The Economic Effects of International Openness with Firm Heterogeneity

by

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Abstract

This dissertation adds to the literature on international openness and economic growth by studying and quantifying the effects of openness to trade and multinational production using a model of endogenous innovation with firm heterogeneity. The first chapter discusses the contribution of this dissertation to the theoretical and empirical literature on international openness. The second chapter studies and quantifies the long-run effects of openness to trade and multinational production in the context of advanced economies using a model of endogenous innovation with firm heterogeneity. Counterfactual experiments conducted using a calibrated version of a theoretical model find that the US would experience a significant welfare cost in consumption terms by restricting openness to both trade and horizontal multinational production with other OECD countries, with the growth effect accounting for a substantial part of the cost.

Chapter Three extends the theoretical model presented in Chapter Two to include features specific to the North-South context. I show that allowing for the possibility that the South may switch from being an imitator to becoming an innovator is essential for examining the long-run growth effect of stronger intellectual property rights. In particular, the North and the South both prefer stronger intellectual property rights because this will achieve the fastest long-run economic growth. If the South is an imitator country, the North

needs to maintain its absolute advantage in technology creation by maintaining a sufficiently large pool of uncopied ideas. Otherwise both countries will fall into a slow-growth equilibrium in the long run.

In Chapter Four, I account for transitional dynamics and study the gains from openness and stronger intellectual property rights that arise in the North-South context. Counterfactual experiments based on a calibrated version of the model presented in Chapter Three find that the transitional welfare gains from further trade openness between China and the OECD countries can be significant. In contrast to the existing growth literature, a deterrence of imitation has limited welfare effects when the South can switch from being an imitator to becoming an innovator country. This points to a source of potential bias in the welfare estimates provided by the existing literature.

Dedication

To my parents: Thank you for your unconditional love and encouragement throughout my life. I am honoured to have you as my parents.

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Chapter 1

Introduction

The world has witnessed a phenomenal increase in global economic integration through trade, multinational production, and technology diffusion over the past few decades. My dissertation adds to the literature on international openness and growth by studying and quantifying the effects of openness to trade and multinational production using a model with endogenous innovation and firm heterogeneity. I first study the effects of openness amongst advanced economies, with special attention paid to the difference in quality between the types of technology diffused through trade and multinational production. I then extend the theoretical framework with a focus on openness across advanced and emerging economies to study the long-run implications from stronger intellectual property rights. Finally, I conduct quantitative exercises examining both the transition and balanced growth paths to measure gains from openness across advanced and emerging economies as well as from protecting intellectual property rights.

With the establishment of the General Agreement on Tariffs and Trade (GATT), its successor the World Trade Organization (WTO), and many other bilateral and multilateral trade agreements, trade barriers have decreased as a result of mutually-agreed trade rules that are enforceable upon nations worldwide. In an effort to further promote global economic integration, a set of multilateral standards called the Trade-Related Aspects of Intellectual Property Rights (TRIPS) protects intellectual property rights among the member countries of the WTO. At the national level, investment promotion agencies have also played a key role in attracting resources from foreign multinational enterprises and enhancing the efficiencies of allocating foreign resources towards target industries in the domestic economy.[1] A goal of this dissertation is to investigate the economic implications of these elements of international openness, both theoretically and quantitatively.

The empirical trade literature has long recognized the importance of trade openness on economic welfare, but mixed results have been found regarding the impact on long-run economic growth. For instance, Dollar (1992), Sachs and Warner (1995), Frankel and Romer (1999), Wacziarg and Welch (2003), and Dollar and Kraay (2004) develop various openness indices and instrumental variables to identify the effects of trade liberalization on income and growth. They find a positive linkage between trade and growth. Brunner (2003), Rodriguez and Rodrik (2001), and Rodriguez (2006), however, point out that trade indices and instruments in these empirical studies cannot fully control for endogeneity bias between trade and growth. These authors argue that there is little evidence that trade openness leads to economic growth after correcting for the endogeneity problem. An alternative approach to addressing this measurement problem is to conduct a quantitative analysis within the controlled environment provided by a theoretical model.

Another potential source of bias can come from the missing link between trade and multinational production, and the diffusion of technology associated with trade and foreign

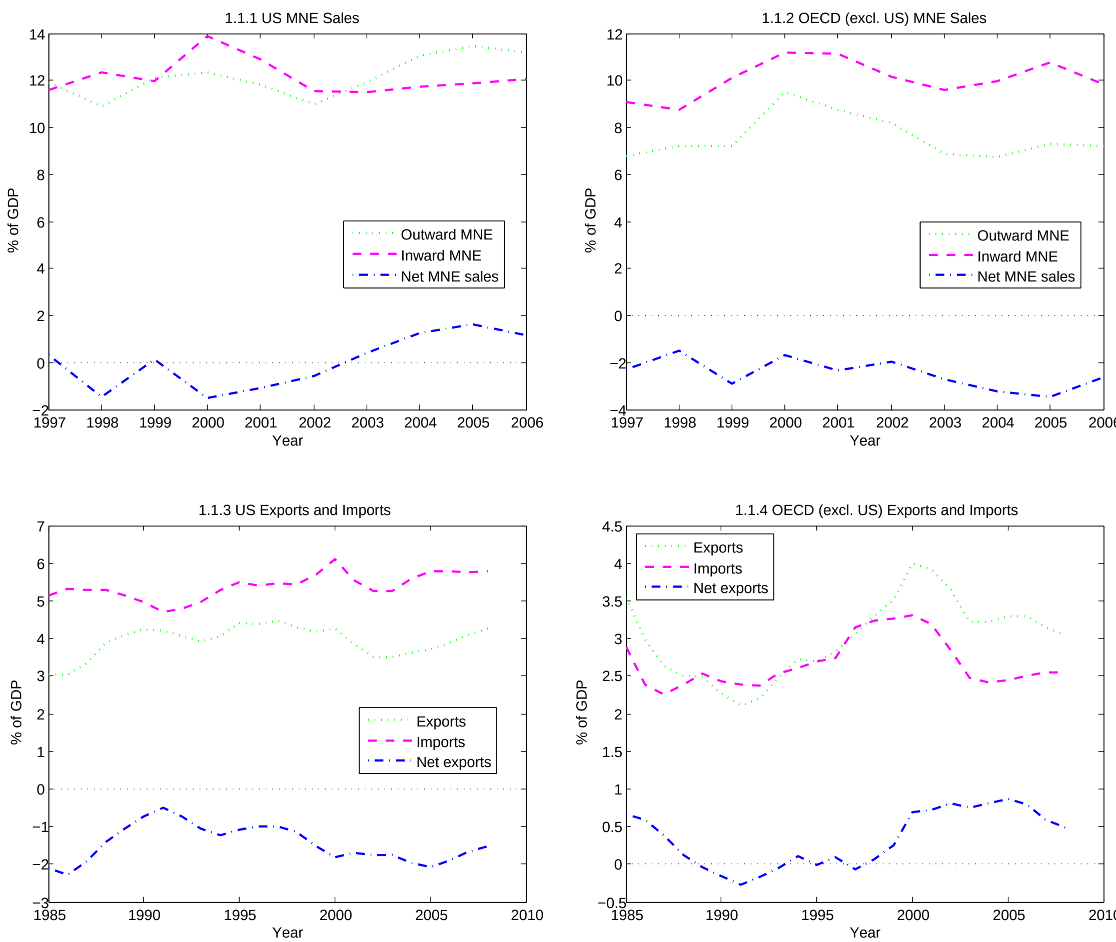
[1]For example, Charlton and Davis (2007) conducts an empirical analysis that supports the importance of investment promotion in attracting foreign direct investment inflows.

direct investment flows. To illustrate the importance of both trade and multinational production, Figure 1.1 shows the horizontal multinational sales and trade shares of GDP for the US and the OECD-18 countries.[2] The US saw its gross multinational sales with the OECD-18 countries as a share of GDP staying at double-digit levels over the ten years in the sample period. The ratios are much larger than the single-digit US exports and imports shares against the same set of countries. The OECD-18 countries also experienced a similar pattern. It is therefore important to include both trade *and* multinational production when measuring gains from openness.

To further investigate the importance of other channels of international openness on economic growth and welfare, more recent research focuses on broader measures of openness by including trade and multinational production, while some studies further extend the measures to include technology diffusion. For instance, using a modified version of the neoclassical growth model with technology capital, McGrattan and Prescott (2009) find large gains from openness for the advanced economies when multinational production acts as a channel of technology diffusion. Ramondo and Rodriguez-Clare (2009) build on the Ricardian model of comparative advantage developed in Eaton and Kortum (2002) and find significant gains from openness through both trade and multinational production. Studies using micro-level data also find large static productivity gains from openness through trade and multinational production, such as Rodrigue (2010) who estimates an extension of the Helpman, Melitz, and Yeaple (2004) model using Indonesian plant-level manufacturing

[2]The OECD-18 countries consists of Australia, Austria, Belgium/Luxemburg, Canada, Denmark, Finland, France, Germany, Greece, Italy, Japan, Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, and the United Kingdom. For illustration, the United States is separated from the OECD group to provide a consistent picture with the quantitative analysis in Chapter Two. Also note that the OECD-18 share of GDP is the average of each member country's share of GDP. Moreover, the multinational sales here includes only horizontal multinational sales. Vertical multinational sales, in which products are produced abroad and shipped back home, have been excluded. This is again for consistency with the model presented in Chapter Two. Trade data are from the OECD STAN. Multinational sales data are from the US Bureau of Economic Analysis. GDP data are from the World Bank's World Development Indicators.

Figure 1.1: Trade and Multinational Sales - US and OECD-18



data. In short, studies that use broader measures of openness conclude that welfare gains from openness can be significant, but the size of these gains remain an open question.

Since international technology spillovers can affect long-run economic growth, it is important to investigate the impacts of protecting stronger intellectual property rights on economic growth and welfare in an open-economy context. The extensive literature includes the seminal work of Grossman and Helpman (1991) and Helpman (1993), and the work of many others including Glass and Saggi (2002), Glass and Wu (2007), Dinopoulos and Segerstrom (2011) and Gustaffson and Segerstrom (2010b and 2011). Existing studies, however, are mostly concerned with balanced growth paths when they examine the policy implications related to international openness and intellectual property rights. Ignoring the transitional dynamics can possibly lead to biased estimates of policy impacts on growth and welfare. While studies such as Arnold (2007), Connolly and Valderrama (2005a and 2005b), and Mondal and Gupta (2009) have addressed such bias by exploring transitional dynamics, they assume that an imitator country does not switch to become an innovator country even in the long run. This shortcoming is another source of bias when assessing the growth effects and welfare gains from protecting intellectual property rights.

In Chapter Two, I develop a model of endogenous innovation with firm heterogeneity, and apply it to study and quantify the long-run effects of openness to trade and horizontal multinational production. The model emphasizes the importance of allowing firms to access multiple markets in providing incentives for innovation and highlights the role of international technology spillovers in promoting growth. When trade is liberalized, some multinationals find it more profitable to export and forego the cost of maintaining capacities in multiple markets. In the trade literature, this is referred to as the "proximity-concentration trade-off". As discussed in Saggi (2002), technology spillovers from imported goods are weaker than from multinationals. Thus, trade liberalization may not always be beneficial as the number of exporters increases at the cost of MNEs exiting, lowering the quality of technology diffused as a result.

Based on a calibrated version of the model using trade and multinational sales data from the United States and eighteen other OECD countries, I measure the growth and welfare effects from changes in the degrees of openness to trade and multinational production. Focusing on balanced growth paths, I find that by fully restricting openness to trade and horizontal multinational production with other OECD countries, the US would experience a welfare cost that is equivalent to a 39% drop in consumption, with the growth effect accounting for at least 40% of the estimated welfare cost. Allowing for endogenous growth therefore implies that openness has substantial implications for welfare beyond that quantified in previous studies. By examining the effects of trade liberalization alone, I find a U-shaped relationship between economic growth and trade costs for the US. Since multinationals tend to use relatively high quality technology, trade liberalization on its own can lead to an adverse effect on economic growth and consumer welfare by reducing the level of multinational production.

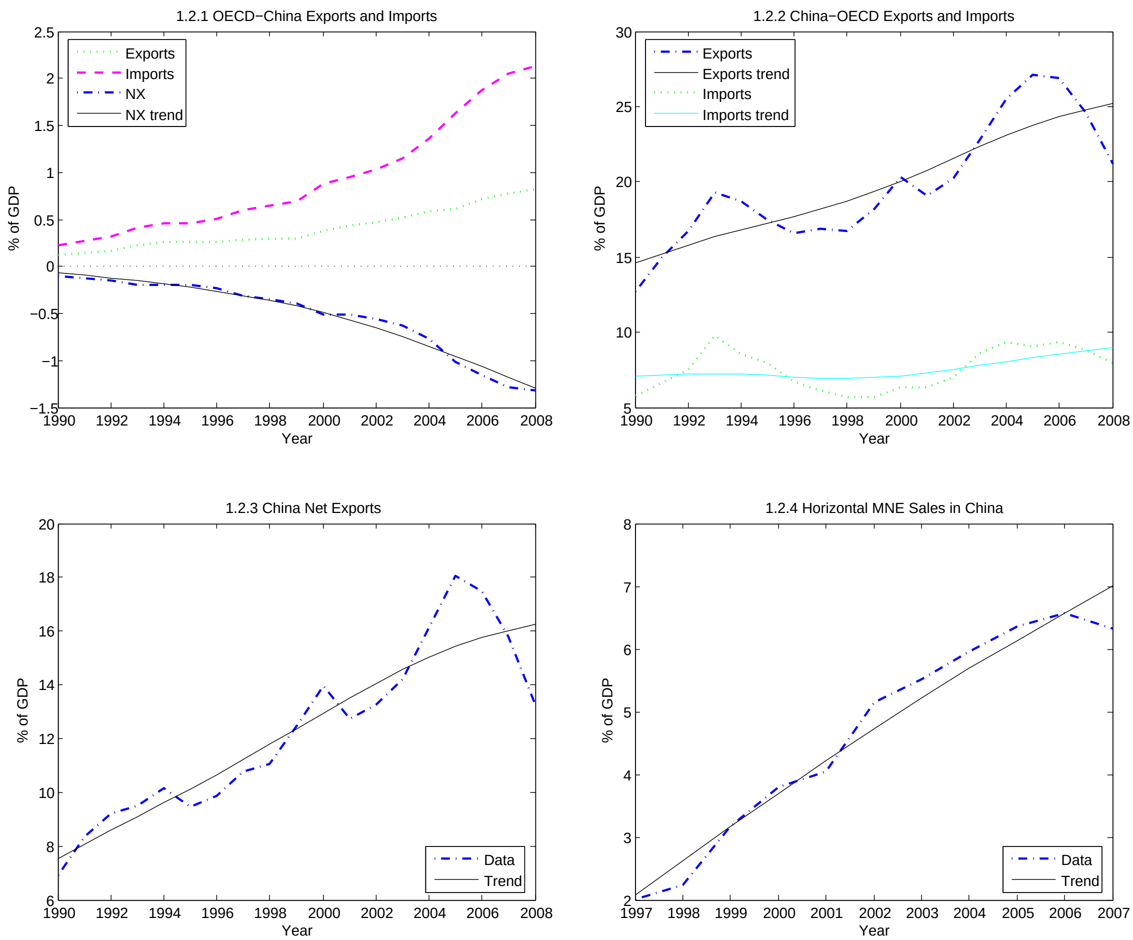
Since the effects of openness to trade and multinational production among advanced economies can be significant, it is natural to ask how big the impacts of openness can be between advanced economies (the *North*) and emerging economies (the *South*). This question cannot be fully addressed without assessing the impacts of protecting intellectual property rights on technology spillovers across the North and the South. In Chapter Three, I extend the theoretical framework in Chapter Two to develop a North-South model of endogenous innovation, with endogenous changes in firm distributions that can affect long-run growth. I emphasize the process of technology creation in the South, in which firms can either choose to imitate products from the North or to develop their own innovations, depending on the costs and benefits of each technology creation process. In addition, firms from the North can set up vertical multinational enterprises by maintaining production facilities in emerging markets to take advantage of lower production costs and then ship the products back to their home country.

My theoretical analysis shows that allowing for the possibility that the South may switch from being an imitator to becoming an innovator country is essential for examining the long-run growth effects of stronger intellectual property rights, thereby adding to the extensive literature where the resulting impact is only temporary. In particular, the per capita long-run equilibrium growth rate is fastest when both the North and the South enforce stronger intellectual property rights. If intellectual property rights protection in the South is weak, the North needs to maintain its absolute advantage in technology creation, or it will fall into a low-growth balanced growth path. In other words, although Southern imitation creates disincentive to Northern innovation, it is still optimal for the North to maintain a sufficiently large pool of uncopied ideas by having a cheaper cost of innovation relative to the South.

Chapter Four attempts to fill a gap in the existing growth literature that is concerned primarily with the analysis of balanced growth paths by emphasizing the importance of transitional dynamics when studying the implications of economic policies. Based on a calibrated version of the North-South model presented in Chapter Three, I conduct a quantitative analysis to measure the impacts of trade openness and the protection of intellectual property rights. I use data from China to represent the economic features of the South, and I treat the OECD countries as the North due to their leadership role in technological development.

As discussed in Mohommad, Unteroberdoerster, and Vichyanond (2011), China has been an integral part of the global supply chain during the past decade alongside its rapid economic development. After joining the WTO in 2001, China has become an increasingly important export destination and import source for the OECD countries, as illustrated

Figure 1.2: Trade and Multinational Sales - China and OECD-19



by the trade shares of GDP in Figure 1.2.1.[3] China's exports to the OECD have also increased rapidly over the decade, as shown in Figure 1.2.2. Its import share from the OECD countries, however, has increased only gradually, resulting in a persistent rise in China's net exports to the OECD countries over the past two decades. It is worthwhile to note that over 50% of the exports from China are associated with vertical multinationals whose

[3]OECD-19 comprises OECD-18 listed in footnote 2, plus the United States. Trade data are from the OECD STAN. Multinational sales data are from the US Bureau of Economic Analysis, the World Bank's World Investment Report, and the China Customs Statistics. GDP data are from the World Bank's World Development Indicators.

parent companies are from the advanced economies. At the same time, horizontal sales by OECD multinationals in China has been increasing dramatically, as shown in Figure 1.2.4, highlighting once again the importance of multinational production as a channel of openness.

Counterfactual experiments based on the model developed in Chapter Three show that the welfare gains from further trade openness between China and the OECD countries can be significant, where the transition accounts for over two-thirds of the total welfare gain for China. On the other hand, since the South in the model can switch from being an imitator to becoming an innovator country, a deterrence of imitation would alter the resource allocation decisions within each economy. Most of this occurs during the earlier part of the equilibrium transition path before switching occurs, and leaves the rest of the path almost unchanged. Consequently, stronger intellectual property rights will have limited welfare effects for both China and the OECD countries, which stands in stark contrast to studies in the literature where large welfare gains have been found. Further quantitative analysis focusing solely on the balanced growth path dynamics confirm that the over-estimation of growth and welfare gains from stronger intellectual property rights in the existing literature can be significant. These together point to a source of potential bias in the welfare estimates in the existing literature.

The remainder of the thesis proceeds as follows: Chapter Two studies and quantifies the long-run effects of openness to trade and multinational production across advanced economies in a model of endogenous innovation with firm heterogeneity. Chapter Three modifies the model presented in Chapter Two to study the policy implications related to intellectual property rights in the North-South context. The fourth chapter quantifies the growth and welfare effects of trade openness and strengthening intellectual property rights using a calibrated version of the model developed in Chapter Three with the data from China and the OECD countries, focusing on both an equilibrium transition path and the balanced growth path. The fifth chapter concludes.

Chapter 2

Firm Heterogeneity, Trade, Multinationals, and Growth: A Quantitative Evaluation

2.1 Introduction

In this chapter I study the long-run effects of openness to both trade and multinational production using a model of endogenous innovation with firm heterogeneity. I examine how the proximity-concentration trade-off between trade and multinational production can affect long-run growth and welfare gains. The model emphasizes the importance of firms' access to multiple markets in providing incentives for innovation and highlights the role of international technology spillovers in promoting growth. Using data from the United States and other OECD countries, I parameterize the model to quantify the gains from goods trade, the gains from multinational production, and the gains when both types of openness are present.

Much of the traditional literature on openness focuses on gains from trade. More recent research, however, focuses on broader measures of gains from openness through both trade and multinational production. Multinational production is an important channel of openness. The total multinational sales of foreign affiliates among OECD countries were at least 20% more than exports sales for the last decade. At the same time, multinational production plays a central role in international technology transfers, while trade still plays a prominent role.[4] Therefore, it is important to include trade *and* multinational production when measuring gains from openness.

Policies on openness are likely to not only affect levels but also the growth rates of income and consumption. Most of the existing studies quantify only the static gains from openness and abstract from growth effects. In the work I present below, I account for both the level and growth effects of welfare from openness to trade and multinational production.

Although the empirical literature suggests that welfare gains from openness can be significant, the size of these gains remain an open question.[5] Recent studies have developed theoretical frameworks to quantify gains from openness. McGrattan and Prescott (2009) find large gains from openness across developed countries when multinational production acts as the channel of technology diffusion. Ramondo and Rodriguez-Clare (2009) observe large gains from openness through both trade and multinational production. Rodrigue (2010) uses Indonesian plant-level manufacturing data and also finds large static gains in productivity from openness through trade and multinational production. Although these studies measure gains using a broader definition of openness, their measures are based on

[4] See survey article by Saggi (2002).

[5] Studies include Sachs and Warner (1995), Brunner (2003), Dollar and Kraay (2004), and Lai and Trefler (2004) suggest that trade liberalization leads to significant growth effects. However, Baldwin (1992) and Broda et al. (2006) suggest that gains from growth are much weaker than static gains from trade liberalization. These studies all focus on gains from trade rather than a broader measure of openness.

static changes in consumption or productivity.

I also examine whether trade liberalization is welfare-improving in the presence of multinational enterprises (MNEs). A firm establishes a foreign subsidiary rather than exporting to the foreign market when the gains from avoiding trade costs outweigh the costs of maintaining capacity in foreign markets — this is referred to as the proximity-concentration trade-off. Using US exports and affiliates data, Helpman, Melitz and Yeaple (2004) confirm the proximity-concentration trade-off and find that MNEs are in general more productive than exporters. Since the quality of a technology is associated with its productivity, the technology diffused from a MNE is of higher quality compared with those diffused through trade. As discussed in Saggi (2002), technology spillovers from imported goods are weaker than from MNEs. Thus, trade liberalization may not always be beneficial as the number of exporters increases at the cost of MNEs exiting, lowering the quality of technology diffused as a result.

I develop a fully endogenous growth model similar to Romer (1990) and Barro and Sala-i-Martin (2004) by allowing international trade, multinational production, and firm heterogeneity as in Melitz (2003) and Helpman, Melitz and Yeaple (2004). Economic growth is generated by the expansion in the variety of intermediate inputs in which the incentives to innovate intermediate inputs are affected by policies on openness to trade and multinational production.[6]

An important feature of the theoretical model is the use of a technology spillovers specification which highlights the importance of variety expansion as well as the quality of

[6]The ‘scale-effect’ problem in common endogenous growth models is corrected for, so that the size of the labour force does not affect the long-run economic growth rate. The semi-endogenous growth models with trade such as Gustafsson and Segerstrom (2010a) avoids the so-called ‘scale effect’. However, the long-run growth rate is usually a linear function of the labour force growth rate and consequently there is no room for policies on openness to have an impact on long-run growth, although policies do have an impact in the short-run.

the technology diffused. As suggested by Eaton and Kortum (1999) and Rodriguez-Clare (2007), and based on the empirical evidence from Alfaro and Charlton (2007), Pradhan (2006), and Smeets (2008), the quality of technology is important for technology diffusion. High quality technologies embody high productivity which can contribute more to the diffusion process. By allowing for this feature in the technology spillover process, the welfare effects of trade liberalization can be ambiguous, depending on the ratio of trade-to-MNE sales of a country.[7]

Using trade and multinational sales data from the United States and eighteen other OECD countries, I measure both the level and growth effects of trade and multinational production. By performing counterfactual experiments, I find that by restricting openness to trade and multinational production with the OECD countries, the US would experience a welfare cost that is equivalent to a 39% drop in consumption. The growth effect accounts for at least 40% of the estimated welfare cost. Allowing for endogenous growth, therefore, implies that openness has substantial implications for welfare beyond that quantified by previous literature. By examining the effects of trade liberalization alone, I find a U-shaped relationship between economic growth and trade costs for the US. Trade liberalization can potentially lead to an adverse effect on economic growth and consumer welfare by reducing the level of multinational production for the US. However, for the OECD countries in general, since their trade-to-MNE sales ratio is large on average, meaning that overall trade sales is important, trade liberalization over the past few decades has been welfare-improving.

Empirical studies that have estimated the effects of trade on growth have produced mixed results. Dollar (1992), Sachs and Warner (1995), Frankel and Romer (1999), Wacziarg

[7] In their theoretical work, Gustafsson and Segerstrom (2010a) find that the effect of trade liberalization is ambiguous, depending on the strength of spillover. Dinopoulos and Unel (2011) and Unel (2010) find similar result for trade liberalization, depending on the specification of the spillover process.

and Welch (2003), and Dollar and Kraay (2004) develop various openness indices and instrumental variables to identify effects of trade liberalization on income and growth. However, as discussed by Brunner (2003), Rodriguez and Rodrik (2001) and Rodriguez (2006), these instruments and indices suffer from various endogeneity problems, which makes it difficult to disentangle the level and growth effects of openness. By correcting for these problems, the authors argue that there is little evidence that trade openness leads to economic growth. Based on a theoretical model, the effects of openness are measured in a controlled environment, which makes it convenient to separate the level and growth effects of welfare.

The next section presents an endogenous growth model of international trade and multinational production with heterogeneous firms. Section 2.3 characterizes the balanced growth path of the model. Section 2.4 studies the gains from openness in a version of the model parameterized to replicate key features of the data. Section 2.5 concludes.

2.2 The Model

2.2.1 The Environment

There are two countries in the world economy, which can be symmetric or asymmetric. I denote the countries by i and j. One can think of country i as the home country and j as the foreign country. There is no aggregate uncertainty. Time is continuous and is indexed by $t \geq 0$. Since the focus here is on long-run per capita growth, I assume that population sizes are fixed without loss of generality.[8] All assumptions below apply to both countries.

[8]The qualitative and quantitative implications are similar with or without population growth.

