots N)$$

Let d denote the R&D input vector $[d_{1h}, d_{2h}, \dots d_{Nh}]^T$, where T is the transpose operator.

Let D denote coefficient matrix for the unknowns:

$$D = \begin{bmatrix} 1 - 1/(a_1\theta) & 1 & 1 & \dots & 1 \\ 1 & 1 - 1/(a_2\theta) & 1 & \dots & 1 \\ 1 & 1 & 1 - 1/(a_3\theta) & \dots & 1 \\ \dots & \dots & \dots & \dots & \dots \\ 1 & 1 & 1 & \dots & 1 - 1/(a_N\theta) \end{bmatrix}$$

Let column vector R denote the vector that contains the right hand side of the first order conditions:

$$R = \left[L_h' - \frac{\lambda_{1h}}{a_1\theta r_{1h}(\lambda_{1h})} \quad L_h' - \frac{\lambda_{2h}}{a_2\theta r_{2h}(\lambda_{2h})} \quad \dots \quad L_h' - \frac{\lambda_{Nh}}{a_N\theta r_{Nh}(\lambda_{Nh})}\right]^T$$

Then the FOC's can be written as:

$$D \cdot d = R$$

Let D_i denote the matrix when we replace the i^{th} column of D with R. According to Cramer's rule, we have:

$$d_{ih} = \frac{|D_i|}{|D|}$$

where $|D_i|$ and $|D|$ are the determinants of D_i and D. Suppose that the country is large enough so that the social planner wants to improve the technology in both sectors.

When there are only two sectors, we have:

$$d_{ih} = \frac{\theta a_i r_{ih}(\lambda_{ih})\left(\lambda_{jh} + r_{jh}(\lambda_{jh})L'_h\right) - r_{jh}(\lambda_{jh})\lambda_{ih}\left(1+\theta a_j\right)}{(\theta+1) r_{ih}(\lambda_{ih}) r_{jh}(\lambda_{jh})},$$

$$i = 1,2; j = 1,2; i \neq j$$

The above result tells us that the R&D input in each sector increases with the research efficiency, consumer's expenditure share on the sector and the country size. It can also be shown that the overall research intensity of a country increases with the country size.

Since the post-innovation technology level of sector i is $\lambda'_{ih} = \frac{\theta a_i}{1+\theta}\left(\left(r_{ih}(\lambda_{ih})\lambda_{jh}\right)/r_{jh}(\lambda_{jh}) + r_{ih}(\lambda_{jh})L'_h + \lambda_{ih}\right)$, the ratio of the two post-innovation technology levels is:

$$\frac{\lambda'_{1h}}{\lambda'_{2h}} = \frac{a_1 r_{1h}(\lambda_{1h})}{a_2 r_{2h}(\lambda_{1h})}$$

Denote the social planner post-innovation technology of sector i level with $\lambda'_{ihs} = \frac{\theta a_i}{1+\theta}\left(\left(r_{ih}(\lambda_{ih})\lambda_{jh}\right)/r_{jh}(\lambda_{jh}) + r_{ih}(\lambda_{jh})L'_h + \lambda_{ih}\right)$, the decentralized one with $\lambda'_{ihd} = \frac{1+\theta(1-\eta)}{1+\theta}\theta a_i r_{ih}(\lambda_{ih})L'_h$ Then we have:

$$\frac{\lambda'_{ihs}}{\lambda'_{ihd}} > \frac{1}{1+\theta(1-\eta)}$$

Since $\eta > 1$, $1 + \theta(1-\eta) < 1$. Therefore we have:

$$\frac{1}{1+\theta(1-\eta)} > 1 => \lambda'_{ihs} > \lambda'_{ihd}$$

This means that the social optimal post-innovation technology level is higher than the one in laissez faire. In laissez faire, researchers set the output level lower than the social optimal level since they can't capture all the profit of new ideas. This leads to lower R&D input and social welfare in the decentralized case.

Summarizing the above results, we have the following theorem:

Theorem 1: No matter whether the R&D decisions are made by a social planner or individuals, in autarky the post-innovation technology of each sector is proportional to its expenditure share and research efficiency. The socially optimal R&D input is greater than the one in laissez faire for both sectors when there are only two sectors.

4.4. R&D Decisions in the open economy

This section studies the R&D patterns in the open economy. Suppose only the home country does research. Its initial population is L_h and the new one is L'_h. The foreign country does not do research and its population remains L_f.

4.4.1. Equilibrium with Decentralized R&D Decisions

We know that the profit earned by a competitive idea in the domestic market is:

$$E\left(\pi_{ihh}(z,u)\right) = \frac{\theta\left(1+\theta(1-\eta)\right)}{(1+\theta)\chi'_{ih}} a_i L'_h w'_h$$

Now let us consider the profit that an idea can earn from the world market in the open economy. The total market size is $L'_h w'_h + L_f w_f$ and the consumer perceived technology level is $\lambda'_{ih} + \lambda_{if}\varphi'_h$. Substituting $L'_h w'_h + L_f w_f$ for $L'_h w'_h$ and $\lambda'_{ih} + \lambda_{if}\varphi'_h$ for χ'_{ih}, we know that the total expected profit that an idea earns is:

$$E\left(\pi_{ihw}(z,u)\right) = \frac{a_i\theta\left(1+\theta(1-\eta)\right)}{1+\theta} \frac{L'_h + L_f w_f/w'_h}{\lambda'_{ih} + \lambda_{if}\varphi'_h} w'_h$$

The expected number of ideas that a researcher finds with a unit of labor is $r_{ih}(\lambda_{ih}, \lambda_{if})$. The expected payoff of a unit of labor allocated to R&D in sector i is $r_{ih}(\lambda_{ih}, \lambda_{if})E\left(\pi_{ihw}(z,u)\right)$. In equilibrium people must be indifferent between doing research and engaging in production:

$$w'_h = r_{ih}(\lambda_{ih}, \lambda_{if})E\left(\pi_{ihw}(z,u)\right)$$

This implies that the new "consumer perceived technology level" is

$$\chi'_{ih} = r_{ih}(\lambda_{ih}, \lambda_{if})\frac{a_i\theta\left(1+\theta(1-\eta)\right)}{1+\theta}\left(L'_h + L_f w_f/w'_h\right)$$

Then we have:

$$\frac{\chi'_{ih}}{\chi'_{jh}} = \frac{a_i r_{ih}(\lambda_{ih}, \lambda_{if}))}{a_j r_{2h}(\lambda_{jh}, \lambda_{jf})}$$

The post-innovation consumer-perceived technology level in each sector is proportional to the expenditure share and the R&D efficiency of the sector.

The above analysis also yields:

$$\lambda'_{ih} = r_{ih}(\lambda_{ih}, \lambda_{if}) \frac{a_i \theta\big(1 + \theta(1 - \eta)\big)}{1 + \theta} \big(L'_h + L_f / \omega_h\big) - \lambda_{if} \varphi'_h$$

Substituting this in the trade balance condition yields:

$$\varphi'_h = \left(\frac{\big(r_{2h}(\lambda_{2h}, \lambda_{2f})\lambda'_{1h} + r_{1h}(\lambda_{1h}, \lambda_{1f})\lambda'_{2h}\big)L_f}{\big(r_{1h}(\lambda_{1h}, \lambda_{1f})\lambda_{2f} + r_{2h}(\lambda_{2h}, \lambda_{2f})\lambda_{1f}\big)L'_h}\right)^{1/(1+\theta)}$$

Therefore the equilibrium is defined by the above three conditions (two equations for R&D input and one condition for trade balance).