Households share identical preferences. Each household has isoelastic preferences:

$$U_i = \int_0^\infty \frac{C_{it}^{1-\theta} - 1}{1-\theta} e^{-\rho t} dt, \tag{2.1}$$

where ρ denotes the rate of time preference, θ denotes the inverse of the elasticity of intertemporal substitution, and C_{it} denotes consumption of a final good. I assume that each person supplies one unit of labour services per unit of time, so that the size of the labour force L_i is the same as the size of population $\bar{L}_i$. A household's dynamic aggregate budget constraint is given by:

$$\dot{B}_{it} = w_{it} L_i + r_{it} B_{it} + Z_{it} - C_{it}, \tag{2.2}$$

where w_{it} denotes the real wage, r_{it} denotes the interest rate, B_{it} denotes the assets owned by the households, $\dot{B}_{it}$ denotes a change in assets position, and Z_{it} denotes transfers from the intermediate goods sector. The representative household earns labour income, investment income, and collects transfers from the intermediate goods sector.

Each country consists of two production sectors: an intermediate goods sector and a final goods sector. The final goods sector is perfectly competitive. Final output is produced using labour and a continuum of intermediate inputs X_{li}, where $l \in [0, N_{it}]$, and N_{it} is the total number of intermediate goods available at country i at time t. This includes intermediates from domestic and foreign firms. Final goods are identical across countries. The final good is the numeraire good and is sold at unit price.[9] Trade of the final good is costless.[10] The aggregate production function for the final good for country i is given by:

$$Y_{it} = A_i L_i^{1-\alpha} \int_0^{N_{it}} X_{li}^{\alpha} dl, \tag{2.3}$$

[9]Identical final goods across countries imply parity of the real exchange rate in this model.

[10]A goal here is to examine how the proximity-concentration trade-off between trade and multinational production can affect the long-run growth rate and long-run welfare gains. Since there is no such trade-off in the final goods sector, I assume the trade cost is zero for the final good.

where Y_{it} is final output, A_i is the aggregate productivity parameter, and $\alpha \in (0, 1)$ controls the elasticity of substitution between intermediate goods, $\epsilon = 1/(1-\alpha) > 1$.

Final output can be used for aggregate consumption C_{it}, the production of intermediate goods M_{it}, investment in research and development (R&D) R_{it}, and net exports NX_{it}:

$$C_{it} + R_{it} + NX_{it} \leq Y_{it} - M_{it}. \tag{2.4}$$

Since profits are paid in the form of the final good, net exports are equal to the negative of net profits repatriated from abroad.

The intermediate goods sector consists of a variety of products. The intermediate goods firms are monopolistically competitive and are heterogeneous in their production technologies. Before an intermediate good can be produced, a firm must first devote resources to research and development (R&D) to innovate a new product. Each firm pays a one-time cost of innovation η_{it} to obtain a blueprint. By paying this sunk cost, the innovating intermediate good firm receives a perpetual patent which allows the firm to become a monopolist over the product it developed. The cost of innovation is a function of technology spillovers. The larger the pool of existing technology, the larger the effects of spillovers and the lower the cost of innovation. For simplicity, I assume that each intermediate firm owns the right to produce a single product.

The production function of each variety is linear. Each unit of intermediate good is produced using a units of the final good, and the units required are different across firms due to productivity heterogeneity. After obtaining a blueprint, each firm receives a unit cost parameter, a, drawn from a stationary Pareto distribution:[11]

$$G_i(a) = Pr(\mathrm{a} < a) = \left(\frac{a}{a_{i0}}\right)^{k_i} \quad , \quad a \in [0, a_{i0}], \tag{2.5}$$

[11] Usually, the Pareto distribution is given by Pr($X > x$)=$(x/x_0)^{-k}$. If we substitute $x = 1/a$ and $x_0 = 1/a_0$ the distribution becomes Pr(a $< a$)=$(a_0/a)^{-k} = (a/a_0)^k$.

where a_{i0} and k_i are the scale and shape parameters of the distribution, respectively. I assume that k_i can be different across different countries, and that $k_i > 2$ for the mean and variance of the distribution to be finite. Note that an intermediate firm only draws the unit cost parameter once and will keep it for its lifetime.

Depending on the draw, a firm chooses either to serve the domestic market, to serve the foreign market by exporting or by becoming a multinational enterprise (MNE), or not to enter at all. A firm that serves the domestic market produces its product using domestic inputs. An exporter also produces domestically and ships its product abroad. A multinational enterprise maintains production capacities at home and abroad. The foreign subsidiary is owned by the parent company at home, and produces using foreign inputs to sell to the foreign market.[12]

To enter the domestic market after obtaining a blueprint, a firm located in country i is required to pay a per-period fixed cost F_{iit} to produce and sell in country i at time t. To export, a firm is required to pay an extra per-period fixed cost F_{xit}, as well as an iceberg trade cost τ for each unit of goods exported. The iceberg trade cost consists of tariffs, costs due to non-tariff barriers, as well as technological costs such as inventory-carrying costs. A firm needs to pay an extra per-period fixed cost F_{jit} to become a MNE and set up a subsidiary abroad. The analogous per-period fixed costs faced by country j's firms are given by F_{jjt}, F_{xjt}, and F_{ijt} for domestic sellers, exporters, and MNEs, respectively. These fixed costs consist of costs to set up production facilities, costs of distribution, lobbying costs and other policy-related costs. Moreover, I assume $F_{sdt} = r_{dt} f_{sd}$ for $s \in \{i, x, j\}$ and

[12]This is referred to as horizontal MNE. In contrast, a vertical MNE is referred to as a firm that sets up a foreign subsidiary to produce abroad to take advantage of the low cost of production abroad. Products are sold locally as well as being shipped back to the home country or to other foreign markets. In the model, marginal cost of production is the same for a firm whether it produces at home or abroad. The only reason a firm would become a vertical MNE is if the fixed cost to set up abroad is so low that even with an iceberg trade cost it is still cheaper than producing at home, which does not seem to be supported by international experiences.

$d \in \{i, j\}$, where r_{dt} denotes the interest rate, f_{sd} denotes a constant, one-time fixed cost, and F_{sdt} is the amortization of this one-time fixed cost. Firms pay the amortized, per-period fixed costs to enter the different markets. If a firm exits certain markets due to changes in openness, as reflected by changes in the fixed costs and iceberg trade costs, then the firm stops paying the per-period fixed costs and exits the respective markets.

To guarantee non-negative average *net* profits for exporters and MNEs, I assume that the constant one-time fixed costs f_{si} for country i satisfy the following condition:[13]

$$f_{ii} < \tau^{\epsilon-1} f_{xi} < f_{ji}. \tag{2.6}$$

The per-period fixed costs also satisfy this condition because they are amortized by a common interest rate r_{it}. Similar conditions are assumed to be satisfied by the fixed costs faced by a firm from country j.

The number of intermediate firms serving each market is changing over time as the world economy expands. N_{iit} denotes the number of firms originating from country i, which includes exporters N_{xit}, MNEs N_{jit}, and the rest of the firms that only serve the domestic market. Similarly, N_{jjt} denotes the number of firms originating from country j, which includes exporters N_{xjt}, MNEs N_{ijt}, and the rest of the firms that only serve the foreign market. Note that these firms numbers account for all the firms that earn non-negative profits in their respective markets. Firms that will suffer losses from operating in the markets will not enter. The total number of intermediate goods available in country i, N_{it}, is the sum of the domestic firms N_{iit}, foreign exporters N_{xjt}, and foreign MNEs N_{ijt}. Similarly, N_{jt} includes N_{jjt} as well as N_{xit} and N_{jit} which are exporters and MNEs from country i, respectively.

The total per-period fixed costs paid by domestic firms, foreign exporters and MNEs to

[13] See Helpman, Melitz and Yeaple (2004) for details on this condition.

enter country i are $N_{iit}F_{iit}$, $N_{xjt}F_{xjt}$ and $N_{ijt}F_{ijt}$, respectively. I assume that these fixed costs of production become part of domestic households' income, and are collected in the form of transfers, Z_{it}, for households in country i. The households in country j also receive analogous per-period fixed costs payments.

Next, I present the households' problems, the final goods producers' problems and the intermediate goods firms' problems. I then define a stationary equilibrium and the balanced growth path of the model.

2.2.2 Representative Household's Problem

The representative household maximizes its lifetime utility function (2.1) subject to the budget constraint (2.2), which yields the following Euler equation:

$$\frac{\dot{C}_{it}}{C_{it}} = \frac{1}{\theta}(r_{it} - \rho). \tag{2.7}$$

Since households receive per-period fixed costs payments from intermediate firms in the form of transfers, Z_{it}, the budget constraint (2.2) can be rewritten as:

$$\dot{B}_{it} = w_{it}L_i + r_{it}B_{it} + N_{iit}F_{iit} + N_{xjt}F_{xjt} + N_{ijt}F_{ijt} - C_{it}. \tag{2.8}$$

A change in the asset position, $\dot{B}_{it}$, includes households' investment and capital gains on asset holdings. The only investment in this economy is the R&D investment made by domestic intermediate firms. Households invest their resources in the domestic firms, which in turn devote these resources to innovation. The domestic households then become the firms' shareholders. As a result, households' investment is equivalent to R&D investment R_{it}, which is given by:

$$R_{it} = \left(\frac{a_{i0}}{a_{iit}}\right)^{k_i} \eta_{it}\dot{N}_{iit}, \tag{2.9}$$

where the inverse of Pareto distribution $(a_{i0}/a_{iit})^{k_i}$ is the number of attempts required before a profitable product is developed, and a_{iit} is the cut-off firm that makes zero profit as discussed below. $\dot{N}_{iit}$ denotes the number of new successful innovators in country i that earn non-negative profits.

Assets are accumulated through R&D investments without depreciation or obsolescence, and are given by:

$$B_{it} = \left(\frac{a_{i0}}{a_{iit}}\right)^{k_i} \eta_{it} N_{iit}. \tag{2.10}$$

Investment income, $r_{it}B_{it}$, consists of the dividends and capital gains earned from the shares of intermediate firms. The total net profits of the intermediate goods sector are distributed to shareholders as dividends, which yields:

$$r_{it}B_{it} = N_{iit}\tilde{\pi}_{iit} + N_{xit}\tilde{\pi}_{xit} + N_{jit}\tilde{\pi}_{jit} + \Upsilon_{it} = N_{iit}\tilde{\pi}_{it} + \Upsilon_{it}. \tag{2.11}$$

where $\tilde{\pi}_{sit}$ with $s \in \{i, x, j\}$ denotes the average net profits earned domestically, from exporting and from multinational production, respectively. $\tilde{\pi}_{it}$ denotes the average net profit for a firm originated from country i, and Υ_{it} denotes the total capital gains arising from changes in the total value of firms. Investment income is therefore the sum of the total domestic net profits, the total exporting net profits, the total net profits from foreign subsidiaries, and the total capital gains.

As illustrated in Appendix A.1, the total spending on intermediate goods is $M_{it} = \alpha^2 Y_{it}$. Together with equations (2.9) and (2.11), and the final good producers' problems given below, the budget constraint from (2.8) can be further written as (See Appendix A.1 for details):

$$Y_{it} = C_{it} + R_{it} + M_{it} + NX_{it}. \tag{2.12}$$

Final output of country i is the sum of consumption, R&D investment, spending on intermediate goods, and net exports.[14] Net exports are given by:

$$NX_{it} = -[(N_{xit}\tilde{\pi}_{xit} - N_{xjt}\tilde{\pi}_{xjt}) + (N_{jit}\tilde{\pi}_{jit} - N_{ijt}\tilde{\pi}_{ijt})], \tag{2.13}$$

where $\tilde{\pi}_{xjt}$ and $\tilde{\pi}_{ijt}$ are the average net profits of foreign exporters and MNEs, respectively. Note that the negative of NX are the net repatriated profits from abroad for country i. Since final goods are identical across countries, positive net repatriated profits require net imports of the final good (or negative net exports) in order to settle the balance of payments. Similarly, negative net repatriated profits require net exports of the final good.

2.2.3 Final Goods Sector

Final goods producers minimize costs by choosing labour and intermediate inputs subject to production function (2.3), taking prices of intermediate goods as given. The producers' problem yields the equilibrium real wage and the demands for intermediate goods. The real wage is given by:

$$w_{it} = (1-\alpha)\frac{Y_{it}}{L_i}. \tag{2.14}$$

The demand for intermediate good l by final good producers in country i is given by:

$$X_{li}(p_l) = \left(\frac{A_i\alpha}{p_l}\right)^{\frac{1}{1-\alpha}} L_i, \tag{2.15}$$

where the price elasticity of demand for each intermediate good is $-1/(1-\alpha)$. Note that X_{li} is constant if the price p_l is constant.

2.2.4 Intermediate Goods Sector — Stage 2: Product Markets

Potential intermediate firms face a two-stage problem. In the first stage, a firm decides whether to devote resources to develop a new intermediate good. In the second stage, a

[14] Note that GDP in this model is $Y_{it} - M_{it}$ because the share of final output used as intermediate inputs is not value-added. GNP is defined as $Y_{it} - M_{it} - NX_{it}$ to account for the net repatriated profits from abroad.

firm draws its cost and decides whether to enter the domestic market and whether to export its products or to become a MNE. To solve the two-stage problem, I proceed by solving the model backward. All results below apply to firms from both countries.

In the second stage, each firm draws its cost from the Pareto distribution given by (2.5). Since all intermediate goods enter the final good aggregate production function (2.3) the same way, with the only difference being the cost draw a for each intermediate good, I denote an intermediate good as good a instead of good l.

An intermediate firm is the only producer of its product. Each firm compares its potential operating profits with the per-period fixed costs associated with each market to decide in which market to operate. A firm with cost a from country i maximizes its operating profits by choosing its optimal price p_{si} to serve the different markets, where $s \in \{i, x, j\}$ denotes the domestic market, exporting, and multinational production, respectively. A firm's problem is given by:

$$\max_{p_{si}} \; (p_{si} - \tau^q a) X_{si}(p_{si}) \tag{2.16}$$

subject to the demand function (2.15). Here $q \in \{0, 1\}$ where $q = 1$ if the firm is exporting and incurs the iceberg trade cost τ, and $q = 0$ otherwise.[15] The optimal prices for a country i firm to serve country i, to export to j and to serve j as a MNE are given by:

$$p_{ii} = \frac{a}{\alpha} \quad , \quad p_{xi} = \frac{\tau a}{\alpha} \quad , \quad p_{ji} = \frac{a}{\alpha}. \tag{2.17}$$

Notice that these prices are constant markups over marginal cost. Substituting the optimal prices (2.17) into equation (2.16), together with demand function (2.15) yields the optimal

[15]To keep the algebra simple, I assume that exporters purchase inputs from the destination country first, then produce the intermediate goods at home and ship these goods to the destination country. Recall that the production inputs of intermediate goods are final goods, and that the price of a final good is unity and there is no trade cost attached to it.

operating profits:

$$\pi_{si}(a) = \left(\frac{1-\alpha}{\alpha}\right) \tau^q a^{-\frac{\alpha}{1-\alpha}} A_d^{\frac{1}{1-\alpha}} \alpha^{\frac{2}{1-\alpha}} L_d, \tag{2.18}$$

with $d = i$ when a firm is serving the domestic market, and $d = j$ when serving abroad. Notice that firm a's operating profit flow is constant in each market, but are different across markets.

Fixed Costs and Cut-off Costs

Based on the condition on fixed costs from equation (2.6), the marginal firm to become a MNE has lower marginal cost a_{jit} than the marginal firm to become an exporter a_{xit} since f_{ji} are the highest among the fixed costs. The marginal firm to serve domestically has the highest marginal cost a_{iit} since f_{ii} are the lowest among the fixed costs. As a result:

$$a_{jit} < a_{xit} < a_{iit}.$$

Notice that all firms from country i will at least serve the domestic market because all the firms with $a \leq a_{iit}$ can make non-negative profits. The most productive firms with the lowest marginal costs become MNEs and serve the domestic market as well, followed by exporters who also serve the domestic market, with the least productive firms solely serving the domestic market. A similar set of inequalities can be derived for country j.

The proximity-concentration trade-off can be seen from this setting. By engaging in multinational production, a firm can avoid the iceberg trade cost, yet it still has to pay a fixed cost to set up a subsidiary abroad. A firm sets up such a foreign subsidiary rather than simply exporting to the foreign market whenever the gains from avoiding trade costs outweigh the costs of maintaining capacity in foreign markets.

Zero Profit Conditions

Before we can determine the cut-off costs, I first define the value of a firm in different markets. The values of firm a to serve domestically, to export, and to serve abroad as a MNE are equal to the present values of future profits from serving these markets respectively. I denote the value of firm a from country i serving each market by V_{sit} where $s \in \{i, x, j\}$. After a firm gets a cost draw a it faces no uncertainty. As a result, the rate of return from serving a particular market, plus the rate of capital gain or loss from the change in the value of the firm, must equal the risk-free interest rate. This equality is given by:

$$r_{it} = \frac{\pi_{si}(a)}{V_{sit}} + \frac{\dot{V}_{sit}(a)}{V_{sit}(a)}, \tag{2.19}$$

where $\dot{V}_{sit}$ is the time derivative of the value of a firm serving market s, which is the capital gain or loss of a firm.

A firm compares the value of selling in market s with the cost of selling there. The cut-off cost to enter the domestic market a_{iit} can be determined by finding the marginal firm that pays the fixed cost to enter and make zero profit, and similarly for the cut-off cost of the exporters a_{xit}. However, the cut-off cost for MNEs is less straight-forward. a_{jit} is the cost at which the marginal firm is indifferent between exporting to foreign market j or to establishing a subsidiary there. The zero profit conditions for the domestic and exports markets, respectively, are given by:

$$V_{iit}(a_{iit}) = f_{ii} \quad , \quad V_{xit}(a_{xit}) = f_{xi}, \tag{2.20}$$

and that for the MNE is given by:

$$V_{jit}(a_{jit}) - f_{ji} = V_{xit}(a_{jit}) - f_{xi}. \tag{2.21}$$

Since the one-time fixed costs are constant, $\dot{V}_{sit}(a) = 0$. Together with equations (2.18)-(2.21) we derive the domestic and export cut-off costs:

$$a_{iit} = \left[\left(\frac{1-\alpha}{\alpha}\right)\frac{\Lambda_i}{F_{iit}}\right]^{\frac{1-\alpha}{\alpha}} \quad , \quad a_{xit} = \left[\left(\frac{1-\alpha}{\alpha}\right)\frac{\Lambda_j}{F_{xit}}\right]^{\frac{1-\alpha}{\alpha}} \tau^{-1}, \tag{2.22}$$

and the MNE cut-off cost:

$$a_{jit} = \left[\left(\frac{1-\alpha}{\alpha}\right)\frac{\Lambda_j(1-\tau^{\frac{-\alpha}{1-\alpha}})}{F_{jit}-F_{xit}}\right]^{\frac{1-\alpha}{\alpha}}, \tag{2.23}$$

where $\Lambda_d = A_d^{\frac{1}{1-\alpha}} \alpha^{\frac{2}{1-\alpha}} L_d$ for $d \in \{i, j\}$, and the per-period fixed costs $F_{sit} = r_{it} f_{si}$ for $s \in \{i, x, j\}$.

Dividing the export and MNE cut-offs by the domestic cut-off gives:

$$a_{xit} = \left(\frac{F_{iit}\Lambda_j}{F_{xit}\Lambda_i}\right)^{\frac{1-\alpha}{\alpha}} \frac{a_{iit}}{\tau} \quad , \quad a_{jit} = \left[\frac{F_{iit}(1-\tau^{\frac{-\alpha}{1-\alpha}})\Lambda_j}{(F_{jit}-F_{xit})\Lambda_i}\right]^{\frac{1-\alpha}{\alpha}} a_{iit}, \tag{2.24}$$

which implies that both a_{xit} and a_{jit} are functions of a_{iit}. As a result, solving for a_{iit} in equilibrium also determines the other two cut-off costs. The cut-off costs a_{jjt}, a_{xjt} and a_{ijt} for country j's firms can be found in similar fashion.

By comparing the export and the MNE cut-off costs, one may notice that as trade cost τ increases, a_{xit} decreases, and the probability to become an exporter drops. In contrast, a_{jit} increases as τ increases, and the probability to become a MNE increases.[16] For the exporters who were originally at the lower end of the exporters' cost distribution, an increase in trade costs induces these productive exporters to become MNEs instead. The exporters at the upper end of the cost distribution are forced to exit the export market and serve the domestic market alone. The key here is that trade and multinational production are *substitutes* due to the proximity-concentration trade-off.[17]

[16]The probabilities of exporters and MNEs conditional on surviving firms are given by $G_i(a_{xit})/G_i(a_{iit})$ and $G_i(a_{jit})/G_i(a_{iit})$, respectively.

[17]See Brainard (1997) for empirical evidence on proximity-concentration trade-off.

Notice that as cut-off costs change, the distributions of firms in different markets change as well. Even though the operating profit flow in each market remains constant for each firm, as shown in equation (2.18), the *average* operating profit in each market changes as the cut-off costs change.

Aggregation

Output in country i is given by equation (2.3). Only the intermediate firms that obtain a cost draw below a_{iit} will survive, so this needs to be taken into account when aggregating the intermediate goods. Equation (2.3) can therefore be rewritten as:

$$\begin{aligned} Y_{it} &= A_i L_i^{1-\alpha}\Bigg[\int_0^{a_{iit}} X_{ii}(a)^\alpha \frac{g_i(a)}{G_i(a_{iit})} N_{iit} da + \int_{a_{ijt}}^{a_{xjt}} X_{xj}(a)^\alpha \frac{g_j(a)}{G_j(a_{xjt}) - G_j(a_{ijt})} N_{xjt} da \\ &\quad + \int_0^{a_{ijt}} X_{ij}(a)^\alpha \frac{g_j(a)}{G_j(a_{ijt})} N_{ijt} da\Bigg], \end{aligned} \tag{2.25}$$

where $g_i(a)/G_i(a_{iit})$ is the density function conditional on firms' survival, $g_j(a)/(G_j(a_{xjt}) - G_j(a_{ijt}))$ is the density function conditional on foreign exporters, and $g_j(a)/G_j(a_{ijt})$ is the density function conditional on foreign MNEs.

Note that the conditional distributions of intermediate firms are governed by the cut-off costs. The number of exporters and MNEs from each country are proportional to the distributions of exporters and MNEs conditional on all domestic firms N_{ddt}, for $d \in \{i, j\}$. Therefore, the numbers of exporters and MNEs are known if the cut-off costs and N_{ddt} are known.

Equation (2.25) can be simplified further by substituting $X_{sd}(a)$ for $s \in \{i, x, j\}$ using equation (2.15), the optimal prices (2.17), and $g_i(a)/G_i(a)$ derived from the Pareto distribution. This becomes (see Appendix A.1 for details):

$$Y_{it} = A_i^{\frac{1}{1-\alpha}} \alpha^{\frac{2\alpha}{1-\alpha}} L_i N_{it} \tilde{a}_{it}^{1-\epsilon}, \tag{2.26}$$

where $\epsilon = 1/1 - \alpha$ is the elasticity of substitution between intermediate goods, and $N_{it} = N_{iit} + N_{xjt} + N_{ijt}$ is the total number of intermediate good firms that serve country i. The average unit cost ($\tilde{a}_{it}$) of intermediate goods firms in country i which consist of both domestic and foreign firms is given by (see Appendix A.1 for details):

$$\tilde{a}_{it} = \left[\frac{N_{iit}}{N_{it}} \tilde{a}_{iit}^{1-\epsilon} + \frac{N_{xjt}}{N_{it}} (\tau \tilde{a}_{xjt})^{1-\epsilon} + \frac{N_{ijt}}{N_{it}} \tilde{a}_{ijt}^{1-\epsilon} \right]^{\frac{1}{1-\epsilon}}, \tag{2.27}$$

where $\tilde{a}_{iit}$ is the average unit cost of domestic firms, $\tilde{a}_{xjt}$ is the average unit cost of foreign firms exporting to country i, and $\tilde{a}_{ijt}$ is the average unit cost of foreign MNEs.

2.2.5 Intermediate Goods Sector — Stage 1: Innovation

In the first stage, an intermediate firm is an innovator who devotes resources to innovation by paying a one-time cost of innovation, which is a sunk cost. A successful innovator may not be producing in the second stage due to an unfavourable productivity draw. Consequently, not all new entrants in the first stage survive in the second stage.

The ex-ante, expected net profit $\tilde{\pi}_{it}$ at time t conditional on surviving the second stage is given by (see Appendix A.2 for details):

$$\tilde{\pi}_{it} = \tilde{\pi}_{iit} + \frac{G_i(a_{xit}) - G_i(a_{jit})}{G_i(a_{iit})} \tilde{\pi}_{xit} + \frac{G_i(a_{jit})}{G_i(a_{iit})} \tilde{\pi}_{jit}, \tag{2.28}$$

where $(G_i(a_{xit}) - G_i(a_{jit}))/(G_i(a_{iit}))$ is the conditional probability of a domestic firm exporting, and $G_i(a_{jit})/G_i(a_{iit})$ is the conditional probability of a domestic firm that becoming a MNE. The ex-ante, expected net profit $\tilde{\pi}_{it}$ is the same as the actual average net profit of an intermediate firm from the second stage, with $\tilde{\pi}_{iit}$, $\tilde{\pi}_{xit}$ and $\tilde{\pi}_{jit}$ denote the average net profits from domestic market, exports and MNEs, respectively.

A potential innovator from country i expects to benefit from a perpetual expected net profit flow after a product is introduced. The ex-ante value of a firm, W_{it}, is given by the present value of the expected future profit flow conditional on surviving the second stage. The expected rate of return from innovation, plus the rate of capital gain or loss from the change in the expected value of a firm, must equal the risk-free interest rate. This equality is given by:

$$r_{it} = \frac{\tilde{\pi}_{it}}{W_{it}} + \frac{\dot{W}_{it}}{W_{it}}, \tag{2.29}$$

Intermediate firms continue to enter as long as their expected value, W_{it}, covers the cost of innovation, denoted by η_{it}. The free-entry condition for a country i firm is given by:

$$\left(\frac{a_{iit}}{a_{i0}}\right)^{k_i} W_{it} = \eta_{it}, \tag{2.30}$$

where $(a_{iit}/a_{i0})^{k_i}$ is the probability of a firm that makes non-negative profits. The free-entry condition for a country j's firm is similar. This condition implies that firms enter until the expected value of innovation, which is given by the probability of surviving the second stage multiplied by the expected discounted future profit flows, is equal to the cost of innovation. The entry of innovators pushes the market interest rate to adjust until the free-entry condition is satisfied. If the expected value of innovation is greater (smaller) than the cost of innovation, then there will be an infinite (zero) number of firms who are willing to enter, which drives the interest rate upward (downward) due to excess (zero) demand of resources for R&D.