4.4.2. The Hicks Path in the Open Economy

Suppose the country size increase from L_h to L'_h. Then R&D input is:

$$d_{ih} = \frac{a_i \theta\big(1 + \theta(1 - \eta)\big)}{1 + \theta} \big(L'_h + L_f / \omega'_h\big) - \frac{\lambda_{if} \varphi'_h + \lambda_{ih}}{r_{ih}(\lambda_{ih}, \lambda_{if})}$$

Suppose

$$r_{ih}\big(\lambda_{ih}, \lambda_{if}\big) = \lambda_{if} \hat{r}_{ih}\big(\lambda_{ih}/\lambda_{if}, 1\big) = \lambda_{if} \psi_{ih}(\lambda_{ih}/\lambda_{if})$$

If $\psi_{ih}(\lambda_{ih}/\lambda_{if})$ is the constant, it implies that the research efficiency solely depends on the technology frontier of the foreign country. If is proportional to $\lambda_{ih}/\lambda_{if}$, the research efficiency depends only on the technology frontier of the home country. If it takes other forms, the research efficiency function will be more complicated.

Let $\rho_{ih} = \lambda_{ih}/\lambda_{if}$ denote the home country's advantage in sector i. Then we have:

$$d_{ih} = \frac{a_i \theta\big(1 + \theta(1 - \eta)\big)}{1 + \theta} \big(L'_h + L_f / \omega'_h\big) - \frac{\varphi'_h + \rho_{ih}}{\psi_{ih}(\rho_{ih})}$$

The relationship between the R&D input and the advantage of a sector is determined by the functional form of $\psi_{ih}(\rho_{ih})$. When $\psi_{ih}(\rho_{ih})$ is constant, R&D input decreases with advantage. This is because the R&D efficiency remains constant while the returns to new ideas are lower when the home country technology frontier is higher. When $\psi_{ih}(\rho_{ih})$ is proportional, R&D input increases with advantage. This is because the research efficiency of the home country increases with its advantage. When $\psi_{ih}(\rho_{ih})$ takes other forms, there might not be a monotonic relation between R&D input and advantage. The following section will study how R&D input varies with advantage in the real world.

4.5. Empirical Analysis

4.5.1. The Econometric Model

The previous section solved the labor input for R&D in sector i. If we convert it into monetary value it is:

$$RD_{ih} = \frac{a_i\theta\big(1+\theta(1-\eta)\big)}{1+\theta}\big(L'_h + L_f/\omega'_h\big)w'_h - \frac{\varphi'_h + \rho_{ih}}{\psi_{ih}(\rho_{ih})}w'_h$$

where RD_{ih} denotes the R&D input in sector i for country h. For each country, we aggregate all other countries and take them as the foreign country.

According to the theoretical model, the R&D input in each sector of a country should be positively correlated with its advantage in this sector (ADV_{hit}), which is defined as the technology frontier of the sector in the home country divided by that of the rest of the world. In the expression for RD_{ih}, $a_i\big(L'_h + L_f/\omega'_h\big)w'_h$ is the world total expenditure spent on the sector after the innovation. In this paper, I assume that the expenditure is equal to the output. The output of a sector can be broken down into the output of the home country and that of the foreign country. According to the theoretical model, they are equally effective on R&D. In the real world, however, the magnitude of their effects may differ due to the presence of trade barriers. Therefore we will include the output of the sector i in year t ($PROD_{hit}$) and that of the rest of the world ($ROWPROD_{hit}$). The econometric model takes the following form:

$$RD_{hit} = \beta_0 + \beta_1 ADV_{hit} + \beta_2 PROD_{hit} + \beta_3 ROWPROD_{hit} + FE_h + FE_i + FE_t + \epsilon_{hit}$$

where h is the country identifier, i is the industry identifier and t denotes the time period. FE_h, FE_i and FE_t are the country, industry and time period fixed effects. ϵ_{hit} is the disturbance.

I will also study the effect of advantage on the research intensity (RDP_{hit}) for each industry. The research intensity is defined as $RDP_{hit}/PROD_{hit}$. The econometric model takes the following form:

$$RDP_{hit} = \beta_0 + \beta_1 ADV_{hit} + FE_h + FE_i + FE_t + \epsilon_{hit}$$

4.5.2. Data and Measurements

I use a set of STAN (**ST**ructural **AN**alysis) databases published by OECD for this inquiry. These datasets fit our purpose for several reasons. First of all, it is one of the few databases that provide the needed information on the industry level with a relatively large number of observations. The STAN databases have been used by some recent papers to conduct other industry level analysis (e.g., Griffith et al., 2001; Zachariadis, 2004; Constinot and Komunjer, 2007; Ulku, 2007). Second, the countries included in the sample account for a large share of the world economic activities. Overall, these countries account for 68.7% of the world GDP (IMF 2007). When it comes to manufacturing, the sectors that I focus on in this work, these countries have an even higher share. Moreover, these countries account for most of the world R&D investments. Third, the trade between these countries is relatively free, which is an assumption of our theoretical model. For example, the Simple average final bound tariff of the United States is 3.5% in 2006, while that of China is 10% and Brazil 31.4% in the same year (WTO 2006[17]). Thus the OECD countries form a good sample for the estimation.

This essay uses the latest version of two STAN datasets, which are STAN ANBERD (Analytical Business Enterprise Research and Development, ed. 2009) and STAN Industry Analysis (ed. 2008). ANBERD database (ed. 2009) reports data on R&D expenditure spent by the business enterprise sector by industry according to the International Standard Industrial Classification (ISIC) revision 3.1. The dataset covers 29 OECD countries and some non-member economies for years 1987 through 2007. STAN Industry Analysis (ed. 2008) reports annual measures of output, value added, labor input, exports, etc. by industry according to 3.0 across countries. Data are available for 27 countries for years 1970 through 2007.

[17] WTO, 2006, World Tariff Profiles 2006. http://www.wto.org

Years 1987-2006 are defined as the sample period since data for 2007 are not available for many countries. In this paper we focus on the manufacturing sector since there is a large quantity of missing data for other sectors. The analysis is conducted mainly at the two-digit level (ISIC 15 - ISIC 37). Due to confidentiality or other reasons, some countries only report aggregated measures for industry groups for some industries. For example, some countries may report the measures for "Food products, beverages and tobacco" (ISIC code 15-16). However, they do not report neither the measures for "Food products, beverages" (ISIC code 15), nor the measures of "Tobacco" (ISIC code 16). To fully utilize the information contained in the datasets, I include those industry groups when no information of any sub-industry is available[18].

The productivity of sector i in country h in year t ($HPRODTY_{hit}$) is defined as the output ($PROD_{hit}$) divided by the "Total Employment Persons" ($EMPN_{hit}$). According to the EK model, if the technology frontier of an industry is λ_{ih}, the productivity associated with each variety (z) is a random draw from the Fréchet distribution $F_{ih}(z) = e^{-\lambda_{ih} z^{-1/\theta}}$. The expected productivity is $\lambda_{ih}^{\theta}\Gamma(1-\theta)$ where $\Gamma(1-\theta)$ is the Gamma function evaluated at $1-\theta$. Therefore the technology frontier of the sector is:

$$\lambda_{ih} = \left(\frac{E(z)}{\Gamma(1-\theta)}\right)^{1/\theta}$$

[18] The industry groups include (by ISIC code): 15-16, 17-19, 21-22, 23-25.