Scale Effect

We now revisit the second stage problem from Section 2.2.4. Note that an increase in country i's labour force L_i would increase the cut-off cost of entry a_{iit} as inferred from equation (2.22), while holding everything else constant. The increase in the cut-off cost increases the probability of surviving. As a result, more firms are willing to enter each period, meaning that an increase in the labour force would lead to an increase in the output growth rate. This is the so-called 'scale effect' in the growth literature, which is not supported by the data.[18]

To correct for the scale effect, I modify the one-time fixed costs f_{sd} to $f_{sd}/(K_{dt}/Y_{dt})$ for $s \in \{i, x, j\}$ and $d \in \{i, j\}$, where K_{dt} is an index of a country's stock of knowledge. K_{dt}/Y_{dt} is the stock of knowledge relative to the size of the economy. This modification implies that the entry cost is proportional to the relative stock of knowledge — the larger the relative stock of knowledge the lower the entry cost. I assume $K_{dt} = \tilde{a}_{dt}^{1-\epsilon} N_{dt}$ so that the stock of knowledge is indexed by the effective number of intermediate goods available in a country. Such a modification is consistent with the results from micro-founded R&D growth model such as Jones (1995b) and Segerstrom (1998).

Note that with this modification, the one-time fixed costs are still constant since:

$$\frac{f_{sd}}{K_{dt}/Y_{dt}} = f_{sd} A_d^{\frac{1}{1-\alpha}} \alpha^{\frac{2\alpha}{1-\alpha}} L_d. \tag{2.31}$$

All the results from the second stage intermediate good firm problem should be modified by replacing the fixed costs with the 'scale-effect-corrected' ones. Other than that, all the results from Section 2.2.4 still hold.

Cost of Innovation and Technology Spillovers

Recall that from the free-entry condition (2.30), the expected value of innovation is equal to the cost of innovation. This one-time cost of innovation is affected by the degree of technology spillovers. A spillover here refers to the degree to which the existing technology can be used for the creation of future technology. The pool of existing technology includes those

[18] The older generation of endogenous growth models such as Romer (1990) and Grossman and Helpman (1991) have been criticized for their 'scale effect' feature. The larger the population size, the more resources devoted to R&D, and the higher the long-run growth rate of an economy. Jones (1995a) used the data from the US and other OECD countries between 1990 and 1987 to show that such a scale effect does not exist.

that are innovated domestically and from abroad. The contribution of foreign technologies to the spillovers process is referred to as international spillovers, whereas the contribution of the pool of existing technology as a whole to the innovation process is referred to as intertemporal spillovers.

In their theoretical work, Eaton and Kortum (1999) show that the quality difference of technology is important for technology diffusion. The diffusion of a high quality foreign technology that embodies high productivity can contribute to the domestic innovation process. Foreign technology that is inferior will become obsolete even if it has been diffused. Rodriguez-Clare (2007) has shown that technology diffusion is beneficial if high-quality intermediate goods are traded. Recent empirical evidence from Alfaro and Charlton (2007), Pradhan (2006), and Smeets (2008) supports these ideas.

I define the productivity per unit of final output spent on innovation as:[19]

$$h_{it} = R_{it}^{-\phi} \left(N_{iit} + \lambda_{it} N_{jjt} \left(\frac{\bar{a}_{xjt}}{\tilde{a}_{iit}} \right)^{1-\epsilon} \right)^{\phi}, \tag{2.32}$$

where λ_{it} is a function that controls the level of international technology spillovers, and ϕ is a parameter that controls intertemporal technology spillovers. I restrict $0 \leq \phi < 1$. $\bar{a}_{xjt}$ is the weighted average unit cost of both imported and foreign MNEs' intermediate goods, in which $(\bar{a}_{xjt}/\tilde{a}_{iit})^{1-\epsilon}$ accounts for the relative productivity of foreign technologies that are introduced domestically, which is also the relative quality of foreign technologies diffused.

Innovation productivity decreases with R&D expenditure R_{it}. Spending more on each new design implies a less productive innovation process. In contrast, an increase in the number of home-grown (N_{iit}) or foreign-grown (N_{jjt}) intermediate goods implies that with more technology available, it is easier to create a new design. The level of international

[19]See Gustafsson and Segerstrom (2010a) and Freire-Seren (2001) for similar specifications.

spillovers is controlled by λ_{it}, which captures the degree to which foreign technology contributes to the home stock of knowledge. Foreign technology is being transferred either through imports or foreign MNEs. As suggested by Unel (2010), I assume that the level of international spillovers is measured by the share of foreign intermediate goods sales in a country's total intermediate goods sales, or (see Appendix A.3 for details):

$$\lambda_{it} = \frac{\text{import sales}_t + \text{foreign MNE sales}_t}{\text{total sales}_t}. \tag{2.33}$$

In particular, an increase in the number of foreign MNEs provides an additional effect on the quality of technology diffused. I define:[20]

$$\bar{a}_{xjt} = \left[\frac{N_{xjt}\tilde{a}_{xjt}^{1-\epsilon} + N_{ijt}\tilde{a}_{ijt}^{1-\epsilon}}{N_{xjt} + N_{ijt}} \right]^{\frac{1}{1-\epsilon}}. \tag{2.34}$$

When the number of foreign MNEs (N_{ijt}) increases, more weight is assigned to the average foreign MNE productivity index $\tilde{a}_{ijt}^{1-\epsilon}$. Since MNEs are more productive than exporters, more MNEs means higher quality technology being diffused. This channel provides additional international technology spillovers which further increases the productivity of innovation.[21]

The cost of innovation paid by an innovator is defined as:

$$\eta_{it} = h_{it}^{-1} \frac{f_i^I}{(K_{it}/Y_{it})^{1-\phi}}. \tag{2.35}$$

The inverse of the innovation productivity, which can be interpreted as the cost per unit of final output spent on innovation, is multiplied by the unit of final output required to innovate, which is given by $\bar{f}_i^I = f_i^I/(K_{it}/Y_{it})^{1-\phi}$, a scale-effect-corrected fixed cost adjusted by the degree of intertemporal spillovers. The intuition here is that international spillovers

[20] This *average* unit cost is constructed similarly as the average cost from equation (2.27)

[21] If two countries are symmetric, the average productivity of the diffused foreign technology will always be higher than the average home-grown technology. This is not necessarily true if countries are asymmetric.

increase the productivity of innovation h_{it}, and thereby decrease the cost of innovation η_{it} and speed up the innovation process. Notice that the scale-effect-corrected fixed cost is similar to those discussed previously, which is a constant cost.

R&D investment in aggregate is given by $R_{it} = \eta_{it}\dot{N}_{iit}$. Using this relationship, innovation exhibits constant-returns-to-scale in aggregate:

$$\dot{N}_{iit} = R_{it}^{1-\phi}\left(N_{iit} + \lambda_{it}N_{jjt}\left(\frac{\bar{a}_{xjt}}{\tilde{a}_{iit}}\right)^{1-\epsilon}\right)^{\phi}(\bar{f}_i^I)^{-1}. \tag{2.36}$$

The free-entry condition (2.30) and the cost of innovation (2.35) together imply that $\dot{W}_{it}/W_{it} = -\dot{h}_{it}/h_{it}$. Equation (2.29) then becomes:

$$r_{it} = \frac{\tilde{\pi}_{it}}{W_{it}} - \frac{\dot{h}_{it}}{h_{it}}. \tag{2.37}$$

Although $\dot{h}_{it}/h_{it}$ can change over time, it must be zero along the balanced growth path, which will be discussed below. I first define a stationary equilibrium, and then I solve for the balanced growth path of the model.

2.2.6 Definition of Stationary Equilibrium

Given the initial state variables, N_{ii0} and N_{jj0}, the stationary equilibrium of this economy consists of a vector of cut-off costs of intermediate goods sector and firm-level variables $\{a_{iit}, a_{xit}, a_{jit}, a_{jjt}, a_{xjt}, a_{ijt}, W_{it}, W_{jt}, \eta_{it}, \eta_{jt}\}$, and vectors of economy-wide sequences $\{Y_{dt}, C_{dt}, R_{dt}, M_{dt}, NX_{dt}, B_{dt}, \dot{B}_{dt}, Z_{dt}, N_{sdt}, w_{dt}, r_{dt}\}_{t\in[0,\infty)}$ for $s \in \{i, x, j\}$ and $d \in \{i, j\}$ that satisfy the following conditions:

(i) Households allocate consumption over time to maximize utility (2.1) subject to the budget constraint (2.2), and the transversality condition $lim_{t\to\infty}e^{-r_{dt}}B_{dt} = 0$ for $d \in \{i, j\}$, taking wage rates and interest rates as given;

(ii) Final goods producers minimize costs by choosing labour and intermediate inputs subject to production function (2.3), taking prices of intermediate goods as given;

(iii) Intermediate goods firms maximize profit function (2.16) by choosing their prices, taking into account the demand function of final goods producers, the marginal cost of production based on their costs draws, and the per-period fixed costs to enter each market;

(iv) The cut-off costs of intermediate goods sector are constant, such that the costs distributions of domestic firms, exporters, and MNEs are stationary;

(v) Free-entry condition (2.30) is satisfied;

(vi) Markets clear in country d, for $d \in \{i, j\}$:

$$\begin{aligned} L_d &= \bar{L}_d, \\ \dot{B}_{dt} &= R_{dt}, \\ Y_{dt} &= C_{dt} + R_{dt} + M_{dt} + NX_{dt}; \end{aligned}$$

and (vii) World markets clear: $NX_{it} = -NX_{jt}$.

2.3 The Balanced Growth Path

In this section, I solve for the model for a balanced growth path (BGP). The balanced growth path is a stationary equilibrium where all endogenous macroeconomic variables grow at constant rates over time. I drop the time subscript for the variables that do not change along the BGP.

I define the rate of innovation, g_i, as the rate at which the number of home-grown intermediate goods (N_{iit}) expands, and is constant along the BGP. Recall that non-profitable innovators do not enter and are not counted as part of N_{iit}. The rate of innovation, g_i, then only accounts for the new entrants of domestic intermediate firms that make non-negative profits by entering the markets. Since there is no population growth, the growth rates of the macroeconomic variables are equivalent to their per capita growth rates.

First, we examine the relationship between N_{it} and N_{iit}:[22]

$$N_{it} = N_{iit} + N_{xjt} + N_{ijt} = N_{iit} \left(1 + \frac{G_j(a_{xj})}{G_j(a_{jj})} \frac{N_{jjt}}{N_{iit}} \right). \tag{2.38}$$

Along the balanced growth path, the ratio N_{jjt}/N_{iit} is constant.[23] The intuition is that if this ratio is, for example, larger than the equilibrium ratio, meaning that $N_{jjt}/N_{iit} > (N_{jjt}/N_{iit})^*$, where the asterisk denotes equilibrium, then the innovation productivity h_{it} will be higher than in equilibrium. This in turn reduces the cost of innovation so that a greater variety of intermediate goods will be developed and produced. As long as country i's rate of innovation is higher than country j's, the N_{jjt}/N_{iit} ratio keeps decreasing, which in turn decreases the innovation productivity h_{it} over time. This process continues until the equilibrium ratio is reached. The reverse is true when this ratio is below its equilibrium value. This result implies that in order for N_{jjt}/N_{iit} to be constant, the growth rates of N_{iit} and N_{jjt} must be equal. Hence, the rates of innovation across countries are equal: $g_i = g_j = g$. This result holds as long as international spillovers are present when $\lambda_{it} > 0$.[24]

Not only are the rates of innovation across countries equal, but all endogenous macroeconomic variables grow at the same rate. Since N_{jjt}/N_{iit} is constant along the BGP, and the costs distributions are stationary, equation (2.38) implies that $\dot{N}_{it}/N_{it} = g$ along the BGP. The final output equation (2.26) implies that Y_{it} is a linear function of N_{iit}. R&D

[22] Make use of

$$N_{xjt} = \frac{G_j(a_{xj}) - G_j(a_{ij})}{G_j(a_{jj})} N_{jjt} \quad , \quad N_{ijt} = \frac{G_j(a_{ij})}{G_j(a_{jj})} N_{jjt}.$$

[23] For the symmetric case, $N_{jjt}/N_{iit} = 1$. The model is jump-stable.

[24] If the two countries are in autarky, meaning that there is neither trade nor MNEs, then there is no mechanism for the two rates of innovation to converge when the initial conditions of the two countries are different.

investment R_{it} and net exports NX_{it} are also linear functions of N_{iit} as illustrated in Appendix A.4 and A.1.[25] Also, since intermediate goods spending, M_{it}, is proportional to output, these together imply that C_{it} is also a linear function of N_{iit} based on the aggregate resource constraint (2.12).

Since the endogenous macroeconomic variables are all linear functions of N_{iit}, the growth rates of these variables are all equal to the rate of innovation g across countries, which is also the per capita growth rate. The following proposition summarizes these results:

Proposition 1: *In the presence of international spillovers, the growth rates of final output Y_{dt}, spending on intermediate goods M_{dt}, R&D investment R_{dt}, net exports NX_{dt}, the number of intermediate firms N_{dt}, and aggregate consumption C_{dt} for $d \in \{i, j\}$ are all equal to the rate of innovation given by:*

$$g = \frac{1}{\theta}\left(\left(\frac{a_{ii}}{a_{i0}}\right)^{k_i}\frac{\tilde{\pi}_i}{\eta_i} - \rho\right). \tag{2.39}$$

Proof: To derive this equilibrium growth rate, first note that the innovation productivity equation (2.32) can be rewritten as:

$$h_i = \left(1 + \lambda_i \frac{N_{jjt}}{N_{iit}}\left(\frac{\bar{a}_{xj}}{\tilde{a}_{ii}}\right)^{1-\epsilon}\right)^{\phi}\left(\frac{R_{it}}{N_{iit}}\right)^{-\phi}. \tag{2.40}$$

Stationary costs distributions, a constant N_{jjt}/N_{iit} ratio, a constant λ_i, and a constant R_{it}/N_{iit} ratio along the BGP together imply that h_i is constant as well, so that $\dot{h}_i/h_i = 0$.[26]

[25] From Appendix A.4, $R_{it} = \Gamma_i N_{iit}$, where Γ_i is constant along the BGP. From Appendix A.1, $NX_{it} = \nu_i N_{iit}$. ν is constant along the BGP because: 1) the stationary distributions imply that the shares of exporters and MNEs are constant; and 2) Euler equation (2.7) implies that interest rate is constant along the BGP. The average net profits to serve different markets, as shown in Appendix A.2, are constant due to a constant interest rate r_i.

[26] A constant N_{jj}/N_{ii} ratio and constant cut-off costs imply a constant λ_i. See Appendix A.3 for details of λ_i.

Using this fact, the free-entry condition (2.30) and equation (2.37) yield r_i along the BGP. The equilibrium interest rate and the Euler equation (2.7) together give the equilibrium growth rate (2.39).

Note that the rate of economic growth, g, can be affected by trade and multinational production through two channels: (1) average profit of an intermediate good firm $\tilde{\pi}_i$, and (2) international technology spillovers that drive the cost of innovation η_i.[27] Furthermore, the equilibrium growth rate also implies that the equilibrium interest rates across countries are equal, *i.e.* $r_i = r_j = r$.

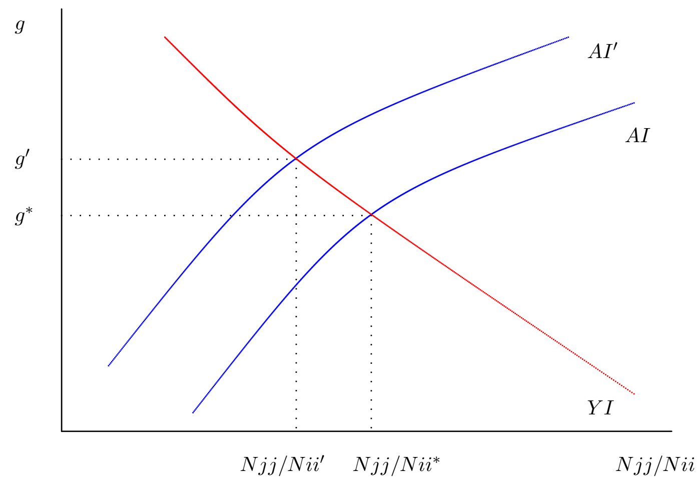
The aggregate innovation equation (2.36) and final output production (2.26) represent two different relationships that link growth rates and the N_{jjt}/N_{iit} ratio. First, I define a relationship (AI) between the rate of innovation and the N_{jjt}/N_{iit} ratio based on aggregate innovation (2.36). Second, I define a relationship (YI) between final output growth and the N_{jjt}/N_{iit} ratio based on the final output equation (2.26). As illustrated in Figure 2.1, the aggregate innovation AI curve is upward sloping and the final output growth curve YI is downward sloping.[28] The g-axis here denotes growth rate in general: the growth rate of output for the YI curve and the rate of innovation for the AI curve.

The AI curve is upward sloping in the (g, N_{jjt}/N_{iit}) space as illustrated in Appendix A.5. When a larger pool of foreign technologies is available for international spillovers as the N_{jjt}/N_{iit} ratio increases, the cost of innovation decreases and more domestic innovators are willing to enter. Consequently, the rate of innovation g_i increases with the N_{jjt}/N_{iit} ratio.

[27] Although $\tilde{\pi}_i$ and η_i are linear functions of L_i as seen in Appendix A.2 and A.4, the L_i's cancel out in $\tilde{\pi}_i/\eta_i$. Since L_i does not affect a_{ii} with the scale-effect-corrected fixed cost, the growth rate does not exhibit scale effect.

[28] The YI curve can have an upward sloping section that can result in an unstable equilibrium. Here we focus on a stable equilibrium that exists on the downward sloping section of the YI curve. See Appendix A.5 for a discussion on the shape of YI curve.

Figure 2.1: Determination of the BGP Growth Rate



Since final output is produced using both domestic and foreign intermediate inputs, output growth depends on both countries' rates of innovation. As a result, the slope of the YI curve must be flatter than the AI curve. As illustrated in Appendix A.5, the YI curve has a downward sloping section in which the domestic output growth decreases with the N_{jjt}/N_{iit} ratio. I focus on the downward sloping section of the YI curve to avoid the possibility of multiple equilibria and the existence of unstable equilibrium on the upward sloping section of the curve. The AI and YI relationships give the following proposition:

Proposition 2: *The intersection of the AI curve at the downward sloping section of the YI curve determines a stable BGP.*

Proof: See Appendix A.5.1.

Intuitively, the production of final output supplies resources for R&D investment. The aggregate innovation governs the demand for R&D investment in aggregate. The two relationships together determine the BGP growth rate — output and innovation must grow at the same rate along the BGP, otherwise resources allocated to innovation would either be too much or too little. The point where the two curves intersect determines a stable, long-run growth rate g^*, with the corresponding ${N_{jjt}/N_{iit}}^*$ ratio which is constant along the BGP.

2.3.1 The Effects of Openness on Growth

In this section we examine how a change in the openness policy can affect the BGP growth rate. We first examine the effects of changing the fixed costs of MNEs, then analyze the effects of trade liberalization.

The Effects from Attracting MNEs

As discussed in Section 2.2.1, fixed costs in general consist of costs to establish production facilities, costs of distribution, lobbying costs and other policy-related costs. Since part of the MNE fixed costs are policy-related, we treat the MNE fixed costs as a policy variable for attracting MNEs from abroad.[29]

When the foreign country j unilaterally decreases the fixed cost of MNEs to encourage firms from country i to allocate their subsidiaries there, the AI curve of country i shifts up. The foreign market expansion increases the average profit of intermediate firms for all N_{jjt}/N_{iit} ratio, thus more resources are demanded by potential entrants for R&D. The AI curve shifts to a new position at AI', as shown in Figure 2.1. The BGP growth rate g is now higher, with a lower N_{jjt}/N_{iit} ratio in equilibrium due to a relatively larger expansion in N_{iit}.

If country i also decreases the fixed cost of MNEs, the AI curve will shift up even

[29] A majority of countries around the globe established investment promotion agencies (IPAs) to help their home countries to attract foreign direct investments. Particularly, these agencies have made efforts to effect changes in regulations, laws, and government policies related to taxes, infrastructure, and other areas. See report by UNCTAD (2008) and Charlton and Davis (2007).

further due to extra spillovers from foreign MNEs. The YI curve will also shift up because of the extra expansion of foreign intermediate inputs used in domestic final output production. As a result, the equilibrium growth rate when both countries open is higher than when a country unilaterally opens. The effect on the equilibrium N_{jjt}/N_{iit} ratio is ambiguous, depending on the shifting of the curves.

The Effects from Trade Liberalization

Although a decrease in fixed costs will always result in a rise in the equilibrium growth rate, the effect is not as clear-cut for trade liberalization, as the effect depends on the type and level of technology spillovers. From the Euler equation (2.7), we have:

$$\frac{\partial g}{\partial \tau} = \frac{1}{\theta}\frac{\partial r}{\partial \tau},$$

where τ is the iceberg trade cost. Free-entry condition (2.30) and equation (2.37) together imply:

$$\frac{\partial lnr}{\partial \tau} = \frac{\partial ln\tilde{\pi}_i}{\partial \tau} - \frac{\partial ln\eta_i}{\partial \tau}.$$

Notice that $sign(\partial g/\partial \tau) = sign(\partial lnr/\partial \tau)$.

With quality-adjusted international spillovers as in equation (2.32), an increase in τ can potentially lead to an increase in the growth rate g and can be welfare-improving. Although λ_i decreases as τ increases, $(\bar{a}_{xj}/\tilde{a}_{ii})^{1-\epsilon}$ increases due to the exit of less productive imports and the entry of more productive MNEs. The latter effect dominates the former, so that $\partial ln\eta_i/\partial \tau < 0$. The question is whether $\partial ln\tilde{\pi}_i/\partial \tau$ will offset $-\partial ln\eta_i/\partial \tau$. Due to the proximity-concentration trade-off, firms self-select to become MNEs when they find it more profitable than exporting. As trade cost increases, some exporters exit, and some become MNEs.[30] Particularly, when the trade cost is high, exports sales are small. As trade

[30] As shown in equation (2.24), some firms (existing and new entrants) who would have export along the

costs continue to increase from a high level, small incremental losses in exports sales are more likely to be offset by the gains from MNE sales. The average firm will experience a small profit loss, or even start to gain some profits, thus $\partial ln\tilde{\pi}_i/\partial\tau$ is negative but small, or can be positive, when the trade cost is high. The properties of $\partial ln\eta_i/\partial\tau$ and $\partial ln\tilde{\pi}_i/\partial\tau$ are discussed in Appendix A.6.1. Based on these properties, two scenarios can happen and are summarized in the following proposition.

Proposition 3: *If export losses are less than gains from MNE sales for some range of τ, and if the spillovers process accounts for the adjustment on the quality of technology, then there exists a cut-off trade cost, τ^*, such that $\partial g/\partial\tau > 0$ for $\tau > \tau^*$, and $\partial g/\partial\tau \leq 0$ for $\tau \leq \tau^*$.*[31] *Otherwise, $\partial g/\partial\tau < 0\ \forall\tau$.*

Proof: See Appendix A.6.2.

Graphically, for an economy that initially has a $\tau > \tau^*$, the AI curve in Figure 2.1 shifts down when τ decreases due to a decline in quality-adjusted technology spillovers as trade becomes more liberalized. Although the YI curve shifts up due to an increase in imported intermediates, the shift of the AI curve dominates and growth decreases. If the initial $\tau < \tau^*$, or if τ^* does not exist, then a decrease in τ will always lead to a higher growth. In this case, both AI and YI curves shift up when trade is liberalized across countries.

If the spillovers process does not account for the adjustment on the quality of technology, then equation (2.32) becomes:

$$h_i = R_i^{-\phi}\left(N_{iit} + \lambda_i N_{jjt}\right)^{\phi}, \tag{2.41}$$

original BGP will exit the foreign market along the new BGP with a higher trade cost, while some would find it profitable to become MNEs along the new BGP.

[31] An increase in trade costs can be welfare-improving in this model because firms do not take into account the externalities coming from international spillovers. This does not happen in an efficient economy without such externality.

which is standard in the growth literature.[32] The following proposition can be established:

Proposition 4: *Trade restriction will result in a decrease in the equilibrium growth rate for $\tau < \tau'$ if the spillovers process does not account for the adjustment on the quality of technology,* i.e. $\partial g/\partial \tau < 0$ *for* $\tau < \tau'$*. Moreover,* $\tau^* < \tau'$*.*

Proof: See Appendix A.6.3.

As the trade cost τ increases, some exporters exit and the total foreign intermediates sales decrease. Although it is partially offset by an increase in MNE sales, the effect on the degree of international spillovers λ_i is still negative, which causes the cost of innovation η_i to rise and induces R&D expenditure to drop. The interest rate is driven down due to a decrease in demand for resources used in R&D. For $\tau < \tau'$, the average plant productivity and average profit falls as τ increases, which further reduces the real return on investment, hence a lower equilibrium growth rate.

2.4 Quantitative Results

In this section we use the model to quantify the effects of openness to trade and multinational production on growth and welfare. The first exercise measures the gains from openness for the US and for an economy represented by a set of eighteen OECD countries: Australia, Austria, Belgium/Luxemburg, Canada, Denmark, Finland, France, Germany, Greece, Italy, Japan, Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, and the United Kingdom. I call this the 'US-OECD' case. In the second exercise, the US is treated the same as the other OECD countries and I examine the average gains from openness across the nineteen countries. I call this the 'average OECD case'. The two scenarios

[32] For example, see Gustafson and Segerstrom (2010a) and Freire-Seren (2001).

differ in terms of the countries' trade-to-MNE sales ratios, which allow us to examine how the different trade-to-MNE sales ratios can affect long-run consumer welfare as trade is liberalized.

2.4.1 Calibration

Table 2.1 illustrates the parameter values and the targets to which the individual parameters are calibrated. The cost distribution parameter (k_i) is the same across countries, and it satisfies the firm size dispersion ($k_i - \epsilon + 1$) of 1.25 as suggested by Helpman, Melitz, and Yeaple (2003) based on US and European countries firm-level data. I normalize the minimum possible value of unit costs (a_{i0}) to be 1. The elasticity of substitution (ϵ) of 3.8 comes from Bernard, Eaton, Jensen and Kortum (2003) which is calibrated based on fitting US plant and macro trade data. The intertemporal spillovers parameter (ϕ) of 0.2 is an estimate from Bloom, Schankerman, and Van Reenen (2007) based on US patent data from 1980 to 2001. As suggested by Novy (2008), the iceberg trade cost of 1.42 among OECD countries is the estimated trade-weighted average of US bilateral trade costs. The risk aversion parameter (θ) is chosen to be 2. The time preference parameter (ρ) is calibrated to fit the relationship between the per capita growth rate and the historical real return on stock of 7%. Finally, the output used per innovation (f_i^I), which is part of the cost of innovation, is calibrated to match the long-run per capita growth rate of 2%. This is the long-run average per capita real GDP growth rate and real consumption growth rate among OECD countries for the period from 1970 to 2008.

Table 2.2 describes two sets of facts used in the two quantitative exercises, respectively. To match these facts, I jointly calibrate the aggregate productivity parameters A_d and the fixed costs f_{sd} for $s \in \{i, x, j\}$ and $d \in \{i, j\}$. For the US-OECD case, I match the model

Table 2.1: Single Parameters Calibrated

Params	Descriptions	Values	Targets
k_i	cost distribution	3.75	firm size dispersion in Helpman et al. (2003)
a_{i0}	minimum cost draw	1	normalization
ϵ	elasticity of substitution	3.8	Bernard et al. (2003)
ϕ	intertemporal spillovers	0.2	Bloom et al. (2007)
τ	OECD trade cost	1.42	Novy (2008)
θ	risk aversion	2	Ghironi & Melitz (2005)
ρ	time preference	0.03	real return on stock 7%
f_i^I	output used per innovation		per capita real GDP growth 2%

with the US goods export and import share of GDP, and the US shares of outward and inward MNE goods sales of GDP.[33] I account for the US trade and MNE sales of goods with the eighteen OECD countries. I also match the model with the US to the eighteen OECD countries' per capita GDP ratio and the labour force ratio to control for the relative size of the economies and thereby improve the relevance of welfare measures. These two ratios are calculated based on the data from the World Bank's World Development Indicators for the period from 1970 to 2008. The export and import data are from the OECD STAN data set for the period from 1988 to 2008. The MNE sales averages are adjusted to exclude intrafirm trade and other non-local sales. The inward and outward MNE sales data are from the US Bureau of Economic Analysis for the period from 1997 to 2007. For the average OECD case, I calculate the average trade and MNE sales shares of GDP from the sample of nineteen OECD countries.

[33] Unlike in the data, final output Y_{it} and GDP $Y_{it} - M_{it}$ are different in this model as described in Footnote (14). Since intermediate goods M_{it} and final output Y_{it} are proportional, calibrating the fixed costs to match the various sales-to-final output ratios in the model with the sales-to-GDP ratios in the data would reflect the foreign shares of intermediate goods and therefore reflecting the degrees of openness in the data. Contrary, matching sales-to-'GDP' ratios of the model to the data would be inconsistent with reflecting openness in the data.

Table 2.2: Multiple Parameters Calibrated

A_d aggregate productivity for $d \in \{i, j\}$	
f_{sd} fixed costs, $s \in \{i, x, j\}$	
For the US vs the rest of OECD case:	
US-OECD per capita GDP ratio	1.35
US-OECD labour force ratio	0.45
US export share of GDP	3.9%
US import share of GDP	5.4%
US outward MNE sales share of GDP	12.3%
US inward MNE sales share of GDP	12.1%
For the average OECD case:	
Average trade sales share of GDP	19.4%
Average MNE sales share of GDP	24.6%

Table 2.3 illustrates other quantitative implications which are generated by the parameterized version of the model, but were not targeted as part of the calibration. These implications are from the US-OECD case, and the results are similar for the average OECD case. First, the elasticity of substitution (ϵ) of 3.8 would yield a 36% markup over marginal cost in the model, which is much higher than the markup suggested by the macroeconomic literature such as Basu and Fernald (1997). However, due to the presence of per-period fixed costs, the markup over *average* cost is 22% for the average OECD country, which is consistent with the literature. The elasticity of 3.8 further implies a labour share of 26%, which is close to the average labour share in gross manufacturing production of 21% as suggested by Eaton and Kortum (2002) based on the same set of nineteen OECD countries.[34] The cost of innovation is 58% of per capita final output, which is consistent with

[34]This implies an intermediate sector's share of final output (α) of 0.7368, which is consistent with the growth literature. One can think of intermediate goods as service flows from a broad base of capital, which includes both physical and human capital. In this model, such capital is fully depreciated once it becomes an input of the final good. The intermediates share α can be interpreted as the capital share, which ranges from 0.6 to 0.75 according to Howitt (2000) and Barro and Sala-i-Martin (2004).

the values reported by Barseghyan and DiCecio (2009). Furthermore, the model yields a R&D expenditure shares of final output of 3.8% for the average OECD country, which is well-within the upper end of the R&D-to-GDP ratio among the OECD countries.

Table 2.3: Other Quantitative Implications - US-OECD case

Model	Values	Sources	Values
Markup over average cost	22%	Basu & Fernald (1997)	19%
Manufacturing labour share	26%	Eaton & Kortum (2002)	21%
Cost of innovation (per Y/L)	58%	Barseghyan & DiCecio (2009)	50%
R&D share of output	3.8%	OECD (highest)	4.2%
OECD trade/MNE sales with the US (as a share of final output)			
OECD export share	3.3%	OECD STAN	3%
OECD import share	2.4%	OECD STAN	2.7%
OECD outward MNE sales	7.3%	OECD STAN	7.6%
OECD inward MNE sales	7.4%	OECD STAN	10%
Fixed costs (per-period)	**Values**	**Rodrigue (2010)**	
Domestic	\$3,071	\$3,000-4,600	
Exporters	\$4,278	\$3,000-9,200	
MNEs	\$46,106	\$17,000	

The middle panel of Table 2.3 shows the OECD trade and MNE goods sales with the US implied by the model as shares of the OECD final output. These implied shares are consistent with the actual shares found in the data, except that the implied inward MNE sales share is lower than the actual share.

The bottom panel of Table 2.3 shows the dollar values of the per-period fixed costs implied by the model for domestic producers, exporters, and MNEs. The amounts are expressed in 2000 US dollars. I compare these values to Rodrigue (2010)'s estimates based on Indonesian plant-level data.[35] The domestic and exporters fixed costs are well-within

[35] The fixed costs values are expressed in 1983 US dollars. These values are converted to 2000 US dollars for comparison.

the ranges of values estimated by Rodrigue (2010). While the MNEs fixed cost is higher than his estimates, it is consistent with what the literature suggests.[36]

2.4.2 The US-OECD Case

I conduct numerical exercises to quantify the effects of openness on growth and welfare by restricting trade or multinational production, or both. Tables 2.4 and 2.5 present the numerical results for the US-OECD case.

Table 2.4 presents the long-run per capita growth rates of the US-OECD case under different degrees of openness. The first two columns indicate the trade and MNE status: 'bench' indicates that the trade or MNE sales share of final output is matched with the *benchmark* from the data; 'hist' indicates that the ice-berg trade cost is increased to the *historical* level of 1.74 in 1970; and 'no FDI' indicates that the cost of forming MNEs in the world economy is infinite.[37] The first row shows that the benchmark growth rate is 2% across all specifications of spillovers processes.[38]

I first discuss the results from the third and fourth columns, in which international technology spillovers are absent from the model.[39] The changes in growth rates are similar across the two economies. These results are also similar to the results presented in the fifth column when international spillovers are present, which imply that endogenous growth in this model does not rely on international spillovers. Since the results are similar with or

[36]Irarrazabal, Moxnes, and Opromolla (2009) suggest that MNE fixed costs can be up to several hundred times of exporters' fixed costs.

[37]The historical iceberg trade cost of 1.74 in 1970 is an estimate from Novy (2008). The autarkic trade cost is the upperbound of trade cost according to condition (2.6), and the autarkic MNE fixed cost is infinity.

[38]For each of the three spillovers setting, I re-calibrated the aggregate productivity parameters, the output used per innovation, and the fixed costs to match with the benchmark growth rate, the per capita GDP ratio, and the trade and MNE sales shares of GDP.

[39]I set $\lambda_i = \lambda_j = 0$. The BGP growth rates are not equal across countries because in the absence of international spillovers, there is no mechanism for growth rates to converge, as discussed in Section 2.3.

Table 2.4: Changes in Growth Rates: US-OECD

Trade	MNE	Growth (%)			
		no spill		w/ spill	w/quality
		US	OECD		
bench	bench	2.00	2.00	2.00	2.00
hist	bench	1.96	1.97	1.96	**2.37**
bench	no FDI	1.83	1.90	1.87	1.58
autarky (US)		1.63		1.54	1.55
autarky (OECD)			1.77	1.73	1.75

Notes: 'bench' indicates the case in which the trade or MNE sales share of final output is matched with the data; 'hist' indicates that the ice-berg trade cost is increased to the historical level of 1.74 in 1970; and 'no FDI' indicates that the cost of forming MNEs in the world economy is infinite. 'no spill' means without international spillovers process, in which the BGP growth rates are not equal across countries; 'w/ spill' means with withinternational spillovers but without quality adjustment; and 'w/ quality' means with quality-adjusted international spillovers.

without international spillovers, I continue the discussion focusing on the spillovers case.

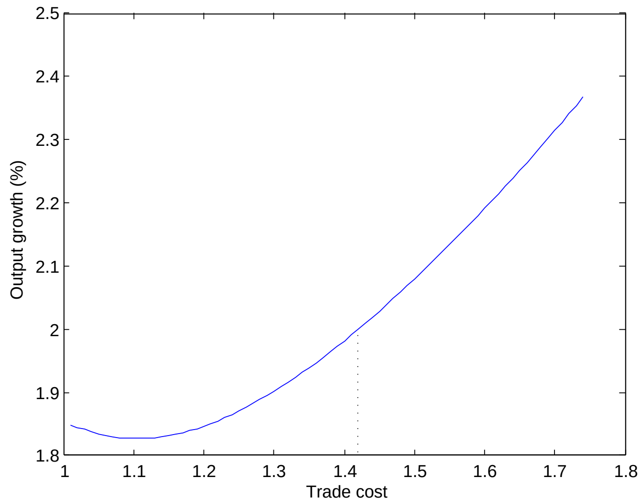
The fifth column shows the results in the presence of international spillovers but without quality-adjustment. We see that if we impose a trade cost back to the 1970 level, the growth rate would drop slightly to 1.96%, as shown in the second row.[40] From the third row, when MNEs are fully restricted, the growth rate drops to 1.87%.[41] The decrease in the growth rate is much larger when MNEs are restricted than when trade is restricted. These results show the importance of multinational production relative to trade on economic growth. When the world economy is in autarky, the US and the OECDs growth rates drop to 1.54% and 1.73%, respectively.[42]

[40] By pushing the trade cost to its upper bound, the growth rate would drop to 1.95%.

[41] MNEs are fully restricted when the fixed costs of MNEs are set to infinity.

[42] In autarky there are no international spillovers, so there is no mechanism for the growth rates to converge.

Figure 2.2: Output Growth and Trade Cost - US and OECD



Next, I focus on the results in the last column, in which the quality of technology is adjusted for in the spillovers process. When the historical level of trade cost is imposed, the growth rate increases to 2.37%, as shown in the second row of the last column. Figure 2.2 illustrates the relationship between the long-run growth rate and the iceberg trade cost. After a cut-off trade cost τ^* at 1.1, the long-run growth rate rises as the trade cost rises towards the historical cost of 1.74. As the trade cost is reduced from 1.1 towards 1, the growth rate rises as well, creating a U-shaped pattern between the growth rate and the trade cost. This U-shaped pattern could explain the weak empirical results on the effects of trade on growth in the empirical trade literature. For instance, if empirical estimates are based on the data that are near the bottom of the U-shaped curve, the marginal effects of reducing trade costs could be zero, although a complete trade liberalization should have large effects if we examine the entire spectrum of trade costs and output growth rates.

If the US and OECDs countries were to impose trade barriers from the benchmark trade cost of 1.42, the long-run economic growth rate would rise due to the improvement in the quality of technology diffused through multinational production. As discussed in Section

2.3.1, the exit of less productive imports and the entry of more productive MNEs together improve the quality of technology diffused from abroad, which lead to a lower cost of innovation. Also, an increase in MNEs can offset a large part of the profit losses in exports, which further provide incentives for innovation.[43] As previously discussed, if we do not account for the impact of trade openness on the quality of technology, then imposing trade barriers would still cause the long-run growth rate to fall due to disincentive to innovate as market size decreases.

To obtain a measure of welfare changes, I solve for $\triangle c_i$ in the following equation:

$$\bar{U}_i = \int_0^\infty e^{-\beta t} \frac{(c_i^0 + \triangle c_i)^{1-\theta} - 1}{1-\theta} dt \tag{2.42}$$

where $\beta = \rho - (1-\theta)g_i$. $\bar{U}_i$ is the level of lifetime utility attained along the BGP for a particular degree of international openness. I define $c_i^0 = C_{it}^0 / N_{iit}^0$ as the benchmark consumption per domestic intermediate good, which is constant along the BGP. $\triangle c_i$ is the change in consumption per domestic intermediate good that compensates the benchmark consumption to attain $\bar{U}_i$. The benchmark case here refers to the state of the world that is described by the data. The welfare gain is expressed as $\triangle c_i / c_i^0 \times 100$. Similarly, the welfare gain of country j is expressed as $\triangle c_j / c_j^0 \times 100$. Since there is no population growth, the welfare gains based on aggregate and per capita consumption are the same.

The welfare gains are dynamic in nature since consumption grows over time along the BGP, which is accounted for in the discount factor β. To separate out the level and growth effects, I measure the level effect separately in a stationary equilibrium in which there is no growth in the economy. The growth effect is the difference between the total gain and the level effect.

[43] In fact, for the US-OECD case, the average profit function $ln\tilde{\pi}_i$ is a U-shaped function in trade cost — first decreasing then increasing in τ. The function bottoms out at a $\hat{\tau} > \tau^*$ so that τ^* is on the decreasing side of the function, which is consistent with the analysis in Appendix A.6.

Table 2.5 illustrates the welfare results of the US-OECD case. The top, middle and bottom panels illustrate the results with quality-adjusted spillovers, spillovers without quality-adjusted, and without spillovers, respectively. The first two columns indicate the degree of openness. The third column illustrates the total welfare gains of the US, which are the sums of growth and level effects, and the fourth and fifth columns show the level and growth effects of welfare, respectively. The last three columns show the welfare results for the other OECD countries.

Table 2.5: Welfare Effects: US-OECD

With Quality-Adjusted Spillovers							
Trade	MNE	US Welfare (%)			OECD Welfare (%)		
		Total	Level	Growth	Total	Level	Growth
bench	bench	0.00	0.00	0.00	0.00	0.00	0.00
hist	bench	**14.71**	-3.19	**17.90**	**15.63**	-1.65	**17.28**
bench	no FDI	-27.11	-10.38	-16.73	-23.93	-6.40	-17.53
autarky		-37.22	-23.40	-13.82	-30.00	-13.88	-16.12
Spillovers Without Quality-Adjusted							
bench	bench	0.00	0.00	0.00	0.00	0.00	0.00
hist	bench	-4.26	-3.19	-1.07	-3.90	-1.65	-2.25
bench	no FDI	-17.56	-10.38	-7.18	-13.90	-6.40	-7.50
autarky		-39.05	-23.40	-15.65	-30.64	-13.88	-16.76
Without Spillovers							
bench	bench	0.00	0.00	0.00	0.00	0.00	0.00
hist	bench	-4.94	-3.19	-1.75	-3.29	-1.65	-1.64
bench	no FDI	-17.35	-10.38	-6.97	-13.35	-6.40	-6.95
autarky		-36.17	-23.40	-12.77	-27.55	-13.88	-13.67

Notes: The top, middle, and bottom panels illustrate the results with quality-adjusted spillovers, without quality-adjusted spillovers, and without any spillovers, respectively. The changes in welfare are compared with the benchmark case in which the growth rate is at 2% and the trade and MNE sales shares are matched with the US and OECD data. The gains are zero in the first row of each panel when the benchmark case is compared to itself. Total welfare gain is the sum of level and growth effects.

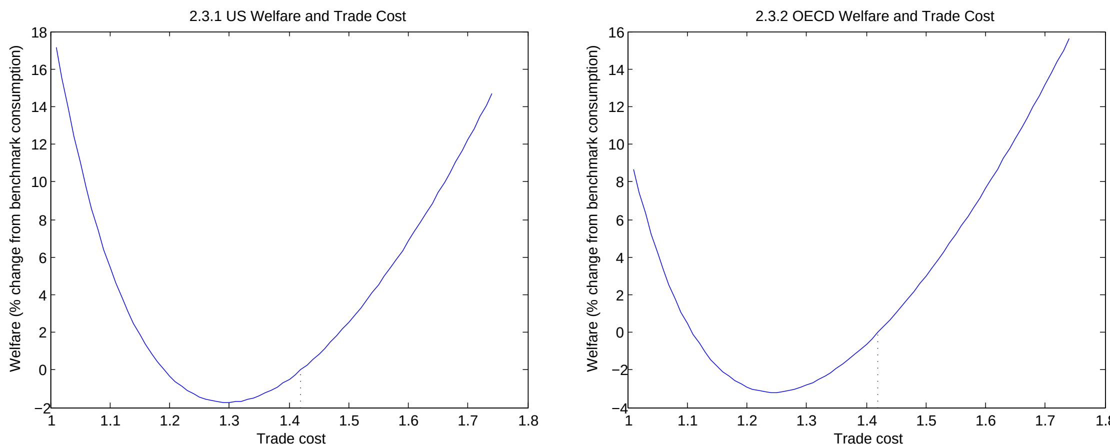
Consistent with the results from Table 2.4, the results from the top panel of Table 2.5 that are based on the model with quality-adjusted spillovers process are different from the results in the other two panels, with or without the presence of not-quality-adjusted spillovers, respectively.

In the first row of the top panel, the welfare gains are zero as the benchmark case is compared to itself. In the second row, the US and the OECDs would experience welfare gains of 14.71% and 15.63%, respectively, as the trade cost increases to the 1970 level, holding constant the costs of engaging in foreign investment. Recall that from Table 2.4, when the improvement on the quality of technology diffused is being considered, imposing trade barriers cause the growth rate to increase to 2.37%. An increase in trade costs alone makes both economies better off by attracting productive technologies from multinational production as a substitute for imports. The strong positive growth effects for both economies are more than offsetting the negative level effects coming from having less intermediate varieties for output production.

Figure 2.3.1 shows that there is a U-shaped relationship between the welfare gains of a US household and the trade cost. The curve bottoms out at a trade cost of about 1.3. This is the point where the change in welfare gain from growth is equal to the change in welfare cost from a negative level effect. From the benchmark trade cost of 1.42, the US can gain by raising the trade cost. Figure 2.3.2 shows that the welfare gains of an OECD household, which excludes the US, also displays a U-shaped relationship.

In contrast to the results in the top panel of Table 2.5, the middle panel shows that imposing trade barriers causes welfare to fall for both the US and the OECDs when the impact on the quality of technology is not accounted for. Recall that from Table 2.4, imposing trade barriers causes the growth rate to drop when the spillovers process is not quality-adjusted.

Figure 2.3: Welfare and Trade Cost - US and OECD



As a result, the growth effect is negative, contributing to the negative welfare effect.

When MNEs are restricted as shown in the third row of the three panels, the welfare costs are large, which highlight the importance of multinational production on consumer welfare. The welfare costs are larger in the top panel than in the other two panels due to the larger negative growth effect, which is a consequence of a larger drop in growth rate as shown in the last column of Table 2.4.

To understand why restricting MNEs is costly, I consider the welfare costs associated with the level and growth effects separately. Recall that from equation (2.39), the equilibrium growth rate is a function of the average profit of an intermediate good firm. The average profit consists of profits from domestic market, exports and multinational production. MNEs are more profitable than exporters due to productivity differences. When MNEs are restricted, the average profit is lower than when trade is restricted. This attracts fewer new entrants, and leads to a lower growth rate and a large negative growth effect on welfare. As for the level effect, since profits from the intermediate goods sector affect the consumption level, the absence of MNEs results in a larger negative level effect than in the absence of trade due to the differences in their profitabilities.

When the world economy is in autarky, the welfare costs for the US and the OECDs can go up to 39.05% and 30.64%, respectively, from the middle panel of Table 2.5. The autarkic level effects are 23.4% and 13.88%, respectively, which are comparable to the welfare costs suggest by McGrattan and Prescott (2009), Ramondo and Rodriguez-Clare (2009), and Rodrigue (2010). The growth effects account for 40% of the total welfare costs for the US, and 55% for the OECDs. Welfare costs may be substantially underestimated if the growth effects are not accounted for.

2.4.3 The Average OECD Case

In this section I discuss the quantitative results for the average OECD case, in which the model is calibrated to fit the average trade and MNE sales shares of GDP as shown in the bottom panel of Table 2.2. These results provide a sensitivity analysis of the growth and welfare effects of openness for the *average* country among the nineteen OECD countries in the sample.[44]

Since the results from the no spillovers case in the third column are similar to those in the fourth column, I focus on the results from columns 4 and 5 in Table 2.6 when international spillovers are present. The benchmark growth rate is 2% as shown in the first row. In the second row, when the trade cost is increased to the historical level in 1970, the growth rate drops to 1.87% when the spillovers process is not quality-adjusted. However, the growth rate rises to 2.14% with quality-adjusted spillovers, consistent with the US-OECD case. From the third row, when MNEs are restricted, the growth rate drops to 1.79% and 1.66%, respectively, across the two spillovers settings. These results reinforce

[44]The theoretical model is jump-stable for the symmetric case. The quantitative results from the average OECD case can serve as a robust check for the US-OECD case.

the importance of multinational production on economic growth. When the economy is in autarky, the growth rate drops to 1.36% and 1.46%, respectively.

Table 2.6: Changes in Growth Rates: Average OECD

Trade	MNE	Growth (%)		
		no spill	w/ spill	w/ quality
bench	bench	2.00	2.00	2.00
hist	bench	1.88	1.87	**2.14**
bench	no FDI	1.82	1.79	1.66
autarky		1.45	1.36	1.46

The relationship between the growth rate and the iceberg trade cost is illustrated in Figure 2.4.1. After a cut-off trade cost τ^* at 1.38, the growth rate of the average OECD country rises as the trade cost increases. As the trade cost is reduced from 1.38 towards 1, the growth rate rises as well, creating a U-shaped pattern between the growth rate and the trade cost similar to the US-OECD case.

Figure 2.4: Symmetric Countries - Average OECD

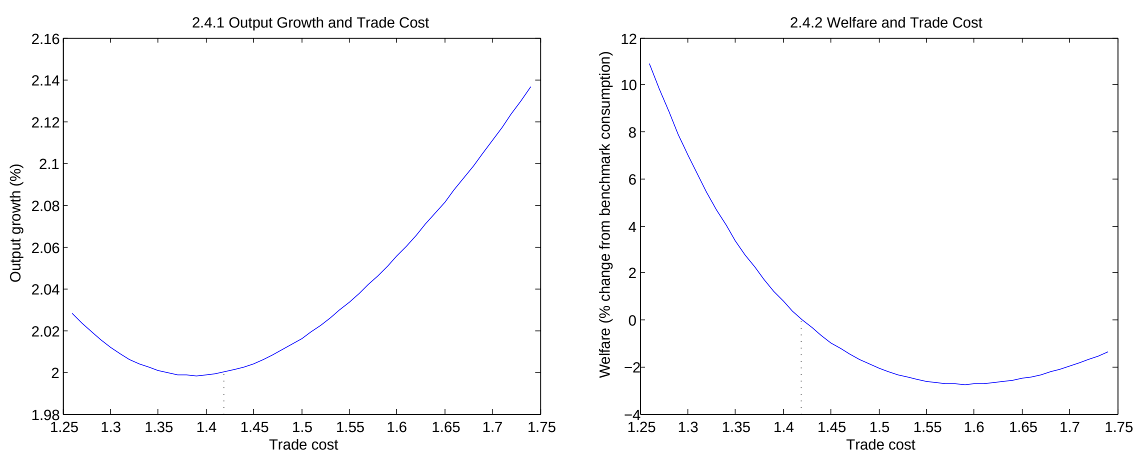


Table 2.7 illustrates the welfare results for the average OECD case. In the second row, the average OECD country would experience a 1.36% welfare loss when the historical

trade cost is imposed, despite a positive growth effect due to an increase in growth rate as shown in the last column of Table 2.6. To understand the reason behind, first notice that from Table 2.2, the trade-to-MNE sales ratio for the average OECD country is about 4/5, whereas the US export-to-outward MNE sales ratio is about 1/3, which is much smaller. The larger trade-to-MNE sales ratio for the average OECD country implies that it is more difficult for an increase in MNE sales to offset the loss in exports sales. The strong negative level effect comes from the decrease of intermediate firm's average profit and consumption level as exports sales are substantial to begin with, contrary to the US-OECD case in which exports sales are relatively less important.

Table 2.7: Welfare Effects: Average OECD

With Quality-Adjusted Spillovers				
Trade	MNE	Welfare (%)		
		Total	Level	Growth
bench	bench	0.00	0.00	0.00
hist	bench	**-1.36**	-7.34	**5.98**
bench	no FDI	-24.75	-11.37	-13.38
autarky		-47.99	-32.51	-15.48
Spillovers Without Quality-Adjusted				
bench	bench	0.00	0.00	0.00
hist	bench	-12.95	-7.34	-5.61
bench	no FDI	-19.73	-11.37	-8.36
autarky		-51.23	-32.51	-18.72
Without Spillovers				
bench	bench	0.00	0.00	0.00
hist	bench	-12.31	-7.34	-4.97
bench	no FDI	-18.75	-11.37	-7.38
autarky		-48.85	-32.51	-16.34

Figure 2.4.2 shows that the consumer welfare of a household is decreasing with the trade cost initially due to the dominance of the level effect, but rises back up after a trade

cost of 1.59. Yet, at the historical trade cost of 1.74, the overall welfare effect is still negative.

The welfare cost is around 20% when MNEs are restricted, as shown in Table 2.7. The autarkic welfare cost can go up to 51.23%, which is much larger than in the US-OECD case in Table 2.5. Restricting openness with all other countries would have a much severe damage than in autarky with the US alone. Moreover, the growth effect accounts for 36.5% of the total cost, a substantial part of the welfare cost despite the dominance of the level effect.

To summarize, when the trade-to-MNE sales ratio is large, as it is in the average OECD case, my results imply that trade liberalization over the past few decades has been welfare-improving. In contrast, when the trade-to-MNE sales ratio is small as it is in the US-OECD case, the effect of trade liberalization, holding constant the restrictions on multinational activity, can be negative once we account for the lower quality of technology being diffused by a smaller share of multinational production.