The average productivity of each industry is an estimate of the expected productivity, so the technology frontier of sector i for country h ($HLambda_{hit}$) can be measured as:

$$HLambda_{hit} = \hat{\lambda}_{hit} = \left(\frac{HPRODTY_{hit}}{\Gamma(1-\theta)}\right)^{1/\theta}$$

Following Alvarez and Lucas (2007), I use values of θ in the range [0.1, 0.25] with 0.15 being the preferred value. To check the robustness, I also set θ to 1, which means that the technology frontier of a sector ($HLambda_{hit}$) is simply measured by the average productivity of the sector ($HPRODTY_{hit}$).

According to the EK model, the technology frontiers of different countries are additive. That is, the combined technology frontier of a group of countries is the sum of their technology frontier weighted by wage and trade barriers. In this essay the world is divided into the home country and the rest of the world, so the technology frontier of the rest of the world ($ROWLambda_{hit}$) should be measured as the sum of the weighted technology frontier for all other countries. However, I only have the information for the OECD countries and it is not easy to get complete information on wages and pair-wise trade barriers. As an alternative, the technology frontier is measured as the sum of the (un-weighted) technology frontier of all other OECD countries. This does not follow the theoretical setup closely, but it is still a good measure. First, the OECD countries include majority of the most productive countries. The technology frontier calculated from them should be a good measure of the world technology frontier. Second, OECD countries bear substantial resemblance and their mutual tariffs are low and close, so the variation of the weight on their technology frontier should not be large.

All the monetary values are in 2006 PPP million dollars. All the head counts are in persons. The PPP exchange rate is from STAN. The discount rate is from the BLS.

4.5.3. Empirical Results

This section reports the empirical results. Preliminary regressions show that the R&D input decreases with the advantage for technology leaders of an industry (top 20%-30%), increases for the middle class countries (middle 40%-60%) and decreases for the bottom class (bottom 20%-30%). Then I check the robustness of the results.

4.5.3.1. Preliminary Results

This section reports the OLS results. The countries are first divided into three groups based on their rank on the technology frontier for each industry. The three groups are: the top 20%, the middle 60% and bottom 20%. To calculate the world production, we need the output of each country. Since there is a large quantity of missing data on production for years before 1995 and after 2005, I narrow the sample period to 1995 to 2005. The results are reported in the first three columns of Table 4-1, with all results concerning dummies suppressed. The results show that the R&D input decreases for the top and bottom groups, but increases for the middle groups.

Table 4-1: R&D Input and Advantage (OLS, PROD as Output)

	Bottom (20%)	Middle (60%)	Top (20%)	Bottom (20%)	Middle (60%)	Top (20%)
ADV	-7600	5200	-0.001			
	-0.469	2.245 **	-0.007			
ADVn				-260	680	-940
				-2.144 **	2.110 **	-2.209 **
PROD	0.022	0.020	0.023	0.022	0.020	0.023
	23.229 ***	19.568 ***	9.093 ***	23.389 ***	19.798 ***	8.997 ***
ROWPROD	-1.7E-04	-0.001	0.002	0.000	-0.001	0.001
	-3.076 ***	-3.105 ***	1.001	-3.098 ***	-3.095 ***	0.772
N	1135	2891	804	1135	2891	804
R^2	0.555	0.454	0.694	0.556	0.454	0.696

	Bottom (20%)	Middle (60%)	Top (20%)
adv	-6.3	24	-180
	-3.742 ***	1.599	-2.848 ***
PROD	0.022	0.021	0.023
	23.657 ***	20.037 ***	9.211 ***
ROWPROD	0.000	-0.001	0.002
	-3.273 ***	-3.138 ***	0.893
N	1135	2891	804
R^2	0.560	0.453	0.697

Note:

- The t-ratios are reported below the corresponding coefficients.
- *: significant at 10% level; **: significant at 5% level ; ***: significant at 1% level.

A potential problem for the regression is that the relation between R&D and advantage is not linear as we can see from the analytical form of RD. If we look at the magnitudes of ADV, it ranges $1.4 * 10^{-16}$ to 16706. This is because the productivity is raised to nearly the 6th power to calculate the technology frontier. The ADV for technology followers clusters between 0 and 1 while that of leaders spread over a wide range above 1. This means that the above results for ADV may be caused by misspecification. The following graph is the histogram of ADV.

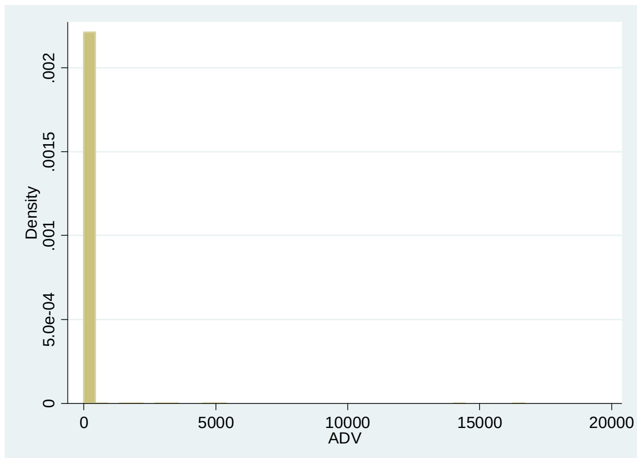

Figure 4-1: The Distribution of ADV

To address this problem, I defined the following measures for advantage:

$$ADVn_{hit} = (ADV_{hit})^{\theta}$$
$$adv_{hit} = log(ADV_{hit})$$

$ADVn$ ranges between 0.004 and 4.3; adv ranges between -36.5 and 9.7. The following histograms show that the measures are more evenly spread over the support.

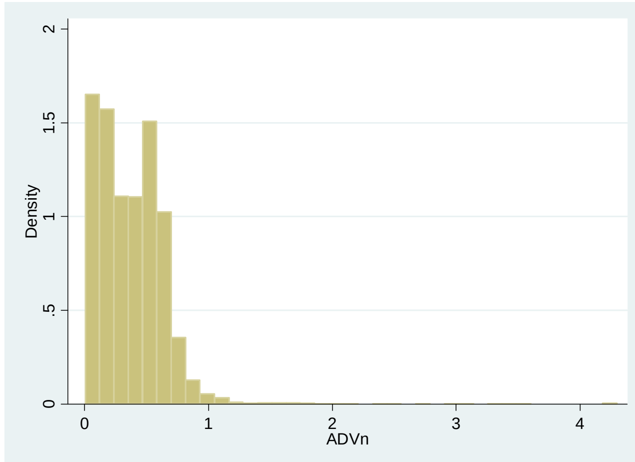

Figure 4-2: The Distribution of ADVn

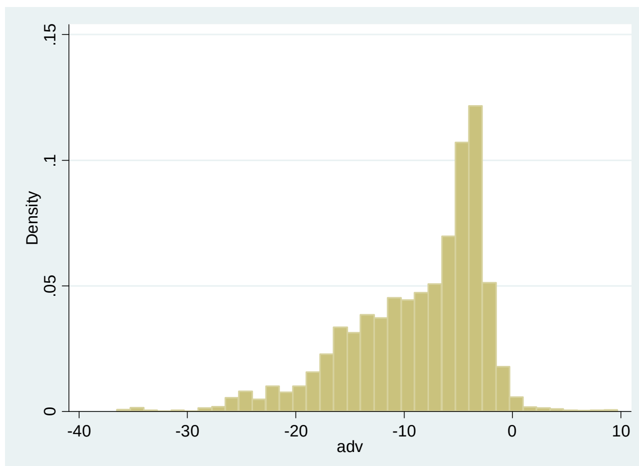

Figure 4-3: The Distribution of adv

I run the regressions with the new measures of advantage and the results are reported in the last six columns of Table 4-1. The regressions confirm the above results that the R&D input decreases for the top and bottom groups, but increases for the middle groups.