2.5 Conclusion

In this chapter I studied the long-run effects of openness to trade and multinational production in the context of advanced economies using an endogenous growth model with firm heterogeneity in which openness can affect the long-run growth rate. I examine how the proximity-concentration trade-off between trade and multinational production can affect the long-run growth and welfare gains. By restricting both types of openness with the other OECD countries, the US would experience a welfare cost that is equivalent to a 39% drop in consumption. The growth effect accounts for at least 40% of the total welfare cost, which has substantial implications for consumer welfare.

When the quality of technology diffused is accounted for within the technology spillovers process, the effect of trade liberalization on economic growth and welfare is ambiguous. As suggested by the empirical literature, multinational enterprises (MNEs) are more productive than exporters in general. Technology diffused from a MNE is of higher quality compared with those diffused through trade, when quality of a technology is associated with its productivity. Due to the proximity-concentration trade-off, the most productive exporters find it more profitable to become MNEs when trade barriers are imposed. Higher quality technology is diffused which lowers the cost of innovation and promotes growth.

The welfare effect of imposing trade barriers hinges on both the level and growth effects. Firms suffer a profit loss from not being able to export. If a country's trade-to-MNE sales ratio is small, the increase in MNE sales can offset most of the losses in exports sales when trade barriers are imposed. The positive growth effect can potentially dominate the small negative level effect under trade restrictions if MNE sales is relatively important to begin with. Hence, trade restrictions may not necessarily be welfare-reducing. To interpret it differently, trade liberalization on its own may lead to an adverse effect on economic growth and consumer welfare by reducing the level of multinational production.

By matching with OECD data and performing counterfactual experiments, I find a U-shaped relationship between economic growth and trade cost for the US. Trade liberalization can potentially lead to an adverse effect on economic growth and consumer welfare by reducing the level of multinational production for the US. However, for the OECD countries in general, since their trade-to-MNE sales ratio is large on average, trade liberalization over the past few decades has been welfare-improving.

Multinational production is an important channel of openness. The empirical literature on openness and growth tends to focus mainly on trade and to a much lesser extent on

MNEs. Therefore, it is important for empirical studies to consider trade, MNEs, and technology spillovers as the channels of openness. Also, since the results in my study suggest the importance of trade-to-MNE sales ratio in determining the effect of trade liberalization on consumer welfare, it will be interesting to investigate what causes countries to rely on trade or multinational sales more, whether it is purely due to proximity-concentration trade-off, or is it due to sectoral differences or comparative advantage.

Chapter 3

Intellectual Property Rights and Growth in a North-South Model of Firm Heterogeneity, Innovation, and Imitation

3.1 Introduction

In this chapter I develop a theoretical framework of endogenous innovation with firm heterogeneity in the North-South context to study economic implications from strengthening intellectual property rights. One can think of the North economy as a group of advanced economies, and the South economy as economies in transition, such as China, India, and the Eastern European countries. I extend the open-economy model of endogenous innovation with firm heterogeneity presented in Chapter Two, with an emphasis on the process of technology creation in which *both* imitation and innovation are allowed in the South. The model provides long-run economic implications of the enforcement of intellectual property rights and accounts for endogenous changes in firm distributions that can affect long-run growth.

Most recent studies on the economic implications of intellectual property rights are based on semi-endogenous growth models, in which the long-run economic growth rate is determined by growth in the labour force. In this class of models, which includes Jones (1995b), Dinopoulos and Segerstrom (2011), and Gustaffson and Segerstrom (2010b and 2011), economic growth hinges on growth in the R&D sector, which grows alongside R&D employment in equilibrium. Although, in those models, economic policies can generate long-run welfare effects through changes in the *level* of consumption, they generally do not have any long-run *growth* effects. Gustaffson and Segerstrom (2011) argue that a semi-endogenous growth model fits the US experience well where its TFP and per capita GDP growth rates have been stable historically, suggesting that public policies play only a small role in promoting long-run growth. On the other hand, Ha and Howitt (2007) find that while TFP growth has been stable in the US, there has been a fall in labour engaged in the R&D sector by more than three-fold since 1953. This fact undermines the key proposition of a semi-endogenous growth model in which long-run growth is determined by labour growth in the R&D sector. Ha and Howitt (2007) further show that fully-endogenous growth models are better than the semi-endogenous growth models at forecasting long-run swings in growth rates. Adding to the existing literature, this chapter presents a fully-endogenous growth model with firm heterogeneity to provide a theoretical assessment of the long-run impacts of intellectual property rights. The model can readily be extended to explore, quantitatively, the transitional dynamics of the North-South model, which will be the focus in Chapter Four.

A key feature of the model is the possibility for the South to switch from being an imitator to becoming an innovator country. Firms can choose to imitate or innovate by comparing the costs and benefits of each. This feature reflects the path of economic development in Japan and South Korea in the post-war period, and in China more recently. Moreover, the possibility of a technology creation switchover in the South is essential for examining the long-run growth effect of stronger intellectual property rights.

Firm heterogeneity allows the model to pin down the distributions of domestic firms, exporters, and multinationals based on differences in firm-level productivity. This plays a key role in determining the impact of enforcing intellectual property rights in the South for at least two reasons. Firstly, models with homogeneous firms can over-state the impact of stronger intellectual property rights on the rate of innovation. In the seminal work of Grossman and Helpman (1991), Helpman (1993), as well as the subsequent literature, all firms that serve the domestic market would also export, and they are are equally productive.[45] An improvement in intellectual property rights in the South increases the ex-ante value of a Northern firm by increasing its expected profits from both home and abroad. This causes the Northern rate of innovation to rise. But in reality, since not all firms export, increases in the ex-ante firm value and Northern rate of innovation are likely being over-stated. In a model with firm heterogeneity, firms are divided into exporters and non-exporters, so that the ex-ante value of a Northern firm will account for the fact that not all firms can export.

Secondly, the impact of stronger intellectual property rights on the level and growth of output can also be over-stated in models with homogeneous firms. This is because intellectual property rights can have asymmetric effects on the extensive margin of the exporters and multinationals. While more Northern firms will export to the South when

[45]The extensive list of studies in the literature include Glass and Saggi (2002), Glass and Wu (2007), Connolly and Valderrama (2005a and 2005b), Arnold (2007), Mondal and Gupta (2009), Dinopoulos and Segerstrom (2011), and Gustaffson and Segerstrom (2010b and 2011). Some of these studies focus on North-South trade, while some focus on Northern firms engaging in FDI in the South without the option to export.

intellectual property rights become stronger, there will be a smaller increase in the number of Northern multinationals since the setup cost of a multinational is higher to begin with. This feature is well-captured in a model with firm heterogeneity, but not when firms are homogeneous in their productivity because the impacts are symmetric on all types of firms. It is therefore important to account for changes in firm productivity distributions to properly measure the impact of stronger intellectual property rights.

The model developed here also includes *vertical* multinational production as a channel of openness between the North and the South. Emerging economies are often characterized as experiencing export-led growth which derives from having a large external sector. In particular, many multinational enterprises from advanced economies have set up production facilities in emerging markets, and export their products back to their home country or to other advanced economies. This type of business activity is known as vertical multinational production, where affiliates of foreign multinationals take advantage of lower production costs in the emerging economies. Some of the products produced locally are sold locally, while a large portion is exported to the advanced economies. In fact, intrafirm trade accounts for a substantial part of exports from emerging economies in the data. For example, over 50% of China's total exports in the past decade was related to vertical multinational production.

By analyzing the balanced growth path of the model, I find that when intellectual property rights are strictly enforced in the North, it is the best for the South to strengthen its intellectual property rights so that both economies end up experiencing a fast per capita long-run growth rate. However, if the intellectual property rights protection in the South is weak, the North needs to maintain its absolute advantage in technology creation. Otherwise it will converge to a balanced growth path with an even lower growth rate as the pool of uncopied products becomes exhausted by Southern imitation. In other words, the North not only needs to maintain a cheaper cost of innovation relative to the South, but more importantly, it needs to maintain a sufficiently large pool of uncopied ideas. This is a result of the disincentives created by Southern imitation which drives down the expected profits of Northern innovators that export or form multinationals.

The next section presents an extension of the endogenous growth model developed in Chapter Two, which has been modified to account for features in a North-South context. Section 3.3 characterizes the balanced growth path equilibrium of the model. Section 3.4 studies the economic implications from stronger intellectual property rights. Section 3.5 concludes.

3.2 The Model

3.2.1 The Environment

There are two countries in the world economy, the North and the South, which are at different stages of economic development. One can think of the North as the advanced economies, and the South as the emerging economies. Let country $i \in \{n, s\}$, where n and s denote the North and the South, respectively. There is no aggregate uncertainty. Time is continuous and is indexed by $t \geq 0$. I assume that population sizes $\bar{L}_i$ are fixed without loss of generality.[46] There are many commonalities between the model below and the one presented in Chapter Two. However, the intermediate goods sector has been modified in several ways to account for economic phenomena experienced by a typical emerging economy.

[46]The qualitative and quantitative implications are similar with or without population growth.

Households share identical preferences across economies, given by equation (2.1) in Chapter Two. Each household maximizes its lifetime utility by choosing consumption of a final good C_{it} for $i \in \{n, s\}$, subject to a dynamic budget constraint given by equation (2.2). The associated notation is described in Section 2.2.1.

There are two production sectors in each economy: a monopolistically competitive intermediate goods sector and a perfectly competitive final goods sector. The final good Y_{it} is the numeraire good and is sold at unit price. Final goods are identical across economies and can be traded without cost. The final good for country i is produced using labour L_{it} and a continuum of intermediate inputs according to (2.3). Final output is divided between aggregate consumption C_{it}, the production of intermediate goods M_{it}, investment in research and development (R&D), R_{it}, and net exports, NX_{it}, as in (2.4).

The intermediate goods sector is monopolistically competitive. Firms in this sector are heterogeneous in their production technologies. In contrast with the model presented in Chapter Two, intermediate firms in different economies face a different business environment. Intermediate firms in the North are innovators due to strict enforcement of intellectual property rights. Each Northern firm must first devote resources to innovate and to obtain a perpetual patent on a blueprint by paying a one-time cost η_n, which I assume to be constant over time for simplicity. As for the South, intermediate firms can either imitate or innovate, depending on the costs of imitation and innovation. These costs of technology creation are increasing in the number of existing technologies in the South, which reflect the increasing difficulties to imitate or innovate over time. I denote η_{st} as a one-time cost of innovation paid by a Southern innovator at time t. If the cost of imitation is smaller than that of innovation, a Southern entrant imitates and incurs a one-time cost of η_{st}^I for copying existing products from the North, where the superscript I denotes *imitation*. Note that once a Northern product has been imitated by a Southern firm, no other Southern firms will copy that same product because they would end up in Bertrand competition with the existing Southern firm and earn zero profits. The new firms can always copy new products at the same cost but enjoy a "monopoly" position over the newly-imitated product. Unlike innovation, imitation is limited by the number of existing products from the North.

Each unit of the intermediate good is produced according to a linear technology using a units of the final good, where a varies across firms reflecting heterogeneity in productivity. After obtaining a blueprint, each intermediate firm, whether it is an innovator or an imitator, learns at the beginning of each period its unit cost parameter, a, drawn from a stationary Pareto distribution given by equation (2.5). This assumption helps to maintain the smoothness of the unit cost distributions.[47] In each period, some Northern firms exit the Southern market if their products have been imitated by Southern firms. This creates a discontinuity in the unit cost distributions of the Northern exporting firms and multinationals. By drawing a unit cost parameter at the beginning of each period, the unit cost distributions are *reshuffled* as the distributions' cut-off points change each period. The details of the cut-off points are discussed in the next section.

Firms always serve their domestic markets once they have obtained a blueprint.[48] A Northern firm can choose to serve the domestic market by producing domestically, or by forming a vertical multinational enterprise (MNE) to produce abroad and ship back its product to take advantage of lower production cost in the South. Moreover, a Northern firm can choose to serve the foreign market by exporting or by becoming a horizontal MNE, a decision driven by the proximity-concentration trade-off. An exporter produces

[47] This assumption is different from the one in Chapter Two, where an intermediate firm only draws the unit cost parameter once and will keep it for its lifetime.

[48] This is different from Chapter Two where openness can affect firms' survival through a change in cut-off cost for domestic firms.

domestically and ships its product abroad, while a horizontal MNE maintains production capacities at home and abroad. However, a Northern firm exits the Southern market if its product has been imitated by a Southern firm and will not enter the Southern market again. On the other hand, Southern firms can choose to serve abroad through exporting or by becoming a horizontal MNE. They do not form vertical MNEs because their unit costs to produce locally is lower than if they produce in the North. Thus Southern firms do not have any incentive to produce abroad and ship products back home.

The foreign subsidiary of a horizontal or vertical MNE is owned by the parent company at home and produces using foreign inputs to sell to the foreign market. It is a separate decision to become a horizontal or a vertical MNE, unlike the more conventional setup used by studies such as Rodrigue (2010) in which a vertical MNE would serve both home and foreign markets.[49]

An intermediate firm located in country i is required to pay a per-period fixed cost F_{iit} to produce and sell in the domestic market. Alternatively, a Northern firm can form a vertical MNE by paying a per-period fixed cost F^{v}_{snt} to set up a subsidiary in the South for production and ship its products back home, where superscript v denotes vertical MNE. As discussed above, this option is not available for a Southern firm. To serve abroad, both Northern and Southern firms will either pay an extra per-period fixed cost F_{xit} and an iceberg trade cost τ for each unit of goods to export, or a per-period fixed cost F_{jit} to become a horizontal MNE and set up a subsidiary abroad.

To guarantee non-negative average *net* profits for exporters and MNEs, the per-period

[49]This assumption reflects the situation for an emerging economy like China where its economic policies promote foreign firms to engage in export-oriented activities, while the costs of distribution channels to serve the local market for foreign firms were much higher.

fixed costs F_{cit} for $c \in \{n, x, s\}$ and $i \in \{n, s\}$, and F^v_{snt} satisfy the following conditions:[50]

$$F_{iit} < \tau^{\epsilon-1} F_{xit} < F_{jit} \;\; \text{for} \;\; i \in \{n, s\}, j \neq i; \tag{3.1}$$

$$F_{nnt} < \tau^{\epsilon-1} F^v_{snt}. \tag{3.2}$$

In contrast to Chapter Two, I assume F_{iit} to be constant, and that the least productive firm will break-even and will always be willing to serve their domestic markets. To guarantee a positive number of Northern vertical MNEs, I further assume that the iceberg trade cost τ is less than the inverse of γ, which I define as the unit production cost discount in the South relative to the North, with $0 < \gamma < 1$. The rationale is that when the iceberg trade cost becomes too expensive, it can more than offset the benefits from cheaper production in an emerging economy. Consequently, Northern firms will no longer find it profitable to form vertical MNEs.

The number of intermediate firms in both the North and the South will be expanding over time. Following the notations from Chapter Two, N_{nnt} denotes the number of firms originating from the North, which includes exporters N_{xnt}, horizontal MNEs N_{snt}, and vertical MNEs N^v_{snt}, and the rest of the firms that produce at home to serve the domestic market. Similarly, N_{sst} denotes the number of firms originating from the South, with exporters and horizontal MNEs denote by N_{xst} and N_{nst}, respectively. Only firms that earn non-negative profits in their respective markets are counted. For example, Northern firms whose products have been imitated by Southern firms will exit the South and are therefore not counted, but they are still counted within N_{nnt} as they remain operational in the North. Moreover, the total number of intermediate goods N_{it} available in country $i \in \{n, s\}$ is the sum of the domestic firms N_{iit}, foreign exporters N_{xjt}, and foreign horizontal MNEs N_{ijt}. Note that vertical MNEs N^v_{snt} is already counted as part of N_{nnt}.

[50]This condition is similar to equation (2.6) in Chapter Two.

The total per-period fixed costs paid by domestic firms, foreign exporters and horizontal MNEs to enter country i are $N_{iit}F_{iit}$, $N_{xjt}F_{xjt}$ and $N_{ijt}F_{ijt}$, respectively, with the South receiving an additional $N_{snt}^{v}F_{snt}^{v}$ from vertical MNEs from the North. As discussed in Chapter Two, the fixed costs collected by households in country i take the form of transfers, Z_{it}, which are part of the households' budget constraint in equation (2.2).

In the sections below, I present the problems faced by each sector and characterize a stationary equilibrium and the balanced growth path of the model.

3.2.2 Representative Household's Problem

The representative household's Euler equation can be derived as in Chapter Two, where the lifetime utility function (2.1) is maximized subject to the budget constraint (2.2):

$$\frac{\dot{C}_{it}}{C_{it}} = \frac{1}{\theta}(r_{it} - \rho) \quad \text{for} \quad i \in \{n, s\}. \tag{3.3}$$

The budget constraint (2.8) can be modified for the Southern household to incorporate the total fixed costs from vertical MNEs:

$$\dot{B}_{st} = w_{st}L_s + r_{st}B_{st} + N_{sst}F_{sst} + N_{xnt}F_{xnt} + N_{snt}F_{snt} + N_{snt}^{v}F_{snt}^{v} - C_{st}. \tag{3.4}$$

where the Northern household's budget constraint can be written as:

$$\dot{B}_{nt} = w_{nt}L_n + r_{nt}B_{nt} + N_{nnt}F_{nnt} + N_{xst}F_{xst} + N_{nst}F_{nst} - C_{nt}. \tag{3.5}$$

As in Chapter Two, a change in the asset position, $\dot{B}_{it}$, includes households' investment and capital gains on asset holdings. Households invest their resources to domestic firms which invest in innovating or imitating R&D activities. The domestic households then become the firms' shareholders. As a result, households' investment is equivalent to R&D

investment R_{it}, which is given by:

$$\begin{aligned} R_{it} &= \eta_{it}\dot{N}_{iit} \quad \text{for the North and an innovating South,} \\ R_{st} &= \eta^I_{st}\dot{N}_{sst} \quad \text{for an imitating South.} \end{aligned} \tag{3.6}$$

Assets are accumulated through R&D investments without depreciation or obsolescence, and are given by:

$$\begin{aligned} B_{it} &= \eta_{it}N_{iit} \quad \text{for the North and an innovating South,} \\ B_{st} &= \eta^I_{st}N_{sst} \quad \text{for an imitating South.} \end{aligned} \tag{3.7}$$

Investment income, $r_{it}B_{it}$, consists of the dividends which are the total net profits of the intermediate goods sector distributed to shareholders, and capital gains earned from the shares of intermediate firms. The Southern household's investment income is given by:

$$r_{st}B_{st} = N_{sst}\tilde{\pi}_{sst} + N_{xst}\tilde{\pi}_{xst} + N_{nst}\tilde{\pi}_{nst} + \Upsilon_{st} = N_{sst}\tilde{\pi}_{st} + \Upsilon_{st}, \tag{3.8}$$

and the Northern household's investment income is given by:

$$\begin{aligned} r_{nt}B_{nt} &= (N_{nnt} - N^v_{snt})\tilde{\pi}_{nnt} + N_{xnt}\tilde{\pi}_{xnt} + N_{snt}\tilde{\pi}_{snt} + N^v_{snt}\tilde{\pi}^v_{snt} + \Upsilon_{nt} \\ &= N_{nnt}\tilde{\pi}_{nt} + \Upsilon_{nt}. \end{aligned} \tag{3.9}$$

where $\tilde{\pi}_{cit}$ with $c \in \{n, x, s\}$ denotes the average net profits earned in different markets, respectively, and $\tilde{\pi}_{it}$ denotes the average net profit for a firm originating from country i, and Υ_{it} denotes the total capital gains arising from changes in the total value of country i's firms.

Following the aggregation procedure describes in Appendix A.1, we use equations (3.6), (3.8) and (3.9), and the final good producers' problems presented in Section 2.2.3 to rewrite the budget constraints (3.4) and (3.5) as:

$$Y_{it} = C_{it} + R_{it} + M_{it} + NX_{it} \;\; \text{for} \;\; i \in \{n, s\}. \tag{3.10}$$

where net exports for the North are given by:

$$NX_{nt} = -[(N_{xnt}\tilde{\pi}_{xnt} - N_{xst}\tilde{\pi}_{xst}) + (N_{snt}\tilde{\pi}_{snt} - N_{nst}\tilde{\pi}_{nst}) - N^v_{snt}F^v_{snt}], \tag{3.11}$$

and net exports for the South are given by:

$$NX_{st} = -[(N_{xst}\tilde{\pi}_{xst} - N_{xnt}\tilde{\pi}_{xnt}) + (N_{nst}\tilde{\pi}_{nst} - N_{snt}\tilde{\pi}_{snt}) + N^v_{snt}F^v_{snt}]. \tag{3.12}$$

Note that the negative of NX equals the net repatriated profits from abroad for country i. Since final goods are identical across countries, positive net repatriated profits require net imports of the final good (or negative net exports) in order to settle the balance of payments. Similarly, negative net repatriated profits require net exports of the final good.

Since the final goods sector is the same as in Section 2.2.3 in Chapter Two, I move on to the intermediate goods sector which has been modified to include key features in a North-South context.

3.2.3 Intermediate Goods Sector — Stage 2: Product Markets

Both Northern and Southern intermediate firms face a two-stage problem. In the first stage, a Northern firm decides whether to devote resources to develop a new intermediate good. A Southern firm decides whether to imitate an existing North product that has not yet been imitated, or to develop a new product if the cost of doing so is lower. In the second stage, both Northern and Southern firms draw their per-period unit costs at the beginning of every period, after they have paid the first stage entry cost. Based on the unit cost draw each period, intermediate firms decide whether to export their products, or to become a MNE to serve abroad. A Northern firm, however, exits the Southern market once their products have been imitated. This is because, first of all, a Southern firm can always charge a cheaper price on the same product than a Northern exporter can, given the cost advantage in the South. Secondly, the domestic fixed cost is generally lower than the fixed cost of foreign MNEs, unless there are some preferential policies that are highly-skewed towards favouring foreign MNEs over domestic firms. I abstract from such policies for simplicity. Consequently, a Southern firm can undercut its Northern counterpart until the Northern firm makes a loss and exits. Northern firms have the additional option of forming a vertical MNE to produce abroad and ship back the products to the domestic market. This decision is not subject to the risk of imitation because the North is the final destination, where intellectual property rights are strictly enforced. To solve the two-stage problem, I proceed by solving the model backwards.

In the second stage, each firm draws its unit cost from the Pareto distribution given by (2.5). As in Chapter Two, I index intermediate goods with their unit cost a. An intermediate firm is the only producer of its product and will always serve the domestic market. To decide whether to serve abroad, each firm compares its potential operating profits from exporting or forming a horizontal MNE with the associated per-period fixed costs.

However, Northern firms will need to account for the probability of being imitated if they serve the Southern market. I define $\phi_{nt} = \phi$ as the probability of imitation for Northern exporters and horizontal MNEs when Southern firms are imitators, while $\phi_{nt} = 0$ for Northern domestic firms and vertical MNEs. After the South switches to become an innovator country, ϕ would be zero since no Southern firms have incentives to imitate beyond the point of switchover. On the other hand, Southern firms always face $\phi_{st} = 0$ because potential entrants will only copy products from the North. Subsequently, I will discuss how the probability of imitation is determined in the intermediate sector first stage problem.

A firm with cost a from country i maximizes its operating profits by choosing its optimal price p_{ci} for $c \in \{n, x, s\}$ to serve the respective markets. A firm's problem is given by:

$$\max_{p_{ci}} \, (1 - \phi_{it})(p_{ci} - \tau^q \gamma_i a) X_{ci}(p_{ci}) \tag{3.13}$$

subject to the demand function (2.15) from the final goods producers' problems. Here $q \in \{0, 1\}$, where $q = 1$ if the firm is exporting and incurs the iceberg trade cost τ, and $q = 0$ otherwise.[51] Since γ captures the relative unit cost difference between the North and the South, I set $\gamma_n = 1$ for production facilities in the North and $\gamma_s = \gamma$ with $0 < \gamma < 1$ for production facilities in the South. The optimal prices for a country i firm to serve the domestic market, to export to $j \neq i$, to serve abroad as a horizontal MNE, and for a Northern firm to form a vertical MNE, respectively, are given by:

$$p_{ii} = \frac{\gamma_i a}{\alpha} \quad , \quad p_{xi} = \frac{\tau \gamma_i a}{\alpha} \quad , \quad p_{ji} = \frac{\gamma_i a}{\alpha} \quad , \quad p^v_{sn} = \frac{\tau \gamma_s a}{\alpha}. \tag{3.14}$$

These prices are constant markups over marginal cost. Substituting the optimal prices (3.14) into equation (3.13), together with demand function (2.15) yields the optimal operating profits:

$$\pi_{ci}(a) = \left(\frac{1 - \alpha}{\alpha} \right) (1 - \phi_{it}) \tau^q (\gamma_i a)^{-\frac{\alpha}{1-\alpha}} A_d^{\frac{1}{1-\alpha}} \alpha^{\frac{2}{1-\alpha}} L_d, \tag{3.15}$$

with $d = i$ when a firm is serving the domestic market, and $d = j \neq i$ when serving abroad. Notice that firm a's operating profit flow is different across markets and across time because the unit cost is drawn repeatedly at the beginning of each period.

[51] Refer to Footnote (15) in Chapter Two, for simplicity I assume that exporters purchase inputs from the destination country first, then produce the intermediate goods at home and ship these goods to the destination country. Recall that final goods, which are costless to trade, are used as production inputs.

Fixed Costs and Cut-off Costs

Based on condition (3.1) on the per-period fixed costs, the marginal firm to become a MNE has lower marginal cost a_{jit} than the marginal firm to become an exporter a_{xit}, followed by the least productive domestic firm who has the highest marginal cost a_{iit}. This is because F_{jit} and F_{iit} are the highest and the lowest among the three fixed costs, respectively. Based on condition (3.2), the marginal Northern firm to become a vertical MNE has a lower marginal cost a^v_{snt} than the least productive domestic firm. These results are given by:

$$a_{jit} < a_{xit} < a_{iit} \quad , \quad a^v_{snt} < a_{nnt}.$$

Notice that the least productive firms serve only the domestic market, while more productive firms also serve abroad by exporting. The most productive firms become horizontal MNEs. As discussed in Chapter Two, the proximity-concentration trade-off results in the formation of horizontal MNEs as a way to avoid the iceberg trade cost when this option is more profitable. Moreover, Northern firms that are productive would serve domestic market by producing in the South due to the cost advantage.