I use value added as the output of each industry and run all the above regressions again. The results are reported in Table 4-2. We can see that the results are consistent with what those in the previous table.

Table 4-2: R&D Input and Advantage (OLS, VALU as Output)

	Bottom (20%)	Middle (60%)	Top (20%)	Bottom (20%)	Middle (60%)	Top (20%)
ADV	-300000	5600	-0.1955			
	-1.743 *	2.606 ***	-1.417			
ADVn				-450	780	-1800
				-3.454 ***	2.615 ***	-4.921 ***
VALU	0.086	0.047	0.076	0.088	0.047	0.076
	19.308 ***	15.478 ***	9.154 ***	19.633 ***	15.611 ***	9.255 ***
ROWVALU	-0.0005	-0.0035	0.0004	-0.0005	-0.0035	0.0002
	-2.350 **	-2.617 ***	0.064	-2.442 **	-2.662 ***	0.026
N	1136	3197	887	1136	3197	887
R^2	0.504	0.422	0.686	0.508	0.422	0.694

	Bottom (20%)	Middle (60%)	Top (20%)
adv	-7.6	26	-280
	-4.297 ***	1.881 *	-5.220 ***
VALU	0.087	0.048	0.077
	19.813 ***	15.891 ***	9.449 ***
ROWVALU	-0.0006	-0.0036	0.0012
	-2.614 ***	-2.698 ***	0.18
N	1136	3197	887
R^2	0.511	0.421	0.695

Note:

- The t-ratios are reported below the corresponding coefficients.
- *: significant at 10% level; **: significant at 5% level ; ***: significant at 1% level.

I also check if the results are robust to the value of θ. Previous literature (Eaton and Kortum 2002, Alvarez and Lucas 2007) shows that a reasonable range for θ is [0.1, 0.25]. I find that the results are consistent to those when θ is 0.15. Finally, I set θ to 1, which means that the average productivity is used as the technology frontier of an industry.

Table 4-3: R&D Input and Advantage (OLS, θ=1)

	PROD as output			VALU as output		
	Bottom (20%)	Middle (60%)	Top (20%)	Bottom (20%)	Middle (60%)	Top (20%)
ADV	-6000	10000	-6900	-8000	11000	-17000
	-4.421 ***	2.893 ***	-1.53	-5.463 ***	3.391 ***	-4.340 ***
PROD	0.022	0.020	0.023	0.091	0.047	0.076
	23.884 ***	19.877 ***	9.079 ***	20.253 ***	15.696 ***	9.244 ***
ROWPROD	-0.0002	-0.001	0.002	-5.6E-04	-0.00358	-4.8E-05
	-3.173 ***	-3.139 ***	0.887	-2.580 **	-2.699 ***	-0.007
N	1135	2891	804	1136	3197	887
R^2	0.562	0.455	0.695	0.516	0.423	0.692

Note:

- The t-ratios are reported below the corresponding coefficients.
- *: significant at 10% level; **: significant at 5% level ; ***: significant at 1% level.

The above results may be sensitive to how we categorize countries leaders and followers. As an alternative, I divide them into the top 30%, the middle 40% and bottom 30%. The results are reported in table 4-4 for $\theta = 0.15$ and $\theta = 1$. They confirm the patterns that I get from other regressions.

I also try other ways to partition the countries. It turns out that the pattern preserves as long as the percentage of the top group and the bottom group is around 20%.

Table 4-4: R&D Input and Advantage (OLS, Alternative Categorization)

Panel a: $\theta = 0.15$

	PROD as output			VALU as output		
	Bottom (30%)	Middle (40%)	Top (30%)	Bottom (30%)	Middle (40%)	Top (30%)
ADV	-49000	27000	-0.11	-86000	1000	-0.28
	-1.750 *	0.793	-0.899	-3.213 ***	0.327	-2.359 **
PROD	0.025	0.019	0.022	0.112	0.047	0.069
	30.261 ***	15.091 ***	10.999 ***	32.214 ***	13.428 ***	10.684 ***
ROWPROD	-2.5E-04	-0.001	0.001	-8.2E-04	-0.005	0.000
	-2.519 **	-3.414 ***	0.888	-2.267 **	-3.191 ***	0.096
N	1538	2093	1199	1562	2358	1300
R^2	0.783	0.437	0.642	0.791	0.418	0.640

Panel b: $\theta = 1$

	PROD as output			VALU as output		
	Bottom (30%)	Middle (40%)	Top (30%)	Bottom (30%)	Middle (40%)	Top (30%)
ADV	-320	13000	-8900	-4000	12000	-16000
	-0.177	2.438 **	-2.562 **	-2.270 **	2.634 ***	-5.295 ***
PROD	0.025	0.019	0.022	0.112	0.047	0.070
	29.626 ***	15.248 ***	11.106 ***	31.561 ***	13.515 ***	10.903 ***
ROWPROD	-2.5E-04	-0.001	0.001	-7.6E-04	-0.005	0.000
	-2.491 **	-3.356 ***	0.859	-2.117 **	-3.146 ***	0.043
N	1538	2093	1199	1562	2358	1300
R^2	0.783	0.438	0.644	0.791	0.420	0.647

Note:

- The t-ratios are reported below the corresponding coefficients.
- *: significant at 10% level; **: significant at 5% level ; ***: significant at 1% level.

4.5.3.2. Heteroskedasticity

Since the data consists of different countries and industries, heterogeneity is a concern. This section checks if the results of the previous section are robust to heterogeneity. The results are consistent with those of the OLS regressions except a few changes.

Table 4-5: R&D Input and Advantage (Heteroskedasticity corrected, PROD as Output)

	Bottom (20%)	Middle (60%)	Top (20%)	Bottom (20%)	Middle (60%)	Top (20%)
ADV	dropped	1400	-0.23			
		13.844 ***	-2.619 ***			
ADVn				-54	120	-700
				-10.631 ***	39.196 ***	-8.527 ***
PROD	0.0070	0.0152	0.0224	0.0072	0.0158	0.0229
	18.805 ***	59.749 ***	33.996 ***	19.011 ***	65.925 ***	32.703 ***
ROWPROD	0.0E+00	-8.2E-05	-6.1E-04	4.0E-06	-1.0E-04	-7.8E-04
	0.033	-27.533 ***	-12.960 ***	3.525 ***	-50.620 ***	-15.367 ***
N	1135	2891	804	1135	2891	804

	Bottom (20%)	Middle (60%)	Top (20%)
adv	-0.47	6	9.5
	-5.506 ***	25.386 ***	0.772
PROD	0.0071	0.0156	0.0232
	18.733 ***	62.624 ***	32.735 ***
ROWPROD	4.0E-06	-8.5E-05	-7.6E-04
	2.589 ***	-22.038 ***	-15.522 ***
N	1135	2891	804

Note:

- The t-ratios are reported below the corresponding coefficients.