Zero Profit Conditions

A firm compares the profits of selling in market $c \in \{n, x, s\}$ with the per-period fixed cost of selling there. Since I assume that even the least productive firm can serve the domestic market, a_{iit} represents the cut-off cost to enter the domestic market i and makes zero profit. The cut-off cost of exporters is given by a_{xit}. The cut-off cost of horizontal MNEs a_{jit} is the cost at which the marginal firm is indifferent between exporting to foreign market j or setting up a subsidiary there. Similarly, the cut-off cost of Northern vertical MNEs, a^v_{snt}, is the cost at which the marginal firm is indifferent between producing at home or abroad when serving the domestic market. I define the per-period fixed costs as follows:

$$F_{iit} = \psi_{ii} A_i^{\frac{1}{1-\alpha}} \alpha^{\frac{2\alpha}{1-\alpha}} L_i \quad , \quad F_{xit} = \psi_{xi} A_i^{\frac{1}{1-\alpha}} \alpha^{\frac{2\alpha}{1-\alpha}} L_i,$$
$$F_{jit} = \psi_{ji} A_i^{\frac{1}{1-\alpha}} \alpha^{\frac{2\alpha}{1-\alpha}} L_i \quad , \quad F^v_{snt} = \psi^v_{sn} A_n^{\frac{1}{1-\alpha}} \alpha^{\frac{2\alpha}{1-\alpha}} L_n, \tag{3.16}$$

where the various ψ terms are constant. The fixed costs here are defined in such a way as to eliminate scale effects in the output growth rate as discussed in Section 2.2.5. The zero profit conditions for the domestic and exports markets, respectively, are given by:

$$\pi_{iit}(a_{iit}) = F_{iit} \quad , \quad \pi_{xit}(a_{xit}) = F_{xit}, \tag{3.17}$$

and those for the horizontal and Northern vertical MNEs are given by:

$$\pi_{jit}(a_{jit}) - F_{jit} = \pi_{xit}(a_{jit}) - F_{xit} \quad , \quad \pi^v_{snt}(a^v_{snt}) - F^v_{snt} = \pi_{xnt}(a^v_{snt}) - F_{xnt}. \tag{3.18}$$

Using equations (3.15) to (3.18), various cut-off costs can be derived in similar fashions as in Section 2.2.4. The domestic cut-off cost is given by:

$$a_{iit} = \left[\frac{\alpha(1-\alpha)}{\psi_{ii}}\right]^{\frac{1-\alpha}{\alpha}}, \tag{3.19}$$

while the export and horizontal MNE cut-off costs can be expressed as functions of a_{iit}:

$$a_{xit} = \left((1-\phi_{it})\frac{\psi_{ii}}{\psi_{xi}}\frac{\Lambda_j}{\Lambda_i}\right)^{\frac{1-\alpha}{\alpha}} \frac{a_{iit}}{\tau} \quad , \quad a_{jit} = \left[(1-\phi_{it})\frac{\psi_{ii}(\gamma_i^{\frac{-\alpha}{1-\alpha}} - \tau^{\frac{-\alpha}{1-\alpha}})}{\psi_{ji} - \psi_{xi}}\frac{\Lambda_j}{\Lambda_i}\right]^{\frac{1-\alpha}{\alpha}} a_{iit}, \tag{3.20}$$

where $\Lambda_d = A_d^{\frac{1}{1-\alpha}} \alpha^{\frac{2}{1-\alpha}} L_d$ for $d \in \{i, j\}$. The Northern vertical MNE cut-off cost can be found in a similar way:

$$a^v_{snt} = \left[\frac{\psi_{nn}((\tau\gamma)^{\frac{-\alpha}{1-\alpha}} - 1)}{\psi^v_{sn} - \psi_{nn}}\right]^{\frac{1-\alpha}{\alpha}} a_{nnt}. \tag{3.21}$$

Note that the assumption $\tau > 1/\gamma$ guarantees a^v_{snt} to be non-negative.[52]

To guarantee that firms always serve their domestic markets in the second stage problem, I assume

$$\psi_{ii} = \frac{\alpha(1-\alpha)}{a_{i0}^{\frac{\alpha}{1-\alpha}}} \tag{3.22}$$

so that $a_{iit} = a_{i0}$, where a_{i0} is the upper bound of the Pareto distribution (2.5). Once we solved for a_{iit} for $i \in \{n, s\}$, all the other cut-off costs can be derived recursively. The probability of imitation ϕ_{nt} plays a role in determining the expected profit flows of Northern firms, and will thereby affect their entry decision in the first stage problem. Before moving to this first stage problem, I shall first discuss the aggregation of the intermediate goods sector production into final goods production.

Aggregation

The final good in each country i is produced using a continuum of intermediate inputs and labour, as given by equation (2.3). Following Section 2.2.4, the North's aggregate

[52]On the other hand, Southern firms do not choose to form vertical MNEs when the total cost of production at home is cheaper than to produce abroad. To see this, the cut-off cost of Southern vertical MNEs can be found in a way similar to that of Northern vertical MNEs, and is given by:

$$a^v_{nst} = \left[\frac{\psi_{ss}(\tau^{\frac{-\alpha}{1-\alpha}} - \gamma^{\frac{-\alpha}{1-\alpha}})}{\psi^v_{ns} - \psi_{ss}}\right]^{\frac{1-\alpha}{\alpha}} a_{sst}.$$

The cut-off cost is negative for $\tau > 1$ and $\gamma < 1$, unless the denominator is negative, meaning that the fixed cost to produce in the South is higher than forming Southern vertical MNEs. A condition similar to equation (3.2) can be applied to Southern vertical MNEs to rule out the latter case.

production function for the final good is given by:

$$
\begin{aligned}
Y_{nt} &= A_n L_n^{1-\alpha}\Bigg[\int_{a_{snt}^v}^{a_{nnt}} X_{nnt}(a)^\alpha \frac{g_n(a)}{1-G_n(a_{snt}^v)}(N_{nnt}-N_{snt}^v)da \\
&\quad + \int_0^{a_{snt}^v} X_{snt}^v(a)^\alpha \frac{g_n(a)}{G_n(a_{snt}^v)} N_{snt}^v da + \int_{a_{nst}}^{a_{xst}} X_{xst}(a)^\alpha \frac{g_s(a)}{G_s(a_{xst})-G_s(a_{nst})} N_{xst} da \\
&\quad + \int_0^{a_{nst}} X_{nst}(a)^\alpha \frac{g_s(a)}{G_s(a_{nst})} N_{nst} da\Bigg], \qquad (3.23)
\end{aligned}
$$

where $G_i(\cdot)$ is a Pareto distribution given by equation (2.5), and the $g_i(a)/G_i(\cdot)$ terms for $i \in \{n, s\}$ represent the density functions conditional on firms' survival. This equation implies that final output in the North is produced using intermediate inputs from the domestic Northern firms, the Northern vertical MNEs, imports from the South, and the Southern MNEs, respectively. The number of exporters and MNEs from each country are proportional to the distributions of exporters and MNEs conditional on all domestic firms N_{iit} for $i \in \{n, s\}$. Since the distributions are governed by the respective cut-off costs, the numbers of exporters and MNEs are known if the cut-off costs and N_{iit} are known.

Similarly, the South's aggregate production function is given by:

$$
\begin{aligned}
Y_{st} &= A_s L_s^{1-\alpha}\Bigg[\int_0^{a_{sst}} X_{sst}(a)^\alpha N_{sst} da + \int_{a_{snt}}^{a_{xnt}} X_{xnt}(a)^\alpha \frac{g_n(a)}{G_n(a_{xnt})-G_n(a_{snt})} N_{xnt} da \\
&\quad + \int_0^{a_{snt}} X_{snt}(a)^\alpha \frac{g_n(a)}{G_n(a_{snt})} N_{snt} da\Bigg], \qquad (3.24)
\end{aligned}
$$

in which final output in the South is produced using intermediate inputs from the domestic Southern firms, imports from the North, and the Northern MNEs. Equations (3.23) and (3.24) can be further simplified into modified versions of equation (2.26):

$$
Y_{nt} = A_n^{\frac{1}{1-\alpha}} \alpha^{\frac{2\alpha}{1-\alpha}} L_n N_{nt} \tilde{a}_{nt}^{1-\epsilon}, \qquad (3.25)
$$

$$
Y_{st} = A_s^{\frac{1}{1-\alpha}} \alpha^{\frac{2\alpha}{1-\alpha}} L_s N_{st} (\gamma \tilde{a}_{st})^{1-\epsilon}. \qquad (3.26)
$$

where $\epsilon = 1/(1-\alpha)$ is the elasticity of substitution between intermediate goods. $N_{it} = N_{iit} + N_{xjt} + N_{ijt}$ is the total number of intermediate good firms that serve country i, for

$i \in \{n, s\}$ and $j \neq i$. The average unit costs of intermediate goods firms $\tilde{a}_{nt}$ and $\gamma\tilde{a}_{st}$ are given by the modified versions of equation (2.27):

$$\begin{aligned} \tilde{a}_{nt} &= \left[\frac{N_{nnt} - N^v_{snt}}{N_{nt}}\tilde{a}^{1-\epsilon}_{nnt} + \frac{N^v_{snt}}{N_{nt}}(\tau\gamma\tilde{a}^v_{snt})^{1-\epsilon} \right. \\ &\quad \left. + \frac{N_{xst}}{N_{nt}}(\tau\gamma\tilde{a}_{xst})^{1-\epsilon} + \frac{N_{nst}}{N_{nt}}\tilde{a}^{1-\epsilon}_{nst}\right]^{\frac{1}{1-\epsilon}}, \qquad (3.27) \\ \gamma\tilde{a}_{st} &= \left[\frac{N_{sst}}{N_{st}}(\gamma\tilde{a}_{sst})^{1-\epsilon} + \frac{N_{xnt}}{N_{st}}(\tau\tilde{a}_{xnt})^{1-\epsilon} + \frac{N_{snt}}{N_{st}}(\gamma\tilde{a}_{snt})^{1-\epsilon}\right]^{\frac{1}{1-\epsilon}}, \qquad (3.28) \end{aligned}$$

where $\tilde{a}_{iit}$ for $i \in \{n, s\}$ is the average unit cost of domestic firms, $\tilde{a}_{xjt}$ for $j \neq i$ is the average unit cost of foreign firms exporting to country i, and $\tilde{a}_{ijt}$ is the average unit cost of foreign MNEs. Moreover, $\tilde{a}^v_{snt}$ is the average unit cost of Northern vertical MNEs that produce in the South but sell in the North.

3.2.4 Intermediate Goods Sector — Stage 1: Innovation

The first stage of an intermediate firm's problem follows a similar setup as in Barro and Sala-i-Martin (2004).[53] Intermediate firms in the North are innovators due to strict enforcement of intellectual property rights. They devote resources to innovation by paying a one-time cost η_{nt} which is the same for all Northern entrants. The cost is assumed to be constant over time, so I denote it η_n from here on. To correct for the scale effect in output growth as discussed in section 2.2.5, I assume:

$$\eta_n = \psi_n A_n^{\frac{1}{1-\alpha}} \alpha^{\frac{2\alpha}{1-\alpha}} L_n, \qquad (3.29)$$

where ψ_n is constant. The probability of imitation that a Northern firm faces is determined by the number of new Southern imitators at time t that copy existing products from the

[53] See Chapter 8 in Barro and Sala-i-Martin (2004).

North that have not yet been imitated by incumbent Southern firms. This probability is given by:[54]

$$\phi = \frac{\dot{N}_{sst}}{N_{nnt} - N_{sst}}. \tag{3.30}$$

New entrants in the South pay a one-time cost η_{st}^{I} to imitate an uncopied Northern product. The scale-effect-corrected cost of imitation is given by:

$$\eta_{st}^{I} = \psi_s^I A_s^{\frac{1}{1-\alpha}} \alpha^{\frac{2\alpha}{1-\alpha}} L_s \hat{N}_t^{\sigma^I}, \tag{3.31}$$

where ψ_s^I is a constant term which can be influenced by intellectual property rights, and σ^I is the elasticity of imitation cost with respect to the relative number of intermediate goods. The superscript I denotes *imitation*. $\hat{N}_t = N_{sst}/N_{nnt}$ denotes the relative number of intermediate goods originating from the South. This is an important state variable in the model that summarizes the path of the world economy. I assume $\sigma^I > 0$, so that the cost of imitation increases as the South's technology progresses relative to the North's. I also assume that all Southern entrants at time t will pay the same η_{st}^I. Similarly, the cost of innovation for the South is given by:

$$\eta_{st} = \psi_s A_s^{\frac{1}{1-\alpha}} \alpha^{\frac{2\alpha}{1-\alpha}} L_s \hat{N}_t^{\sigma}, \tag{3.32}$$

where σ is the elasticity of innovation cost with respect to the relative number of intermediate goods, and ψ_s is a constant. $\sigma < \sigma^I$ and $\psi_s < \psi_s^I$ are the two conditions that are

[54] To see that ϕ from equation (3.30) is between 0 and 1, one can rewrite the equation as:

$$\phi = \frac{g_{st}}{\frac{1}{\hat{N}_t} - 1}.$$

where g_{st} is the rate of imitation. I define $\hat{N}_t = N_{sst}/N_{nnt}$. Given that $g_{st} \geq 0$, $\hat{N}_t$ must be smaller than one for $\phi > 0$. Note that $\hat{N}_t$ is always non-negative because the numbers of intermediate goods in both economies are non-negative. On the other hand, the model economy has a corner solution at $\hat{N}_t = 1$ when the pool of uncopied Northern products is exhausted, *i.e.* there is nothing left for Southern firms to copy from. From this point in time onward, all newly-innovated Northern products will be copied by the South. $\phi = 1$ is implied by the corner solution at $\hat{N}_t = 1$. Hence, $0 \leq \hat{N}_t \leq 1$ and $g_{st} \geq 0$ together imply that $0 \leq \phi \leq 1$.

sufficient to allow the South to switch from an imitator country to become an innovator country.[55]

Given this setting, Southern firms will either always imitate, or will become innovators if the cost to innovate is cheaper than to imitate after a certain time period. There is a third possibility: that the pool of uncopied Northern products becomes exhausted, leaving the Southern imitators with nothing new to copy from. This situation happens when $\hat{N}_t = 1$. In the subsequent period, the uncopied pool of Northern products will be replenished as Northern entrants continue to innovate, which will then be imitated by the Southern entrants until the pool is exhausted again. This cycle will continue over time and cannot be stopped internally once it happens.

The ex-ante, expected net profit $\tilde{\pi}_{nt}$ and $\tilde{\pi}_{st}$ at time t are the same as the actual average net profits of Northern and Southern intermediate firms from the second stage problem. These are given by the modified versions of equation (2.28):

$$\begin{aligned}\tilde{\pi}_{nt} &= (1 - G_n(a^v_{snt}))\tilde{\pi}_{nnt} + G_n(a^v_{snt})\tilde{\pi}^v_{snt} \\ &\quad + (G_n(a_{xnt}) - G_n(a_{snt}))\tilde{\pi}_{xnt} + G_n(a_{snt})\tilde{\pi}_{snt}, \qquad (3.33)\\ \tilde{\pi}_{st} &= \tilde{\pi}_{sst} + (G_s(a_{xst}) - G_s(a_{nst}))\tilde{\pi}_{xst} + G_s(a_{nst})\tilde{\pi}_{nst}, \qquad (3.34)\end{aligned}$$

where the various $G_i(\cdot)$ terms for $i \in \{n, s\}$ represent the shares of exporters and MNEs. $\tilde{\pi}_{iit}$, $\tilde{\pi}_{xit}$ and $\tilde{\pi}_{jit}$ denote the average net profits from domestic market, exports and horizontal MNEs, respectively, and $\tilde{\pi}^v_{snt}$ denotes the average net profit for Northern vertical MNEs.

[55]One can get the following equation by setting the cost of imitation (3.31) and the cost of innovation (3.32) equal:

$$\hat{N}_t = \left(\frac{\psi_s}{\psi^I_s}\right)^{\frac{1}{\sigma^I - \sigma}}.$$

As discussed later, $\hat{N}_t < 1$ for a switch to happen in the South. Given this condition, if $\sigma < \sigma^I$ and $\psi_s < \psi^I_s$, then a switch takes place.

The ex-ante value of a firm, V_{it}, is given by the present value of the expected future profit flow. The expected rate of return from either innovation or imitation, plus the rate of capital gain or loss from the change in the expected value of a firm, must equal the risk-free interest rate. This equality is given by equation (2.29) and is presented here again:

$$r_{it} = \frac{\tilde{\pi}_{it}}{V_{it}} + \frac{\dot{V}_{it}}{V_{it}}, \tag{3.35}$$

Potential entrants in the North compare their expected value V_{nt} to the one-time cost η_n to decide whether to enter or not. Similarly, potential imitators in the South compare V_{st} with η^I_{st}, and potential innovators compare their expected value with η_{st}. The free-entry conditions are given by:

$$V_{nt} = \eta_n \qquad \text{for Northern innovators, and} \tag{3.36}$$

$$V_{st} = \min(\eta^I_{st}, \eta_{st}) \qquad \text{for Southern imitators/innovators.} \tag{3.37}$$

Equation (3.36) holds because if the expected value of innovation is greater (smaller) than the cost of innovation, there will be an infinite (zero) number of firms who are willing to enter, which drives the market interest rate upward (downward) due to excess (zero) demand of resources for R&D. Similarly, if the expected value of the last Southern entrant is different from its one-time entry cost, the relative number of Southern intermediate firms $\hat{N}_t$ will adjust until the free-entry condition (3.37) holds. One exception is when South is an imitator country and $\hat{N}_t = 1$. In this case, the number of Southern entrants is limited by the number of newly-innovated Northern products rather than an optimal choice. The free-entry condition (3.37) would carry a ">" sign instead of an equal sign as a result, unless $\hat{N}_t = 1$ is indeed a long-run equilibrium result.

Combining the final goods sector problem and the two-stage intermediate goods sector problem, economic growth relies on an increasing variety of intermediate goods over time. The growth in the number of intermediate goods is sustainable due to non-decreasing returns to intermediate inputs in final output production. Resources allocated to the R&D sector are increasing in output as long as the investment yields a positive rate of return, thereby maintaining a positive rate of imitation or innovation. This is true even for the South where the cost of imitation or innovation is increasing in $\hat{N}_t$.

In the next section, I define a competitive equilibrium and solve for the balanced growth path equilibria of the model.

3.3 Competitive Equilibrium and the Balanced Growth Path

Given the initial state variables, N_{nn0} and N_{ss0}, the competitive equilibrium of the economy consists of a vector of cut-off costs of intermediate goods sector and firm-level variables $\{a_{nnt}, a_{xnt}, a_{snt}, a^v_{snt}, a_{sst}, a_{xst}, a_{nst}, V_{nt}, V_{st}, \eta_{nt}, \eta^I_{st}, \eta_{st}\}$, and vectors of economy-wide sequences $\{Y_{it}, C_{it}, R_{it}, M_{it}, NX_{it}, B_{it}, \dot{B}_{it}, Z_{it}, N_{cit}, N^v_{snt}, w_{it}, r_{it}\}_{t\in[0,\infty)}$ for $c \in \{i, x, j\}$ and $i \in \{n, s\}$ that satisfy the following conditions:

(i) Households allocate consumption over time to maximize utility (2.1) subject to the budget constraint (2.2), and the transversality condition $lim_{t\to\infty} e^{-r_{it}} B_{it} = 0$ for $i \in \{n, s\}$, taking wage rates and interest rates as given;

(ii) Final goods producers minimize costs by choosing labour and intermediate inputs subject to production function (2.3), taking prices of intermediate goods as given;

(iii) Intermediate goods firms maximize profit function (3.13) by choosing their prices, taking into account the demand function of final goods producers, the marginal cost of production based on their costs draws, and the per-period fixed costs to enter each market;

(iv) Free-entry conditions (3.36) and (3.37) are satisfied;

(v) Markets clear in country i, for $i \in \{n, s\}$:

$$\begin{aligned} L_i &= \bar{L}_i, \\ \dot{B}_{it} &= R_{it}, \\ Y_{it} &= C_{it} + R_{it} + M_{it} + NX_{it}; \end{aligned}$$

and (vi) World markets clear: $NX_{nt} = -NX_{st}$.

3.3.1 Balanced Growth Path

The balanced growth path is a stationary equilibrium such that all endogenous macroeconomic variables grow at constant rates over time. In particular, a stationary equilibrium is a competitive equilibrium as defined above, and in addition, the cut-off costs of intermediate goods sector are constant, so that the cost distributions of domestic firms, exporters, and horizontal and vertical MNEs are stationary.

I define g_{nt} as the rate of innovation for the North, and g^I_{st} and g_{st} as the rates of imitation and innovation for the South, respectively. These rates are equivalent to the growth rates of the number of home-grown intermediate goods N_{nnt} for the North, the South as an imitator country, and the South as an innovator country, respectively. Since there is no population growth, the growth rates of the macroeconomic variables are equivalent to their per capita growth rates.

Along a BGP, the state variable $\hat{N}_t$ is constant, and is given by $\hat{N}^*$. This implies that the rates of technology creation are equal across economies, *i.e.* $g^I_{st} = g_{nt}$ or $g_{st} = g_{nt}$. I define g^* as the BGP rate of technology creation. Since $\hat{N}^*$ is constant along the BGP with the rates of technology creation being equal across countries, the cost distributions become stationary. Output growth across countries are the same as the BGP rate of technology creation, as implied by equations (3.25) and (3.26). R&D investment R_{it} also grows at the same rate, as implied by equations (3.6), (3.29), (3.31), and (3.32), and a constant $\hat{N}^*$. Following a similar logic to that described in Appendix A.1, net exports NX_{it} can be solved for as linear functions of N_{iit} for $i \in \{n, s\}$. Based on the aggregate resource constraint (3.10), C_{it} is also a linear function of N_{iit}. Because the endogenous macroeconomic variables are all linear functions of N_{iit}, the growth rates of these variables are all equal to g^*, which is also the per capita growth rate. Proposition 1 from Chapter Two can therefore be modified as follows:

Proposition 5: *The growth rates of final output Y_{it}, spending on intermediate goods M_{it}, R&D investment R_{it}, net exports NX_{it}, the number of intermediate firms N_{it}, and aggregate consumption C_{it} for $i \in \{n, s\}$ are all equal to the rate of technology creation given by:*

$$g^* = \frac{1}{\theta}\left(\frac{\tilde{\pi}_i}{\eta_i} - \rho\right). \tag{3.38}$$

Proof: Stationary costs distributions, a constant $\hat{N}^*$, the free-entry conditions (3.36) and (3.37), and equation (3.35) together yield r_i along the BGP. The equilibrium interest rate and the Euler equation (3.3) together give the equilibrium growth rate (3.38).

The t subscript has been dropped to denote constant values along a BGP. In short, the BGP growth rate is increasing in the average profit of an intermediate good firm, and decreasing in the cost of technology creation.

3.4 Balanced Growth Path Dynamics and Intellectual Property Rights in the South

Depending on the strength of intellectual property rights in the South, there are three distinct types of balanced growth path (BGP) equilibria that can arise in this model. The South becomes an innovator country in one type of equilibrium, while it remains as an imitator country in the other two types of equilibria. In particular, the third type is a corner solution, in which Southern imitation exhausts the pool of uncopied Northern products. I define g_1^* as the BGP growth rate when the South is an innovator country, with the underlying relative number of Southern firms $\hat{N}^* = \hat{N}_1^*$. Similarly, I define g_2^* and g_3^* as the per capita BGP growth rates of the two equilibria when the South is an imitator country, with the relative number of Southern firms being $\hat{N}_2^*$ and $\hat{N}_3^*$, respectively. To be precise, I define:

$$g_1^* = \frac{1}{\theta}\left(\frac{\tilde{\pi}_s}{\eta_s} - \rho\right) \qquad \text{and} \qquad g_2^* = \frac{1}{\theta}\left(\frac{\tilde{\pi}_s^I}{\eta_s^I} - \rho\right). \tag{3.39}$$

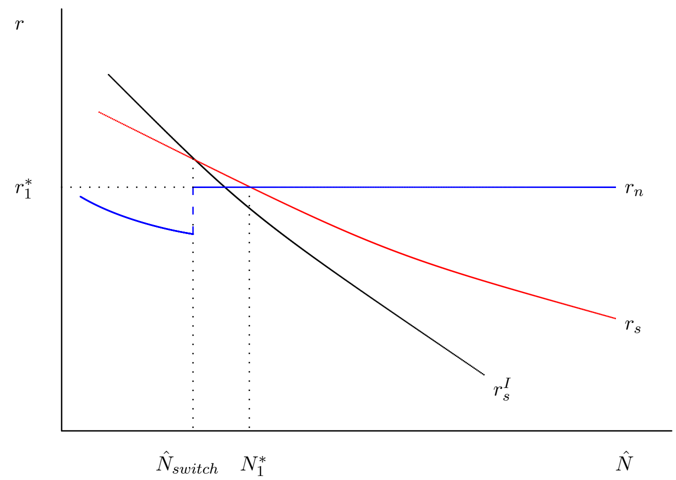
The strength of intellectual property rights in the South can be represented by the parameter ψ_s^I, which enters the cost of imitation η_{st}^I as given by equation (3.31). One can think of ψ_s^I as a reduced form cost parameter that consists of a fixed technological cost of imitation and the cost associated with exiting the market due to the enforcement of intellectual property rights.[56] That is, the stronger the intellectual property rights, the lower the survival probability for an imitator, hence the higher cost of imitation.

[56] I define b as the probability of a Southern imitator being forced to exit due to the enforcement of intellectual property rights. Modifying the free-entry condition (3.37) yields:

$$\begin{aligned}(1-b)V_{st}^I &= \xi A_s^{\frac{1}{1-\alpha}} \alpha^{\frac{2\alpha}{1-\alpha}} L_s \hat{N}_t^{\sigma^I} \\ V_{st}^I &= \frac{\xi}{1-b} A_s^{\frac{1}{1-\alpha}} \alpha^{\frac{2\alpha}{1-\alpha}} L_s \hat{N}_t^{\sigma^I}\end{aligned}$$

By defining $\psi_s^I = \xi/(1-b)$, ψ_s^I becomes a reduced form cost of imitation where the technological cost of imitation is adjusted for the probability of surviving the enforcement of intellectual property rights.