- *: significant at 10% level; **: significant at 5% level ; ***: significant at 1% level.

The following table presents the results when value added (VALU) is used as the output.

Table 4-6: R&D Input and Advantage (Heteroskedasticity corrected, VALU as Output)

	Bottom (20%)	Middle (60%)	Top (20%)	Bottom (20%)	Middle (60%)	Top (20%)
ADV	dropped	13000 15.001 ***	-0.41 -3.889 ***			
ADVn				-120 -23.602 ***	59 7.717 ***	-710 -9.090 ***
VALU	0.0303 25.579 ***	0.0452 64.390 ***	0.0597 27.624 ***	0.0399 39.940 ***	0.0454 64.224 ***	0.0613 26.664 ***
ROWVALU	3.0E-05 9.703 ***	-1.9E-04 -39.333 ***	-1.4E-03 -11.642 ***	3.5E-05 14.720 ***	-8.6E-05 -12.692 ***	-1.8E-03 -22.293 ***
N	1136	3197	887	1136	3197	887

	Bottom (20%)	Middle (60%)	Top (20%)
adv	-1.2 -17.479 ***	3.7 12.750 ***	-22 -2.648 ***
VALU	0.0379 35.225 ***	0.0466 67.220 ***	0.0630 28.111 ***
ROWVALU	5.4E-05 23.507 ***	-7.5E-05 -10.806 ***	-1.6E-03 -15.467 ***
N	1136	3197	887

Note:

- The t-ratios are reported below the corresponding coefficients.
- *: significant at 10% level; **: significant at 5% level ; ***: significant at 1% level.

The following table reports the results when $\theta = 1$.

Table 4-7: R&D Input and Advantage (Heteroskedasticity corrected, PROD as Output, θ=1)

	PROD as output			VALU as output		
	Bottom (20%)	Middle (60%)	Top (20%)	Bottom (20%)	Middle (60%)	Top (20%)
ADV	-930	3900	-3200	-1000	2500	-5000
	-7.085 ***	30.650 ***	-3.728 ***	-10.740 ***	24.329 ***	-5.405 ***
PROD	0.0074	0.0152	0.0206			
	19.216 ***	56.473 ***	32.553 ***			
ROWPROD	2.0E-06	-5.7E-05	-7.9E-04			
	1.928 *	-10.589 ***	-16.299 ***			
VALU				0.0328	0.0438	0.0608
				27.502 ***	62.590 ***	25.814 ***
ROWVALU				1.4E-05	-6.7E-05	-1.3E-03
				4.694 ***	-8.077 ***	-9.851 ***
N	1135	2891	804	1136	3197	887

Note:

- The t-ratios are reported below the corresponding coefficients.
- *: significant at 10% level; **: significant at 5% level ; ***: significant at 1% level.

I also try other values for θ. The results tend to robust to the choice of θ.

4.5.3.3. Endogeneity

There might be concerns over the endogeneity of advantage, although our theoretical model indicates that it is exogenous at period t. In the real world research projects last a long time and endogeneity may arise due to autocorrelation. This section will address this problem with instrumental-variable regressions.

I use a country's percentage share in the world production (PRODShare) as the instrument for the home country's advantage in a sector (ADV) for the same time period. Other candidates for instrument are the export-import ratio (XM) and the lag of advantage (ADV_{hit-1}). However, none of them, or any combination of them with $PRODShare$ can pass the Hausman test for any regression. The results are reported in the following table.

Table 4-8: R&D Input and Advantage (IV)

	PROD as output			VALU as output		
	Bottom (20%)	Middle (60%)	Top (20%)	Bottom (20%)	Middle (60%)	Top (20%)
ADV	-4.3E+13	30000	-2	8.4E+12	78000	-2
	-0.965	2.232 **	-2.215 **	0.684	1.924 *	-1.54
PROD	0.064	0.003	0.021			
	1.358	1.117	4.734 ***			
ROWPROD	1.3E-04	-3.6E-04	-0.002			
	0.748	-3.764 ***	-1.164			
VALU				-0.004	-0.044	0.055
				-0.045	-1.39	2.797 ***
ROWVALU				-9.5E-05	-0.002	-0.009
				0.52	-3.049 ***	-1.556
N	1135	2891	804	1135	2890	804
p-value of Hausman test	0.335	0.026	0.026	0.494	0.054	0.129

Note:

- The t-ratios are reported below the corresponding coefficients.
- *: significant at 10% level; **: significant at 5% level ; ***: significant at 1% level.

The first three columns are the results when PROD is used as output. It confirms the pattern yielded by OLS. I use VALU as output and rerun the regressions and the results are reported in the last three columns. Though the sign of ADV is different from what we got, those of the top group and negative for the middle group remain consistent with previous results. To check if the results are robust to the value of θ, I run the regressions give different values between 0.1 and 0.25. We can see that the results are very similar to those in Table 4-8.

I then use the average productivity as the technology frontier to estimate the effects of ADV. The results are as follows. The results give even stronger support to the OLS results. I find that when θ increases the correlation between ADV and $PRODShare$ increases. Therefore, the difference between the results in tables 4-7 and 4-8 may be because $PRODShare$ becomes a better instrument when θ increases. This is consistent with the results of Hausman tests.

Table 4-9: R&D Input and Advantage (IV, θ=1)

	PROD as output			VALU as output		
	Bottom (20%)	Middle (60%)	Top (20%)	Bottom (20%)	Middle (60%)	Top (20%)
ADV	-26000	40000	-45000	-23000	110000	-46000
	-3.712 ***	2.940 ***	-2.871 ***	-1.385	2.790 ***	-2.043 **
PROD	0.025	0.006	0.023			
	7.473 ***	4.292 ***	6.405 ***			
ROWPROD	-1.5E-04	-3.2E-04	-2.5E-04			
	-3.971 ***	-3.711 ***	-0.275			
VALU				0.102	-0.025	0.053
				2.992 ***	-1.496	3.662 ***
ROWVALU				-3.9E-04	-1.0E-03	-7.3E-03
				-1.556	-2.039 **	-1.875 *
N	1135	2891	804	1135	2890	804

p-value of Hausman test	0.0063	0.0004	0.0158	0.321	0.003	0.0805

Note:

- The t-ratios are reported below the corresponding coefficients.
- *: significant at 10% level; **: significant at 5% level ; ***: significant at 1% level.

I use different approaches to categorize country to see if the above results are robust. The following is the results when countries are broke down into the top 30%, the middle 40% and bottom 30%.

Table 4-10: R&D Input and Advantage (IV, Alternative Categorization)

	PROD as output			VALU as output		
	Bottom (30%)	Middle (40%)	Top (30%)	Bottom (30%)	Middle (40%)	Top (30%)
ADV	-410000	53000	-2.1	24000	130000	-2
	-3.086 ***	1.57	-2.806 ***	0.176	1.042	-1.833 *
PROD	0.0131	0.0001	0.0167			
	14.322 ***	0.024	5.144 ***			
ROWPROD	-1.1E-04	-4.4E-04	-1.4E-03			
	-3.518 ***	-3.511 ***	-1.381			
VALU				0.0381	-0.0602	0.043
				10.1 ***	-0.806	3.106 ***
ROWVALU				-0.0002	-0.002	-0.0062
				-2.256 **	-2.275 **	-1.710 *
N	1538	2093	1199	1537	2093	1199
p-value of Hausman test	0.002	0.1164	0.0049	0.8603	0.2972	0.0704

Note:

- The t-ratios are reported below the corresponding coefficients.

- *: significant at 10% level; **: significant at 5% level ; ***: significant at 1% level.

4.5.3.4. Research Intensity

This section studies the effect of advantage on the research intensity to see if we can get further support for the results we get from OLS estimation. Since the econometric model for research intensity does not include world output, we do not need to worry about the missing data problem. The regressions in this section are based on the sample period 1987-2006. I use the method employed in the first regression to categorize countries (top 20%, middle 60%, bottom 20%). The results are reported in Table 4-11.

Table 4-11: R&D Intensity and Advantage (OLS, θ=0.15)

	Bottom (20%)	Middle (60%)	Top (20%)	Bottom (20%)	Middle (60%)	Top (20%)
ADV	-160.000	0.028	0.000			
	-2.283 **	0.502	0.483			
ADVn				-0.231	0.005	-0.001
				-4.565 ***	0.647	-0.605
adv						
N	1135	2891	804	1135	2891	804
R^2	0.1623	0.4178	0.7286	0.1741	0.4178	0.7286

	Bottom (20%)	Middle (60%)	Top (20%)
adv	-0.0025	0.0002	-0.0004
	-3.518 ***	0.663	-1.177
N	1135	2891	804
R^2	0.1677	0.4178	0.7290

Note:

- The t-ratios are reported below the corresponding coefficients.
- *: significant at 10% level; **: significant at 5% level ; ***: significant at 1% level.

The above results show that the research intensity for the middle groups increases with advantage and decreases for the other two groups, even though the coefficient estimates are not statistically significant.

The following table reports the results when $\theta = 1$.

Table 4-12: R&D Intensity and Advantage (OLS and IV, θ=1)

	OLS			IV		
	Bottom (20%)	Middle (60%)	Top (20%)	Bottom (20%)	Middle (60%)	Top (20%)
ADV	-3.000	0.048	-0.003	-1.3	0.0421	-0.2955
	-5.220 ***	0.565	-0.131	-0.845	0.102	-3.304 ***
N	1135	2891	804	1135	2891	804
R^2	0.1788	0.4178	0.7285			

Note:

- The t-ratios are reported below the corresponding coefficients.
- *: significant at 10% level; **: significant at 5% level ; ***: significant at 1% level.

As the following table shows, the results are robust to heteroskedasticity:

Table 4-13: R&D Intensity and Advantage (Heteroskedasticity corrected, $\boldsymbol{\theta = 0.15}$)

	Bottom (20%)	Middle (60%)	Top (20%)
ADV	-2.4	0.11418	-2E-06
	-3.334 ***	9.609 ***	-2.984 ***
N	1135	2891	804

Note:

- The t-ratios are reported below the corresponding coefficients.
- *: significant at 10% level; **: significant at 5% level ; ***: significant at 1% level.

The above results provide some further support to the pattern we find with OLS.

4.6. Conclusion

Hicks (1953) argued that countries would first improve their technology of the export sector and then that of the import sector. Interesting as it is, there has not been theoretical or empirical study on his argument. This essay extends the Eaton and Kortum (2002) framework into a multi-sector model to analyze the innovation pattern of countries in the open economy. The model shows that in the open economy the R&D input in an industry depends on the country's advantage in the industry. Using the OECD STAN database, the empirical analysis finds some support for Hicks' path but it also indicates that the R&D pattern in the real world might be richer than what Hicks predicted.

4.7. Appendices

4.7.1. Appendix 4.A: The Equilibrium without Technological Improvements

This section solves the equilibrium of the world economy when all firms in a country have access to the best technology within the country. Suppose the technology frontier of sector i in the home country is λ_{ih} and that in the foreign country is λ_{if}. Following Alvarez and Lucas' (2007), the Fréchet distribution of z into the exponential distribution of x with $z = x^{-\theta}$:

$$F_{ih}(x) = 1 - e^{-\lambda_{ih}x}, E(x) = 1/\lambda_{ih}$$

- **Price Indices of the Final Goods**

Consider sector *i*, let $x_i = (x_{ih}, x_{if})$ denote the draws productivity for intermediate goods in two countries. Assume that these draws are independent across countries, so the joint density of *x* is:

$$\phi_i(x_i) = \phi_{ih}(x_i)\phi_{if}(x_i) = \lambda_{ih}\lambda_{if} \exp(-\lambda_{ih}x_{ih} - \lambda_{if}x_{if})$$

Let u follow the above distribution, then the quantity of the final good is:

$$Q_i = \left(\int_{R_+^2} \phi(x) q_i(x)^{1-1/\eta} dx \right)^{\eta/(\eta-1)}$$

I put all the intermediate goods with productivity x_i into to the same group. Following Alvarez and Lucas, the group of goods is labeled with the associated productivity and are called “good x”.

Let us use the home country as an example. In the home country, the price of final goods in each sector is:

$$P_{ih} = \left(\int_{R_+^2} p_{ih}^{1-\eta}(x)\, \phi(x) dx\right)^{1/(1-\eta)}$$

The demand function of intermediate good *x* in the home country is:

$$q_{ih}(x) = p_{ih}^{-\eta}(x) P_i^{\eta} Q_{ih}$$

If the home country producers of the final goods buy intermediate goods from domestic firms, the price is $w_h x_{ih}^{\theta}$; if they buy from foreign firms, the price is $tw_f x_{if}^{\theta}$. The buyers will choose the lowest price among $w_h x_{ih}^{\theta}$ and $w_f x_{if}^{\theta}$. The price that prevail in the home country is:

$$p_{ih}(x) = \min\{w_h x_{ih}^{\theta}, w_f x_{if}^{\theta}\} =>$$

$$p_{ih}^{1/\theta} = \min\left\{w_h^{1/\theta} x_{ih}, w_f^{1/\theta} x_{if}\right\}$$

where $x_{ih}(u) \sim \exp(\lambda_{ih})$, $x_{if}(u) \sim \exp(\lambda_{if})$,. A nice property of the exponential distribution is that(Alvarez and Lucas, 2007):

$$x \sim \exp(\lambda) \; and \; \kappa > 0 \Rightarrow \kappa x \sim \exp(\lambda/\kappa)$$

Consequently we have:

$$w_h^{1/\theta} x_{ih} \sim \exp\left(\lambda_{ih}/w_h^{1/\theta}\right)$$

Another property of the exponential distribution is that(Alvarez and Lucas, 2007):

$$x \sim \exp(\lambda_1), y \sim \exp(\lambda_2), cov(x,y) = 0, \xi = \min(x,y) \Rightarrow \xi \sim (\lambda_1 + \lambda_2)$$

Therefore $p_{ih}^{1/\theta}(x)$ has the following distribution:

$$p_{ih}^{1/\theta}(x) \sim \exp\left(\left(\lambda_{ih} + \lambda_{if} w_h^{1/\theta}/w_f^{1/\theta}\right)/w_h^{1/\theta}\right)$$