Figure 3.1: Southern Innovation and BGP Growth Rate



We first consider a BGP equilibrium where the intellectual property rights in the South are strong, so that Southern firms are innovators along the BGP. The world economy attains a BGP growth rate of g_1^* at a state of $\hat{N}_1^*$, with the rate of return from innovation being r_1^*. This is illustrated in Figure 3.1, where the rates of return on Southern imitation (r_s^I), Southern innovation (r_s), and Northern innovations (r_n) are functions of $\hat{N}$. Recall that the r_s^I and r_s curves are inversely related to their respective cost of entry, according to equation (3.35) and free-entry condition (3.37). As $\hat{N}$ increases, the cost of entry increases, and the rate of return decreases. The r_s^I curve is steeper than the r_s curve because the cost of imitation η_{st}^I increases faster than the cost of innovation η_{st}, which are given by equations (3.31) and (3.32), respectively.[57] I denote $\hat{N}_{switch}$ the intersection of the two curves, so that Southern firms are innovators for $\hat{N} > \hat{N}_{switch}$ since it is cheaper to innovate than to imitate from this point onward.

The r_n curve has two parts. It is downward sloping before $\hat{N}_{switch}$, but it jumps to

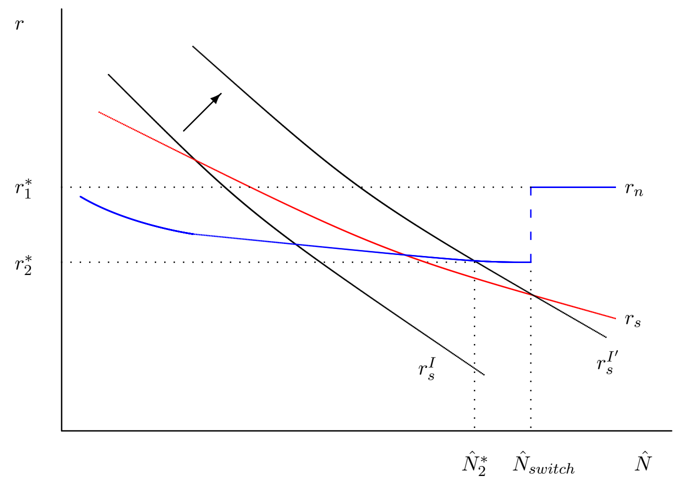
[57]The determination of r_{st} from equation (3.35) involves capital gains or losses arising from changes in the expected value of a firm. The analysis here ignores this part for simplicity. Including the capital gains or losses do not affect the general result.

a higher rate of return and remains constant for $\hat{N} > \hat{N}_{switch}$. The shape of the curve comes from the fact that $\tilde{\pi}_{nt}$ is a function of the probability of imitation ϕ_{nt}, which can be seen by taking equation (3.33) together with (3.19) to (3.21). ϕ from equation (3.30) increases as the the pool of uncopied ideas shrinks faster than the rate of Southern imitation as $\hat{N}$ increases. As a result, the proportions of Northern firms that either export or become horizontal MNEs will shrink as they face a higher probability of being imitated. This drives down the expected profits of Northern entrants, as well as their rates of return r_n. On the other hand, when all Southern entrants innovate for $\hat{N} > \hat{N}_{switch}$, the rate of imitation becomes zero, *i.e.* $\phi = 0$. The expected net profit $\tilde{\pi}_{nt}$ jumps up and stays constant when Northern entrants are no longer threatened by Southern imitation.

Since Southern entrants are innovators at $\hat{N} > \hat{N}_{switch}$, the intersection between the rates of return on Southern innovation r_s and on Northern innovation r_n yields the equilibrium rate of return r_1^*, which corresponds to growth rate g_1^* at $\hat{N}_1^*$.

Next, consider a scenario where the South imposes weaker intellectual property rights by having a smaller ψ_s^I. This is illustrated in Figure 3.2, in which the r_s^I curve is shifted out to $r_s^{I'}$. This shift means that for every $\hat{N}$, the return from imitation rises due to a lower cost of imitation. Since Southern entrants are imitators for $\hat{N} < \hat{N}_{switch}$, the intersection between $r_s^{I'}$ and r_n yields the equilibrium rate of return r_2^*, which corresponds to the BGP growth rate g_2^* at $\hat{N}_2^*$

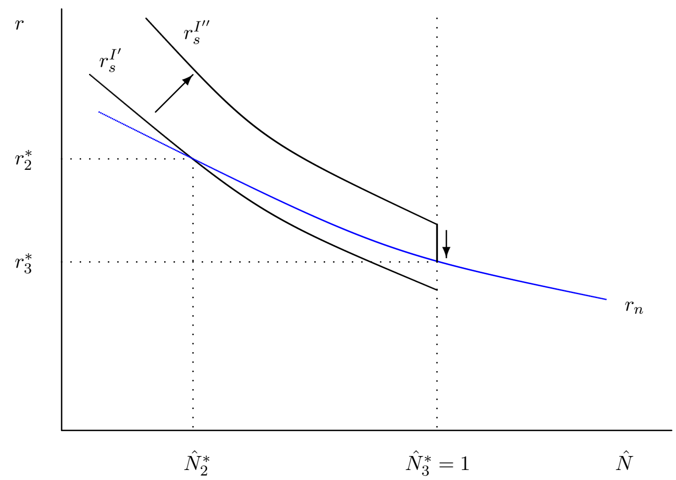
Figure 3.2: Southern Imitation and BGP Growth Rate



From Figure 3.2, r_2^* is lower than $r_1^* = r_n$, the equilibrium rate of return when the South is an innovator country. This implies that $g_1^* > g_2^*$. In other words, the BGP growth rate of the world economy is higher when both North and South are innovator countries, than it is when the North innovates but the South imitates. However, g_2^* can only be attained for an equilibrium $\hat{N}_2^*$ that is smaller than one, with the exception when $\hat{N}_2^*$ is exactly equal to one. Otherwise, a third type of BGP will be reached.

The third type of BGP arises when intellectual property rights in the South are very weak, by having an even smaller value of ψ_s^I than in the second scenario. In this case, the rate of return from imitation is very high, and fast imitation exhausts the pool of uncopied Northern products before the rates of return from Southern imitation and Northern innovation can be equalized to attain an interior solution. The free-entry condition (3.37) would no longer hold, as the number of Southern entrants is limited by the number of newly-innovated Northern products rather than being chosen optimally.

Figure 3.3: The BGP Growth Rate when Northern Innovations are Exhausted



As illustrated in Figure 3.3, this equilibrium happens at $\hat{N}_3^* = 1$, where the $r_s^{I'}$ curve is shifted out to $r_s^{I''}$ to reflect a further weakening in Southern intellectual property rights. Along this BGP, all newly-innovated Northern products are copied by the South, and the rate of return from Southern imitation $r_s^{I''}$ is forced to be equal to the rate of return from Northern innovation r_n.

In this type of equilibrium, the rate of Southern imitation g_s^I is forced to be equal to the rate of innovation g_n in the North. I denote this BGP growth rate g_3^*, which is the lowest among the three BGPs. This is because Northern entrants face a probability of imitation $\phi = 1$, and by equation (3.20) none of the Northern firms will serve abroad. The expected profits of Northern entrants are the smallest among the three BGP equilibria, resulting in the lowest rates of innovation and growth.

These balanced growth path results suggest that different degrees of intellectual property rights protection in the South can generate different economic implications. We can therefore establish the following proposition:

Proposition 6: *The higher ψ_s^I is in the South, the faster the per capita long-run growth rate in the North-South economy, where a higher ψ_s^I is driven by stronger intellectual property rights in the South.*

Since ψ_s^I is a reduced form of imitation cost that can be influenced by the strength of intellectual property rights, we can further tie this idea to the three BGP equilibria in the following proposition:

Proposition 7: *When intellectual property rights are strong in both the North and the South (i.e. when ψ_s^I is big enough such that $\hat{N}_{switch} < 1$ exists), both economies will achieve a faster per capita long-run growth rate than when the South imposes weaker intellectual property rights. A weakening of intellectual property rights protection in the South (i.e. a small ψ_s^I) causes the North-South economy to fall to a slower long-run growth path. If intellectual property rights in the South are so weak that Southern imitation exhausts the pool of uncopied Northern products, the North-South economy falls into the slowest long-run growth path among the three types of BGP.*

The results summarized in Proposition 7 provides implications of intellectual property rights on long-run economic growth. When intellectual property rights are strictly enforced in the North, it is best for the South to also enforce stronger intellectual property rights in order to achieve fast per capita long-run growth rate in both economies.[58] If intellectual property rights protection in the South are weak, the North should still introduce policies to support R&D activities. This helps to maintain its absolute advantage in technology creation by keeping the size of the uncopied pool of ideas. Otherwise, the world economy can

[58]If Northern firms are allowed to imitate, then there will be a switchover of technological leadership when the South becomes an innovator country, as discussed in Barro and Xala-i-Martin (2004). This in turn creates disincentive for Southern innovators to innovate by affecting their expected profits from abroad, resulting in a lower per capita BGP growth rate.

fall into a balanced growth path with a slow growth rate as the pool of uncopied products is exhausted by Southern imitation.

The theoretical results add to the existing literature of North-South trade where most of the recent studies do not provide policy implications on long-run growth, including studies such as Dinopoulos and Segerstrom (2011), and Gustaffson and Segerstrom (2010b and 2011). Although the models in these studies can generate long-run welfare gains through a higher *level* of consumption from a strengthening in intellectual property rights, they generally do not have any *growth* implications. In contrast, the fully-endogenous growth model presented in this chapter, which is free from the "scale effect" problem in the growth literature, can account for long-run effects from enforcing intellectual property rights. It also has other long-run implications such as those regarding policies on openness to trade and multinationals. These will be explored in the next chapter.

3.5 Conclusion

This chapter studies the long-run economic implications from intellectual property rights in the North-South context using a theoretical framework of endogenous innovation with firm heterogeneity. I extend the open-economy model of endogenous innovation with firm heterogeneity presented in Chapter Two and emphasize on the process of imitation and innovation in the South. The model generates long-run growth effects corresponding to different levels of intellectual property rights protection, adding to the recent literature in which the determinants of the long-run economic growth rate are limited to growth in labour force in the R&D sector. The model also accounts for the resulting changes in firm distributions which generate additional long-run growth effects that are missing in growth models with homogeneous firms. I also include the possibility of Northern firms to form horizontal and vertical multinational enterprises to capture their importance in the South's external sector development.

My theoretical analysis shows that allowing for endogenous determination of whether the South is an imitator or an innovator country is crucial for examining the long-run growth effect of stronger intellectual property rights. Depending on the costs and benefits of imitation and innovation, firms from the South can choose how new products are created by maximizing expected profits. When intellectual property rights are strictly enforced in the North, it is best for the South to also enforce stronger intellectual property rights so that the per capita long-run growth rate is maximized for both economies. If intellectual property rights protection in the South is weak, the North needs to maintain its absolute advantage in technology creation by keeping the size of the uncopied pool of ideas. Otherwise, the world economy can fall into a balanced growth path with a slow growth rate as the pool of uncopied products is exhausted by Southern imitation. This is a result of the disincentive to Northern innovation created by Southern imitation.

Firm heterogeneity is key to determining the impact of enforcing intellectual property rights in the South. This feature allows the model to pin down the distributions of domestic firms, exporters, and multinationals based on differences in firm-level productivity, which helps to eliminate the over-statement of the impact of stronger intellectual property rights arising in a model with homogeneous firms.

The existing literature that studies intellectual property rights in the North-South context are generally based on models with homogeneous firms. Studies in the literature either focus on trade or multinational activities between North-South without incorporating both channels under the same model. For instance, Gustaffson and Segerstrom (2010b) study the impact of intellectual property rights on product cycles in a North-South trade model where firms are equally-productive and will always serve the home market and export to the foreign market. Dinopoulos and Segerstrom (2011) and Gustaffson and Segerstrom (2011) study how intellectual property rights can affect the decisions to form vertical multinationals, where trade is only one-way from South to North. As we have seen from the data illustrated in Chapter One, it is essential to include both two-way trade and multinational production as channels of openness. However, it is difficult to incorporate multiple channels of openness into a model with homogeneous firms because it is unclear what the incentives are, for instance, for firms to become exporters over investing in foreign affiliates. The incentives are clear, however, when firms are heterogeneous in their productivities. Firms will forego exporting to become horizontal multinationals when the trade cost is too high comparing to the costs of setting up production abroad — the proximity-concentration trade-off as discussed in Chapter Two. At the same time, Northern firms can still become vertical MNEs to take advantage of cheaper production cost in the South as discussed in the literature.

More importantly, models with homogeneous firms can over-state the impact of stronger intellectual property rights on the rate of innovation. Specifically, an improvement in intellectual property rights in the South increases the ex-ante value of a Northern firm through an increase in its expected profits from both home and abroad, thereby raising the Northern rate of innovation. But in reality, since not all firms export, the increases in the ex-ante firm value and Northern rate of innovation are likely to be over-stated. In a model with firm heterogeneity, firms are divided into exporters and non-exporters, so that the ex-ante value of a Northern firm will account for the fact that not all firms can export.

The impact of stronger intellectual property rights on the level of output can also be over-stated in models with homogeneous firms. Intellectual property rights can have asymmetric effects on the extensive margin of the exporters and multinationals. While more Northern firms will export to the South when intellectual property rights become stronger, there will be a smaller increase in the number of Northern multinationals since the setup cost of a multinational is higher to begin with. The change in the distributions of exporters and multinationals can affect the total number of intermediate inputs available for the production of final output, and can also affect the average productivity of intermediate firms. These two together can generate additional level and growth effects that are missing in a model with homogeneous firms the impacts from policy changes on all types of firms are symmetric.

The results in this chapter suggest there maybe room for policies to prevent the North and the South from falling into a balanced growth path with slow growth. Despite facing Southern imitation, the North may still want to introduce policies to further enhance its ability in technology innovation by encouraging more R&D investment, possibly by subsidizing innovative activities. It is equally important for the South to share the economic burden by strengthening intellectual property rights, a process which may forego current consumption for faster long-run economic growth.

Chapter 4

The Role of Transitional Dynamics on Measuring Welfare Gains in a North-South Model

4.1 Introduction

This chapter attempts to fill a gap in the existing international growth literature by emphasizing the importance of transitional dynamics when studying the positive and normative implications of economic policies. Based on a model of endogenous innovation with firm heterogeneity similar to the one presented in Chapter Three, I conduct a numerical analysis which quantifies the effects of openness to trade and multinational production in the North-South context, as well as the impacts from strengthening intellectual property rights in the South. I modify the baseline model from Chapter Three by including features that capture the increasing openness in emerging economies that have arisen from the liberalizations of current and capital accounts over the past few decades. I focus specifically on the economic relationship between China and the OECD countries. China has become increasingly important in global supply chains during the past two decades and its economic development has been rapid, while the OECD countries are the final export destinations for most Chinese exports and are the leaders in technological development.[59]

The existing theoretical literature is concerned mostly with balanced growth path dynamics when studying policy implications related to international openness and intellectual property rights. Some of the studies in the extensive literature include Glass and Saggi (2002), Glass and Wu (2007), Dinopoulos and Segerstrom (2011), and Gustaffson and Segerstrom (2010b and 2011). However, ignoring the transitional dynamics can lead to biased estimates of the impacts of policies on growth and welfare. Some studies in the literature have addressed such biases by exploring transitional dynamics, but they usually treat the South as an imitator country without the possibility of endogenously switching to become an innovator country. These studies include the seminal work of Grossman and Helpman (1991) and Helpman (1993), and in the more recent work such as Arnold (2007), Connolly and Valderrama (2005a and 2005b), and Mondal and Gupta (2009). This chapter extends the theoretical framework developed in Chapter Three in order to gauge the magnitude of potential biases due to the missing impacts associated with transitional dynamics and the endogenous switchover between imitation and innovation in the South. The latter turns out to be important when assessing the growth and welfare gains coming from stronger intellectual property rights.

I calibrate a version of the model developed in Chapter Three using data from China

[59] See Mohommad, Unteroberdoerster, and Vichyanond (2011) in the April 2011 edition of the IMF Regional Economic Outlooks on the Asia and Pacific region for a discussion on the evolution of China's role in the global and regional supply chain.

and the OECD countries. I then use this to numerically characterize both the equilibrium transition paths and the balanced growth paths under different scenarios. Counterfactual experiments show that welfare gains from further trade openness between China and the OECD countries can be significant, and that transitional gains account for over two-thirds of the total welfare gain for China. On the other hand, since the South in the model can switch from being an imitator to an innovator country, a deterrence of imitation alters the resource allocation decisions within each economy. This occurs mostly along the earlier part of the equilibrium transition path before switching occurs, and leaves the rest of the path almost unchanged. Consequently, stronger intellectual property rights have limited welfare effects for both China and the OECD countries. This is in stark contrast with studies in the literature where large welfare gains have been found.[60] Further quantitative analysis focusing solely on the balanced growth path dynamics confirm that the over-estimation of growth and welfare gains from stronger intellectual property rights in the existing literature can be significant. These together point to a source of potential bias in the welfare estimates in the existing literature.

The next section presents modifications to the model in Chapter Three to better characterize features appeared in the data. Section 4.3 presents the data and the calibration results. Section 4.4 presents an equilibrium transition path of the Chinese economy, as well as the OECD consumption and output paths. Section 4.5 discusses the numerical results from conducting counterfactual experiments to assess the economic impacts of freer trade and stronger intellectual property rights. Section 4.6 concludes.

[60]For instance, see Gustaffson and Segerstrom (2010b and 2011).

4.2 A North-South Model of Endogenous Innovation with Increasing Openness

In this chapter I modify the baseline model from Chapter Three to better characterize the increasing economic integration between the advanced and the emerging economies that has been seen in the past few decades. I allow for the possibility that the fixed costs of exporting and multinational production decrease over time as the South progresses. The decreasing fixed costs represent structural changes arising from the continual liberalization to open up emerging economies to international trade and foreign direct investment.

There are two economies in the world economy, the North and the South. The North consists of the advanced economies, represented by the OECD countries. The South can be a large emerging economy or a group of emerging economies. Here we focus on China as a representative emerging economy. We denote countries by $i \in \{n, s\}$, where n and s denote the North and the South, respectively. Most of the model setting and the characterizations of the balanced growth paths presented in Chapter Three continue to hold here, with the fixed costs in equations (3.16) replaced by:

$$\begin{aligned} F_{iit} &= \psi_{ii} A_i^{\frac{1}{1-\alpha}} \alpha^{\frac{2\alpha}{1-\alpha}} L_i \quad , \quad & F_{xit} &= \hat{N}_t^{-\omega_i} \psi_{xi} A_i^{\frac{1}{1-\alpha}} \alpha^{\frac{2\alpha}{1-\alpha}} L_i, \\ F_{jit} &= \hat{N}_t^{-\kappa_i} \psi_{ji} A_i^{\frac{1}{1-\alpha}} \alpha^{\frac{2\alpha}{1-\alpha}} L_i \quad , \quad & F_{snt}^v &= \hat{N}_t^{-\omega_s} \psi_{sn}^v A_n^{\frac{1}{1-\alpha}} \alpha^{\frac{2\alpha}{1-\alpha}} L_n, \end{aligned} \tag{4.1}$$

for $i \in \{n, s\}$ and $j \neq i$. The domestic per period fixed cost F_{iit} and the various ψ terms are constant. $\hat{N}_t = N_{sst}/N_{nnt}$ denotes the relative number of intermediate goods originating from the South. This is an important state variable in the model that summarizes the path of the world economy. I assume $0 \leq \omega_i < 1$ and $0 \leq \kappa_i < 1$, so that the fixed costs to export and forming MNEs are decreasing as economic development in the South progresses, as represented by an increasing $\hat{N}_t$ over time.[61,62]

Various cut-off costs can be derived using equations (3.15), (3.17), (3.18), and (4.1). The domestic cut-off cost is given by (3.19) and is presented here again:

$$a_{iit} = \left[\frac{\alpha(1-\alpha)}{\psi_{ii}}\right]^{\frac{1-\alpha}{\alpha}}, \tag{4.2}$$

where ψ_{ii} is given by (3.22) so that $a_{iit} = a_{i0}$, where a_{i0} is the upper bound of the Pareto cost distribution (2.5) and is constant. This assumption guarantees firms that have obtained a blueprint either by imitation or innovation will always serve their domestic markets. The export and horizontal MNE cut-off costs can be expressed as functions of domestic cut-off cost:

$$a_{xit} = \left(\frac{(1-\phi_{it})}{\hat{N}_t^{-\omega_i}}\frac{\psi_{ii}}{\psi_{xi}}\frac{\Lambda_j}{\Lambda_i}\right)^{\frac{1-\alpha}{\alpha}}\frac{a_{iit}}{\tau} \quad , \quad a_{jit} = \left[(1-\phi_{it})\frac{\psi_{ii}(\gamma_i^{\frac{-\alpha}{1-\alpha}} - \tau^{\frac{-\alpha}{1-\alpha}})}{\psi_{ji}\hat{N}_t^{-\kappa_i} - \psi_{xi}\hat{N}_t^{-\omega_i}}\frac{\Lambda_j}{\Lambda_i}\right]^{\frac{1-\alpha}{\alpha}} a_{iit}, \tag{4.3}$$

where $\Lambda_d = A_d^{\frac{1}{1-\alpha}}\alpha^{\frac{2}{1-\alpha}}L_d$ for $d \in \{i, j\}$. The Northern vertical MNE cut-off cost can be found in a similar way:

$$a_{snt}^{v} = \left[\frac{\psi_{nn}((\tau\gamma)^{\frac{-\alpha}{1-\alpha}} - 1)}{\psi_{sn}^{v}\hat{N}_t^{-\omega_s} - \psi_{nn}}\right]^{\frac{1-\alpha}{\alpha}} a_{nnt}. \tag{4.4}$$

As $\hat{N}_t$ increases, the cut-off costs change accordingly, and the distributions of exporting firms and MNEs change as well. The average operating profits for exporters and MNEs change as a result of changes in the distributions. These assumptions do not affect the characterization of the balanced growth path equilibria discussed in Chapter Three. They

[61] I assume ω_i and κ_i to be less than one. The trade and multinational production fixed costs will drop at decreasing rates as $\hat{N}_t$ increases, such that the growth in exports, imports, and multinational productions will not be explosive.

[62] The per-period fixed cost of Northern vertical MNEs F_{snt}^{v} is a function of ω_s instead of ω_n because these firms export from the South back to the North, thus the function should be governed by the cost parameter in the South.

are crucial for extending the baseline model to explore the transition path of the North-South model, and providing incentives for intermediate firms in both the North and the South to explore markets abroad.

4.2.1 Transitional Dynamics

In this section I describe how the North-South economy attains the three distinct types of balanced growth path (BGP) equilibria discussed in Section 3.4, with focus on the transition paths. The first type of BGP is attained when the North and the South are both innovators. The second type is attained when intellectual property rights are weak in the South, so that the South imitates Northern innovations. The third type is a corner solution when the pool of uncopied Northern technologies are exhausted.

We begin by illustrating the impact of stronger intellectual property rights on the transition paths of the North-South economy. This is illustrated in Figure 4.1, where the rates of return on Southern imitation (r_s^I), Southern innovation (r_s), and Northern innovations (r_n) are functions of $\hat{N}$. The rate of return in general is given by equation (3.35), and is presented here again:

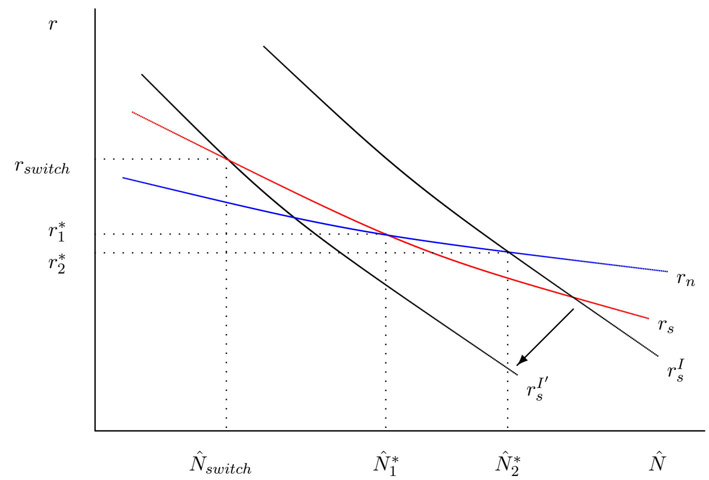
$$r_{it} = \frac{\tilde{\pi}_{it}}{V_{it}} + \frac{\dot{V}_{it}}{V_{it}}, \quad \text{for} \quad i \in \{n, s\}. \tag{4.5}$$

As discussed in Section 3.4, the r_s^I and r_s curves are downward sloping because the cost of entry increases with $\hat{N}$. The costs of imitation (η_s^I) and innovation (η_s) are given by equations (3.31) and (3.32), and are reproduced below:

$$\eta_{st}^I = \psi_s^I A_s^{\frac{1}{1-\alpha}} \alpha^{\frac{2\alpha}{1-\alpha}} L_s \hat{N}_t^{\sigma^I}, \tag{4.6}$$

$$\eta_{st} = \psi_s A_s^{\frac{1}{1-\alpha}} \alpha^{\frac{2\alpha}{1-\alpha}} L_s \hat{N}_t^{\sigma}. \tag{4.7}$$

Figure 4.1: Southern Technology Switchover: Transition Paths and BGPs



Given that $\sigma < \sigma^I$, the cost to imitate increases faster than the cost to innovate. r_s^I decreases faster than r_s as a result.[63] I denote $\hat{N}_{switch}$ as the intersection of the two curves, where the Southern firms are imitators for $\hat{N} < \hat{N}_{switch}$.

In contrast to Figure 3.1, the r_n curve is downward-sloping and does not jump at the point of the switchover. Unlike the constant fixed costs in Chapter Three, the fixed costs to trade and form multinationals that are decreasing in $\hat{N}$ serves to eliminate the jump in the r_n curve. First, as $\hat{N}$ increases, the probability of imitation ϕ from (3.30) increases, which drives down the expected profits of Northern innovation coming from export and horizontal multinational activities. The rate of return on innovation decreases before the point of switchover $\hat{N}_{switch}$ as a result. Beyond the point of switchover, Southern technology creation slows down. Although Northern firms are no longer threatened by Southern imitation and thus their incentive to innovate increases, this can be offset by falling expected profits due to the entry of less productive firms as fixed costs to trade and form multinationals

[63]The determination of r_{it} involves capital gains or losses arising from changes in the expected value of a firm. The analysis here ignores this part for simplicity. Including the capital gains or losses do not affect the general result.

are declining over time. Consequently, the curve can either jump slightly, stay flat, or decline at the point of switchover.[64] For simplicity, I illustrate the case where the r_n curve is downward-sloping.