Let $\chi_{ih} = \lambda_{ih} + \lambda_{if} w_h^{1/\theta}/w_f^{1/\theta}$, then we have:

$$p_{ik}^{1/\theta}(x) \sim \exp\left(\chi_{ik}/w_k^{1/\theta}\right)$$

We can call χ_{ih} the "**consumer-perceived**" sector i technology level in the home country. For ease in writing, I define $\omega_h = w_h/w_f$, $\varphi_h = w_h^{1/\theta}/w_f^{1/\theta}$. Through out this paper, the wage rate in the foreign country is defined as the numéraire. Then we have:

$$\chi_{ih} = \lambda_{ih} + \lambda_{if}\varphi_h$$

Consider $\int_{R_+^2} p_{ih}(x)^{1-\eta}\, \phi(x)dx$. Since $\phi(x)$ is the probability distribution function of *x*, so the integral can be taken as the expectation of $p_{ih}^{1-\eta}(x)$ in the technology spaceR_+^2. $p_{ih}^{1-\eta}(x)$ with $x \sim \phi(x)$ in R_+^2 corresponds to $p_{ih}^{1-\eta}(x) =$

$p_{ih}^{(1/\theta)\theta(1-\eta)} = v^{\theta(1-\eta)}$ with $v \sim \exp\left(\chi_{ih}/w_h^{1/\theta}\right)$ in R_+^1. Here v is the projection of $p_{ih}^{1/\theta}$ on R_+^1. Therefore, the expectation of $p_{ih}^{1-\eta}(x)$ in the technology space is equivalent to the expectation of $v^{\theta(1-\eta)}$ in R_+^1. This implies that

$$P_{ih} = \left(\int_0^\infty v^{\theta(1-\eta)} \chi_{ih}/w_h^{1/\theta} e^{-v\chi_{ih}/w_h^{1/\theta}} dv\right)^{1/(1-\eta)}$$

Let $\sigma = v\chi_{ih}/w_h^{1/\theta}$, we have that:

$$P_{ih} = \left(\chi_{ih}/w_h^{1/\theta}\right)^{-\theta} \left(\int_0^\infty \sigma^{\theta(1-\eta)} e^{-\sigma} d\sigma\right)^{1/(1-\eta)}$$

Let $A = \left(\int_0^\infty \sigma^{\theta(1-\eta)} e^{-\sigma} d\sigma\right)^{1/(1-\eta)}$, which is value of the Gamma function $\Gamma(\gamma)$ at $\gamma = 1 + \theta(1-\eta)$ raised to $1/(1-\eta)$ power. Following Alvarez and Lucas (2007), we assume $1 + \theta(1-\eta) > 0$ so as to guarantee the integral converges. Henceforth, we will take A as a constant. So we have:

$$P_{ih} = A(\chi_{ih})^{-\theta} w_h$$

Likewise, the price of good i in the foreign country is:

$$P_{if} = A\chi_{if}^{-\theta} w_f$$

- **Imports and Exports**

The value of the final goods i consumed in the home country is equal to $P_{ih}Q_{ih}$. Since the market of the final goods is perfectly competitive, $P_{ih}Q_{ih}$ equals the value of the intermediate goods (transportation costs inclusive) used as input. Let m_{ih} denote the share of the sector i intermediate goods that the home country imports from the foreign country. Then the imports of the home country in sector i are:

$$M_{ih} = m_{ih} P_{ih} Q_{ih}$$

In a previous paper, we show that

$$m_{ih} = \frac{\lambda_{if}\varphi_h}{\chi_{ih}}$$

where $\lambda_{if}\varphi_h/T$ is the foreign country's technology level perceived by the home country consumers. The higher is it, the greater m_{ih} is.

Given the Cobb-Douglas utility function, we have:

$$M_{ih} = \frac{a_i \lambda_{if} \varphi_h^{\theta+1} L_h w_f}{\lambda_{ih} + \lambda_{if}\varphi_h}$$

Therefore, the import of the home country is:

$$M_h = \left(\frac{a_1 \lambda_{1f}}{\lambda_{1h} + \lambda_{1f}\varphi_h} + \frac{a_2 \lambda_{2f}}{\lambda_{2h} + \lambda_{2f}\varphi_h}\right) \varphi_h^{\theta+1} L_h w_f$$

Since $\theta > 0$, $M_h$is increasing in φ_h(a monotonic transformation of the relative wage rate), keeping everything else constant.

The sector i export of the home country (X_{ih}) equal the sector i exports of foreign country(M_{if}), so the total exports of the home country are:

$$X_h = \left(\frac{a_1 \lambda_{1h}}{\lambda_{1f}\varphi_h + \lambda_{1h}} + \frac{a_2 \lambda_{2h}}{\lambda_{2f}\varphi_h + \lambda_{2h}}\right) L_f w_f$$

The above equation shows that the exports of the home country decrease with the relative wage rate.

- **Equilibrium**

For notational clarity, let $\rho_{1h} = \lambda_{1h}/\lambda_{1f}, \rho_{2h} = \lambda_{2h}/\lambda_{2f}$ denote the absolute advantage of the home country in two sectors. Plugging them into the trade balance condition $X_h = M_h$ yields:

$$L_f\left(\frac{a_1\rho_{1h}}{\varphi_h+\rho_{1h}}+\frac{a_2\rho_{2h}}{T\varphi_h+\rho_{2h}}\right)=\left(\frac{a_1}{\rho_{1h}+\varphi_h}+\frac{a_2}{\rho_{2h}+\varphi_h}\right)L_h\varphi_h^{\theta+1}$$

4.7.2. Appendix 4.B: The Expected Value of an Idea in Autarky

Suppose the current technological frontier of sector i in the home country is λ_{ih}. The population is L'_h. The expectation of $\pi_{ihh}(z,u)$ is:

$$E\big(\pi_{ihh}(z,u)\big)=\int_{R_+^2}\int_{z\in ch}\pi_{ihh}(z,u)g(z)\phi(x)dzdx$$
$$=A^{\eta-1}{\chi'_{ih}}^{\theta(1-\eta)}a_iL'_h{w'_h}^{\eta}\int_0^\infty\int_{w'_h/p'_{ih}}^\infty(p'_{ih}(u)$$
$$-w'_h/z)g(z)dz{p'_{ih}}^{-\eta}f_{pih}(p_{ih})dp_{ih}$$

where ch denotes the set of z in which the new idea is **c**ompetitive . For ease in writing, we use p to denote p'_{ih} in the integrand. Then we have:

$$E\big(\pi_{ihh}(z,u)\big)=A^{\eta-1}{\chi'_{ih}}^{\theta(1-\eta)}a_iL'_h{w'_h}^{\eta}\int_0^\infty\int_{w'_h/p}^\infty(p$$
$$-w'_h/z)g(z)dzp^{-\eta}f_{pih}(p)dp$$

Since $G(z)=1-z^{-1/\theta}$ => $g(z)=z^{-1/\theta-1}/\theta$, The inner integral is:

$$\int_{w'_h/p}^\infty(p-w'_h/z)g(z)dz=\int_{w'_h/p}^\infty(p-w'_h/z)z^{-1/\theta-1}/\theta dz$$
$$=(w'_h/p)^{-1/\theta}p\frac{\theta}{1+\theta}$$

Then we have:

$$\int_0^\infty\int_{w'_h/p'_{ih}}^\infty(p-w'_h/z)g(z)dzp^{-\eta}f_p(p)dp=\frac{\theta{w'_h}^{-1/\theta}}{1+\theta}\int_0^\infty p^{1+1/\theta-\eta}f_{pih}(p)dp$$

Consider the integral $\int_0^\infty p^{1+1/\theta-\eta} f_{pih}(p)dp$. We know that $p'_{ih}{}^{1/\theta}(x) \sim \exp\left(\chi'_{ih}/w'_h{}^{1/\theta}\right)$, therefore let us denote the integral in terms of $v = p^{1/\theta}, v \sim \exp\left(\chi'_{ih}/w'_h{}^{1/\theta}\right)$:

$$\int_0^\infty p^{1+1/\theta-\eta} f_{pih}(p)dp = \left(\chi'_{ih}/w'_h{}^{1/\theta}\right) \int_0^\infty v^{(1+1/\theta-\eta)\theta} e^{-\left(\chi'_{ih}/w'_h{}^{1/\theta}\right)v} dv$$

Let $\sigma = \left(\chi'_{ih}/w'_h{}^{1/\theta}\right) v => v = \sigma / \left(\chi'_{ih}/w'_h{}^{1/\theta}\right)$:

$$\int_0^\infty p^{1+1/\theta-\eta} f_{pih}(p)dp = \left(\chi'_{ih}/w'_h{}^{1/\theta}\right)^{-(1+1/\theta-\eta)\theta} \int_0^\infty \sigma^{(1+1/\theta-\eta)\theta} e^{-\sigma} d\sigma$$

The last term $\int_0^\infty \sigma^{(1+1/\theta-\eta)\theta} e^{-\sigma} d\sigma$ is value of the Gamma function $\Gamma(\gamma)$ at $\gamma = 1 + (1 + 1/\theta - \eta)\theta = 2 + (1-\eta)\theta$. Let us denote it with $\Gamma(2 + (1-\eta)\theta)$. Since we assumed $1 + \theta(1-\eta) > 0$, $\Gamma(2 + (1-\eta)\theta)$ is defined. Then we have:

$$\int_0^\infty \int_{w'_h/p'_{ih}}^\infty (p - w'_h/z) g(z) dz p^{-\eta} f_p(p) dp = \frac{\theta}{1+\theta} \Gamma(2 + (1-\eta)\theta) \chi'_{ih}{}^{-(1+1/\theta-\eta)\theta} w'_h{}^{1-\eta}$$

Therefore we have:

$$E\big(\pi_{ihh}(z,u)\big) = A^{\eta-1} a_i L'_h \frac{\theta}{1+\theta} \Gamma(2 + (1-\eta)\theta) \chi'_{ih}{}^{-1} w'_h$$

We defined that $A = \left(\int_0^\infty \sigma^{\theta(1-\eta)} e^{-\sigma} d\sigma\right)^{1/(1-\eta)}$, which is value of the Gamma function $\Gamma(\gamma)$ at $\gamma = 1 + \theta(1-\eta)$ raised to $1/(1-\eta)$ power. Therefore:

$$A^{\eta-1} = \left(\Gamma\big(1 + \theta(1-\eta)\big)^{1/(1-\eta)}\right)^{\eta-1} = \Gamma\big(1 + \theta(1-\eta)\big)^{-1}$$

Substituting it into $E\big(\pi_{ihh}(z,u)\big)$ yields:

$$E\big(\pi_{ihh}(z,u)\big) = \frac{\theta\big(1 + \theta(1-\eta)\big)}{(1+\theta)\chi'_{ih}} a_i L'_h w'_h$$

Chapter 5 :
CONCLUSION

5.1. Summary of the Study

This study investigates the optimal strategy and the welfare effects of technology improvements in the open economy. It also studies the effects of the changes in the degree of heterogeneity and tests a prediction concerning comparative advantage.

The first essay studies these questions with the Ricardian model. The paper formally proves Hicks' (1953) insight into the effects of technological improvement. The paper then studies optimal strategies of technological improvement and show that for a small country it is optimal to choose export-biased technological improvement. For a large country, it is optimal to improve technology in both sectors at a rate proportional to the consumers' expenditure share.

The second essay studies the effects of technological changes with a two-sector Eaton and Kortum model. This paper distinguishes two types of technological changes: changes in the technology levels (technology improvements) and changes in the dispersion of productivity of firms. The paper analyzes how the two types of technological changes affect the trade pattern. The paper also analyzes the welfare effects of technology improvements and yields some new results. The theoretical model of the paper shows that the net exports of the comparative advantage sector are positive while those of the other sector are negative. Using the OECD STAN database, the paper tests the prediction and finds strong support for it.

The third essay extends the Eaton and Kortum framework into a multi-sector model to analyze the innovation pattern of countries. The model analyzes the R&D pattern of a country in autarky. The paper also shows that in the open economy the R&D input in an industry depends on the country's advantage in the industry. Using the OECD STAN database, the empirical analysis finds some support for Hicks' path, a technology improvement strategy for countries advanced by Hicks, but it also indicates that the R&D pattern in the real world might be richer than what Hicks predicted.

5.2. Limitations of the Study

The first essay is based on the Ricardian model. As important as the model is, "the problem with the (Ricardian) model as a vehicle for discussing technical change is that too many things can happen (Krugman, 1986)." The discreteness of trade regime switches degenerates the study into a case-by-case study and keeps us from coming to unified conclusions. Moreover, the Ricardian model makes some strong assumptions, such as perfect competition and homogeneous firms.

The second essay solves the problem of trade regime switches that is inherent to the Ricardian model by introducing heterogeneity. However, the model still has some strong assumptions. First, the model assumes a uniform degree of heterogeneity for both industries in all countries. This assumption keeps the model tractable, but it loses some generality since in reality the degree of heterogeneity varies across industries and countries. Second, the Fréchet distribution does not provide a perfect convergence to the traditional Ricardian model when the degree of heterogeneity approaches zero. Third, the sample size of the empirical analysis is relatively small.

The third essay is based on a static model and dispenses with strategic interactions between countries. In reality, it takes time for R&D input turn into new ideas and the R&D input of a project is spread over multiple periods. Therefore, the R&D problem is essentially a dynamic one. The strategic interactions between countries also play an important role in the real world. Due to data availability, it is unclear whether the empirical results apply to non-OECD countries.

Besides the limitations that are specific to individual papers, there are some qualifications that are common to the entire study. First of all, this study does not consider the composition of endowments. Through the inquiry, this work assumes that there is only one endowment while in the real world the composition of endowments varies substantially across countries. The composition of endowments may exert extensive influence on the R&D pattern of a country. Second, the study does not consider technology diffusion, intellectual rights protection. Third, this study does not consider the trend that multi-national companies are doing more and more research overseas.

5.3. Possible Extensions

The second and third essays assume that the degree of heterogeneity remains the same across industries and countries. Perhaps the assumption can be relaxed in future inquiry to study what will happen when the degree of heterogeneity of different industries changes at different paces.

The theoretical model of the third essay can be extended to dynamic versions to study the R&D patterns of countries. This might yield more insights into the R&D strategy.

Perhaps the models of the second and third essays can be extended to incorporate multiple endowments. The models can also be extended to study technology diffusion and intellectual rights protection.

5.4. Conclusion

This study investigates the effects and the strategy of technology improvements in the open economy. It unifies the results existing in the literature, which are mainly based on the Ricardian model. Then the study extends the Eaton-and-Kortum model into multi-sector models to study the above issues. The new models encompass the existing results based on Ricardian model as special cases and yield new some theoretical results. Some of these results are tested empirically and are found to be consistent with the data. The theoretical and empirical results of this study contribute to understanding the effects and strategy of technology improvements in the open economy.

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