We first consider a BGP equilibrium where the intellectual property rights in the South are weak, so that Southern firms always imitate. The world economy attains a BGP growth rate of g_2^* at a state of $\hat{N}_2^*$, with the rate of return from imitation being r_2^*. To attain this equilibrium, the economy begins with an initial state of $\hat{N}_0 = \dot{N}_{ss0}/N_{nn0}$, which I assume to be smaller than the BGP $\hat{N}_2^*$. $\hat{N}$ increases along a transition path for $r_s^I > r_n$. Over time, the cost of Southern imitation is increasing in $\hat{N}$, as seen in equation (4.6), causing r_s^I to decrease over time. Since r_s^I decreases faster than r_n, the gap between the rates shrinks over time and will eventually reach a point where $r_s^I = r_n$ at $\hat{N}_2^*$.

To assess the stability of the BGP, one can perturb the economy by increasing $\hat{N}$ above $\hat{N}_2^*$. The cost of Southern imitation increases as a result of an increase in $\hat{N}$ from its equilibrium value, causing the rate of imitation r_s^I to decline. Given that the Northern cost of innovation is constant, a small perturbation from the BGP does not alter r_n from its equilibrium rate. This implies that $r_s^I < r_n$, causing $\hat{N}$ to drop in the subsequent period. $\hat{N} = \hat{N}^*$ holds again as a result. Similarly, by perturbing the BGP to get $\hat{N} < \hat{N}^*$, $r_s^I > r_n$ as Southern imitation becomes cheaper, $\hat{N}$ increases and will again reach its BGP value.[65] These results also apply to the case when the South is an innovator country.

[64] As discussed in Section 4.4.2 below, the r_n curve is U-shaped when the South is an innovator country. When the South imitates, it creates disincentive for the Northern firms to innovate, causing the innovation rate to decline. But once the Southern firms also become innovators, the disincentive to Northern innovation disappears, while the increasing demand from the South will provide incentives to Northern innovation. Hence the U-shaped time path.

[65] One can refer to Chapter 8 of Barro and Sala-i-Martin (2004) for the existence and the stability of a simplified version of the model, in which there is no openness to trade and MNEs. The results presented there continue to hold in this model because the BGP equilibria here are stationary equilibria, and the costs distributions are well-behaved along the transition paths, which converge towards their respective stationary distributions as the state variable $\hat{N}_t$ approaches its equilibrium value.

Next, imagine that the South imposes stronger intellectual property rights along the transition path by increasing ψ_s^I. As illustrated in Figure 4.1, the Southern transition path shifts from r_s^I to r_s. The downward shift means that for every $\hat{N}$, the return from imitation falls due to a higher cost of imitation. A switchover occurs at $\hat{N}_{switch}$ along the transition path, where the rates of return from imitation ($r_s^{I'}$) and innovation (r_s) are equal for Southern firms. From this point onward, the rate of return from Southern innovation is higher than from imitation, so that Southern firms have no incentive to imitate thereafter. The South moves along the transition path r_s over time until r_s is equal to the return from Northern innovation r_n, the point where r_1^* is attained at a state of $\hat{N}_1^*$.

The third type of BGP arises when intellectual property rights in the South are very weak. In this case fast imitation exhausts the pool of uncopied Northern products before the rates of return from Southern imitation and Northern innovation can be equalized to attain an interior solution. This equilibrium has the lowest rates of innovation and economic growth. Details are discussed in Section 3.4.

In the next section we use the modified version of the North-South model to quantify the effects of openness to trade and multinational production, as well as the impacts of stronger intellectual property rights.

4.3 Calibration

The quantitative analysis in this chapter focuses specifically on the economic relationship between China and the OECD countries. China is a representative *South* country due to its importance in the global supply chain during the past decade and its rapid economic development in the spotlight. I treat the OECD countries as the *North* due to their status in technological leadership. Following the country selection in Chapter Two, the set of North countries comprises nineteen OECD countries: Australia, Austria, Belgium/Luxemburg, Canada, Denmark, Finland, France, Germany, Greece, Italy, Japan, Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, the United Kingdom and the United States.

I calibrate the theoretical model presented in Chapter Three to key features of the data available during the present time - which I call the "initial state". Using the calibrated version of the model, I find the long-run BGP equilibrium attainable in the future. Based on that, I project an equilibrium transition path of the economy from the BGP back to the "initial state" in backward fashion. I assume the "initial period" to be 1997 because of structural changes in the Chinese economy in subsequent periods.[66] I then conduct two counterfactual experiments, freer trade and stronger intellectual property rights, to examine the associated welfare gains for China and the OECD countries, both along the transition path and on the BGP.

Table 4.1 illustrates the parameter values and their individual calibration targets. As in Chapter Two, the cost distribution parameter (k_i) satisfies the firm size dispersion as suggested by Helpman, Melitz, and Yeaple (2003) and is the same across countries. I normalize the minimum possible value of unit costs (a_{i0}) to be 1. The labour share of final output ($1 - \alpha$) of 0.56 is based on the estimates on China's average labour share of GDP from Bai and Qian (2009). The elasticity of substitution (ϵ) is implied by the α estimate. The risk aversion parameter for China (θ_s), which appears in the household's utility function (2.1) and the Euler equation (3.3), is estimated using Chinese consumption growth data from the World Bank's World Development Indicators and the estimates of the

[66]In 1997, the 15th Congress of the Communist Party of China officially endorsed the increase in the role of privately-owned firms. There was a structural shift in industrial production in the presence of the more productive privately-owned enterprise sector which had expanded tremendously thereafter. Another structural shift is the substantial improvement in labour mobility, resulting in more cross-province labour force allocation. See Brandt, Tombe and Zhu (2010), Hsieh and Klenow (2009), and Song, Storesletten and Zilibotti (2011) for further discussions on resource allocation issues in China.

real return on capital from Bai et al. (2006) for the period from 1980 to 2005.[67] On the other hand, the risk aversion parameter for OECD (θ_n) is chosen to be 2, consistent with the calibration exercise in Chapter Two. The σ^I parameter, which controls the shape of the imitation cost function (4.6) and the free-entry condition (3.37), is also estimated using relevant data accordingly. Details on estimating θ_s and σ^I are discussed in Appendix B.1. With reference to the σ^I estimate, σ is selected to ensure the slope of the innovation cost function is no steeper than the imitation cost function.[68]

Table 4.1: Single Parameters Calibrated

Params	Descriptions	Values	Targets
k_i	cost distribution	2.05	firm size dispersion from Helpman et al. (2003)
a_{i0}	minimum cost draw	1	normalization
$1-\alpha$	labour share of output	0.56	average labour share from Bai & Qian (2009)
ϵ	elasticity of substitution	1.8	implied by α
θ_s	risk aversion for China	2.92	estimated from China data
θ_n	risk aversion for OECD	2	Ghironi & Melitz (2005)
σ^I	elasticity of imitation cost	0.1887	estimated from consumption growth data
σ	elasticity of innovation cost	0.188	assumed based on σ^I
ρ	time preference	0.03	real return on stock 7% for OECD
τ	bilateral trade cost	1.7	Novy (2008)
ψ_n	OECD cost of innovation	2.9	OECD per capita consumption growth 2.48%
ψ_s^I	China cost of imitation	9.735	China per capita consumption growth 8.07%
ψ_s	China cost of innovation	9.7	implied at the point of switching

The time preference parameter (ρ) is chosen to be the same as that in Chapter Two. The iceberg trade cost (τ) of 1.7 between China and the OECD is proxied by the average

[67] The sample period for estimation is limited by the sample length of real return on capital estimates provided by Bai et al. (2006). Yet, the consumption growth implied by the estimated Euler equation can well-fit the actual data, with an R^2 of 0.85.

[68] Dividing the cost of imitation (4.6) by the cost of innovation (4.7) yields:

$$\frac{\eta_{st}^I}{\eta_{st}} = \frac{\psi_s^I}{\psi_s}\hat{N}_t^{\sigma^I-\sigma}.$$

Given ψ_s^I/ψ_s, $\eta_{st}^I > \eta_{st}$ only if $\sigma^I > \sigma$ for $\hat{N}_{switch}$ to exist. Otherwise South will always be an imitator.

trade costs of Japan and Korea as suggested by Novy (2008). The ψ_n parameter, which helps to determine the OECD cost of innovation, is calibrated to match the historical average per capita consumption growth rate of 2.48% across the OECD countries. The ψ_s^I parameter, which controls the level of China's imitation cost over time, is calibrated to match the average per capita consumption growth rate of 8.07% for the period from 1980 to 1997. I choose to match consumption growth only up to Year 1997 because it is the "initial period" for the transition path projection as discussed earlier. Details of the calibration are discussed in Appendix B.1. Finally, the parameter ψ_s, which controls for the level of China's innovation cost over time, is implied by the OECD cost of innovation at the point of switching.[69]

Table 4.2 describes the facts that are used to jointly calibrate the aggregate productivity parameters A_d for $d \in \{n, s\}$, the fixed costs parameter ψ_{cd} for $c \in \{n, x, s\}$, the Northern vertical MNE fixed cost paramater ψ_{sn}^*, the γ parameter that controls South's effective unit cost per production input, and ω_s and ω_n, the parameters that control the export fixed costs with respect to relative number of Southern firms $\hat{N}$. Firstly, since China's outward MNE activities were negligible during the sample period, I set the fixed cost parameter ψ_{ns} to infinity, and set the parameter that controls China's outward MNE fixed cost κ_c to zero.[70] The trade fixed costs parameters are calibrated to match the export and import shares of China's GDP, which are based on the OECD STAN data set for the period from 1988 to 2008. Moreover, I calibrate the parameters ω_s and ω_n by matching the simulated exports, imports, and net exports shares of final output for China with the increasing trends as seen

[69]At the point of switching, China's costs of imitation and innovation are equal, and I assume the costs are also equal to OECD's cost of innovation at the switching point to calibrate the China innovation parameter.

[70]Due to capital control, China's outward foreign direct investment did not pick up until 2004, but were still negligible as a share of China's GDP in subsequent years. Given this background, it is not possible to project China's outward MNE on the transition path and along the BGP. This could undermine the importance of economic openness to both China and the OECD countries.

in the data. This is meant to ensure the proper incentives for both Northern and Southern firms in the model to enter the export markets. I then set $\kappa_n = \omega_n$ for consistency.

The MNE fixed costs parameters are calibrated to match the inward-horizontal and vertical MNE sales data that come from the US Bureau of Economic Analysis, the World Bank's World Investment Report, and the China Customs Statistics for the period from 1997 to 2007, where the MNE sales averages have been adjusted to exclude intrafirm trade and other non-local sales. I match the model with the China-OECD per capita GDP ratio of 0.0767 as of 1997, the average labour force ratio of 1.7 since 1980, and China's export, import, inward/horizontal MNEs, and vertical MNEs sales shares of GDP.[71] The relevance of welfare measures can be improved as a result of matching the relative per capita GDP ratio and the relative labour force, in which these two ratios are calculated based on the data from the World Bank's World Development Indicators.

Table 4.2: Multiple Parameters Calibrated

A_d aggregate productivity for $d \in \{n, s\}$	
$\hat{N}_0$ initial state variable	
ψ_{cd} fixed costs, $c \in \{n, x, s\}$	
ψ^*_{sn} fixed costs of Northern vertical MNE	
γ effective unit cost per input	
ω_s and ω_n parameters of export fixed costs	
China-OECD per capita GDP ratio	0.0767
China-OECD labour force ratio	1.7
China domestic export share of GDP	7.4%
China total import share of GDP	7.5%
China inward MNE sales share of GDP	6.3%
China vertical MNE export share of GDP	11.1%

[71] As discussed in Footnote (14) in Chapter Two, final output and GDP are different in this model. I calibrate the fixed costs to match the various sales-to-final output ratios in the model with the sales-to-GDP ratios in the data in order to be consistent with the openness measures implied by the model.

Table 4.3 illustrates other quantitative implications which are generated by the parameterized version of the model, but were not targeted as part of the calibration. First, the labour share of GDP $(1 - \alpha)$ of 0.56 would imply a 127% markup over marginal cost in the model, which is an extremely large markup compared with those suggested by the macroeconomic literature such as Basu and Fernald (1997). However, due to the presence of per-period fixed costs, the markup over *average* cost is only 19.7% in OECD and 23% in China, which is largely in line with the literature. While the costs of innovation, expressed as a share of per capita final output, are much larger than the average cost suggested by Barseghyan and DiCecio (2009), these ratios are still within the range suggested in their paper. The model also yields a R&D expenditure share of final output for the OECD countries that is at the higher end of the R&D-to-GDP ratio among the OECD countries.

The middle panel of Table 4.3 shows the OECD trade and MNE sales with China implied by the model as shares of the OECD final output. These implied shares are consistent with the actual shares found in the data. The bottom panel shows the dollar values of the per-period fixed costs implied by the model for domestic producers, exporters, horizontal and vertical MNEs, respectively, for China and OECD firms. The amounts are expressed in 2000 US dollars.[72] While the vertical MNE fixed cost is close to the estimate from Rodrigue (2010) based on Indonesian plant-level data, the horizontal MNE fixed cost is much larger.[73] This may reflect the difficulty of accessing distribution channels and local markets due to the underdevelopment in transport infrastructure and informal barriers to enter the domestic sales market, as suggested by Amiti and Javorcik (2008).

[72] The fixed costs values in Rodrigue (2010) are expressed in 1983 US dollars. These values are converted to 2000 US dollars for comparison.

[73] Irarrazabal, Moxnes, and Opromolla (2009) suggest that MNE fixed costs can be up to several hundred times of exporters' fixed costs.

Table 4.3: Other Quantitative Implications

Model	OECD	China	Sources	Values
Markup over average cost	19.7%	23.0%	Basu & Fernald (1997)	19%
Cost of innovation (per Y/L)	168%	118%	Barseghyan & DiCecio (2009)	50%
R&D share of output	4.2%	5.6%	OECD (highest)	4.2%

OECD trade/MNE sales with China (as a share of final output)

Model	Values	Sources	Values
OECD export share	0.98%	OECD STAN	0.82%
OECD import share	2.42%	OECD STAN	2.14%
OECD outward MNE sales	0.82%	OECD STAN	0.77%
OECD vertical MNE sales	0.1%	OECD STAN	0.1%

Fixed costs (per-period)	Values	Compare to Rodrigue (2008)
China Domestic	$6,104	$3,000-4,600
China Exporters	$24,371	$3,000-9,200
OECD Domestic	$4,926	$3,000-4,600
OECD Exporters	$4,249	$3,000-9,200
OECD MNEs	$74,852	$17,000 ‡
vertical MNEs	$17,005	$17,000 ‡

‡ 'OECD MNEs' stands for OECD's horizontal MNEs that serve both OECD and China, as oppose to 'vertical MNEs' which also ships goods produced in China back to their home country.

4.4 A Transition Path of the Chinese Economy

Based on the calibrated version of the model, an equilibrium transition path of the North-South model is generated using an algorithm in which a balanced growth path is assumed to be attained in the future. To find the balanced growth path (BGP) attainable in the future, the Euler equations, which characterize the Chinese and OECDs' consumption path, are used for solving the relative number of Chinese firms along the BGP when the consumption growth rates of the two economies are equalized. Following the definition of a BGP, output growth rates are also equal across countries, and the China-OECD per capita output ratio and the various trade and multinational sales shares of final output are constant.

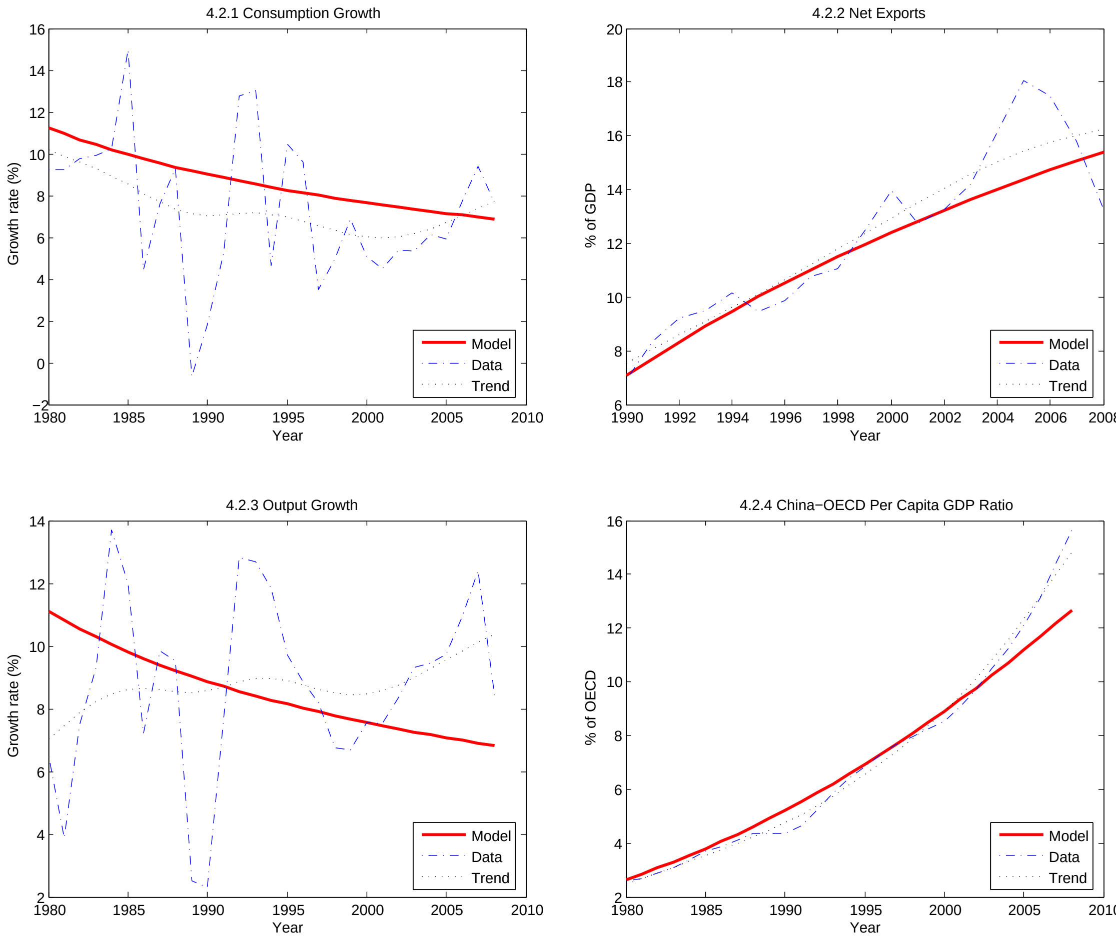
Next, by using the Euler equations, an equilibrium transition path is generated in backward fashion until the economy has reached the "initial state" of the economy as described by the calibration targets in Tables 4.1 and 4.2. In addition, I simulate the path for the period prior to the "initial period" to compare the simulated data and the actual data to evaluate the relevance of the model. Details on the algorithm for generating the equilibrium transition path are described in Appendix B.2.

Figure 4.2 illustrates the *in-sample* transition path of the Chinese economy from 1980 to 2008. Each of the four panels illustrate the transition paths of different variables, and each compares the simulated data to the actual data and their respective HP-filtered trends. The first panel shows that the simulated per capita consumption growth path is reasonably in line with the trend in the actual data which follows a downward sloping path. The upward sloping trend in China's net exports share of GDP, as shown in the second panel, is fitted as a calibration target. The third panel shows a downward trend in the simulated per capita output growth of China. This is in contrast to the upward trend produced by the HP filter, with the actual data being volatile.[74] The fourth panel in Figure 4.2 shows that the simulated China-OECD per capita GDP ratio matched well with the actual data between 1980 and 2004, but slowly diverged afterwards. The downward trend in per capita output growth predicted by the model causes a slower increase in the simulated China-OECD per capital GDP ratio than suggested by the data in the latter period of the sample.

Although the calibration strategy is intended to capture the expansion in the trade sector of the Chinese economy which will further translate into per capita output growth through entry of new Chinese firms, the model still faces limitations in predicting China's per capita

[74]The HP filter is well-known for the so called "end-point problem", in which HP-filtered trends tend to be biased towards the actual data points at the beginning and the end of the time series. Given the volatility of China's per capita output growth, the use of the HP filter to produce a growth trend becomes sensitive to the selection of sample period.

Figure 4.2: Transition Paths - Model and Data



output growth. China's growth experience cannot be explained by expansion in the trade sector alone. As suggested by Bai et al. (2006), China has been experiencing a prolonged period of very slowly diminishing return on investment (capital or intermediate inputs). This is possibly due to increasing inter-provincial factor mobility, the evolution of industrial organizational structure that are unique to China's growth experience, and other structural factors.[75] Nevertheless, the model can capture well the trend of per capita consumption

[75]Recall that firms' entry decision in the model depends on the rate of return on investment in imitating or innovating new technologies. The increasing costs of imitation and innovation from equations (4.6) and (4.7), return on investment from equation (4.5), and the free-entry conditions (3.36) and (3.37) together imply that

growth path for the Chinese economy, which is key to the welfare analysis that will be presented in a latter section.

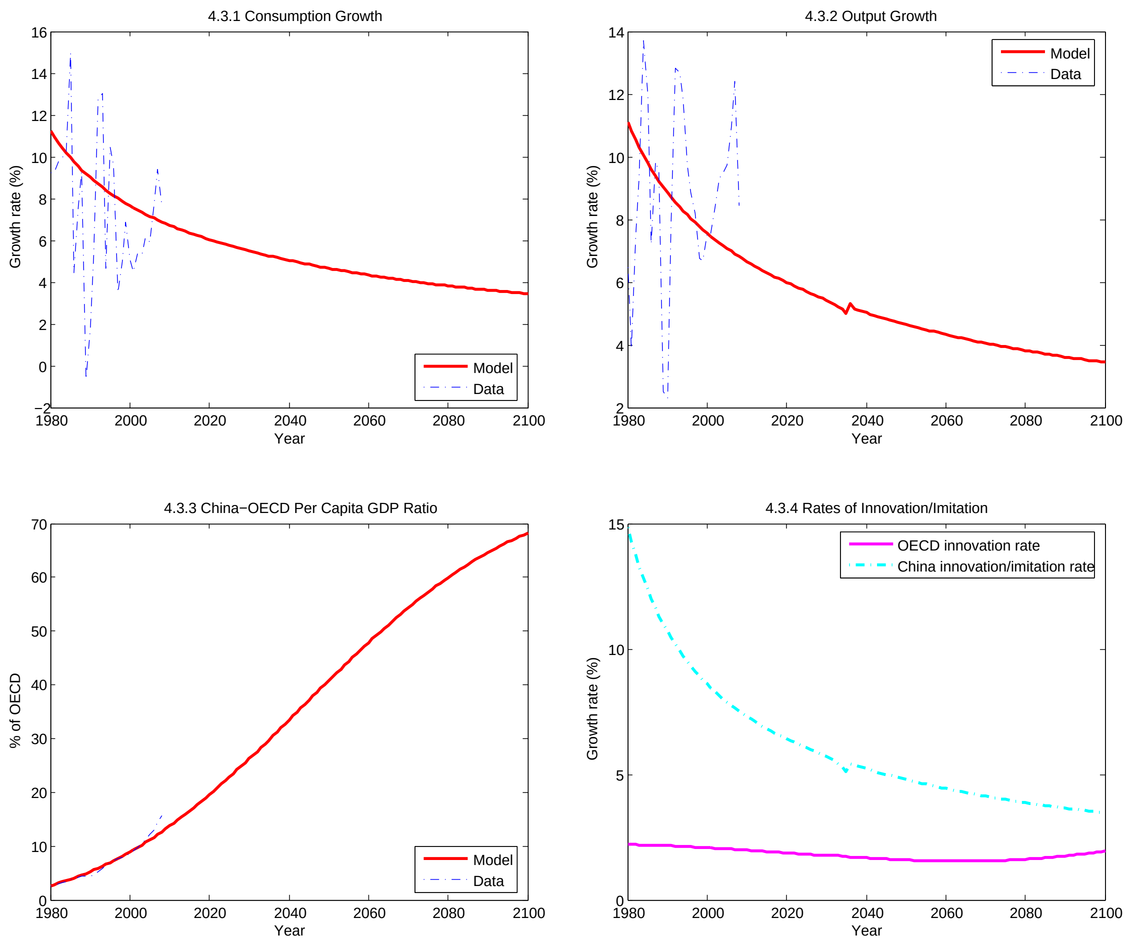
4.4.1 The Out-of-Sample Transition Path

The results for the *in-sample* and *out-of-sample* transition path of the Chinese economy are presented in Figure 4.3. The first two panels show that China's per capita output and consumption growth will moderate over time, with an implied balanced growth path growth rate of around 3% for China and the OECD countries. Moreover, the model predicts that the China-OECD per capita GDP ratio will increase over time, as illustrated in the third panel. Given a small initial per capita GDP ratio between China and the OECD countries, it may not be too surprising that the balanced growth path will take a long time to be reached. The two ratios increase at a slower speed eventually as the economies grow closer to the proximity of the balanced growth path in the very long-run. The S-shaped per capita GDP ratio has to do with the output growth differential between China and the OECD countries. While China's per capita consumption growth is predicted to decrease over time, the OECD's per capita output and consumption growth paths are predicted to follow a U-shaped time path due to changing incentives for innovation in the OECD countries, which will be further discussed in the next section. Taken together, the output growth differential increases initially and shrinks afterwards, thereby creating a S-shaped per capita GDP ratio.

One may note that there is a jump in the output growth path as shown, but not in the consumption growth path. As the theoretical model predicts, China as a Southern country will grow by imitating the technologies developed in the North during its initial stage of economic development. The Southern country will switch to become an innovator country

the rate of return on investment is decreasing in firm's value V_{st} as the number of intermediate firms N_{sst} increases over time. This will in turn generate a downward sloping output growth trend.

Figure 4.3: Transition Paths - Projections



if its firms find it more profitable to innovate than to imitate given the rising cost of imitation. Graphically, a switch occurs at the point where a jump is observed in the South country's output growth rate. Given the free-entry condition in the background, the value of a firm, which diminishes over time, will diminish less by innovating than by imitating along the transition path from this point onward. Hence a higher rate of return will accrue from innovation than from imitation thereafter. Since households smooth their consumption by choosing the level of R&D investment at the same time, they choose to invest in an asset with a higher rate of return - equivalent to investing in innovation at the point of switching. As a result, a larger amount of resources has been allocated to production at the point of switching, causing the output growth to jump subsequently. Once output growth lands on the new trajectory, along which growth is generated by innovation rather than imitation, the output growth path follows a smooth downward trend until the economy reaches the balanced growth path.

4.4.2 The OECD Consumption and Output Paths

We now turn to the consumption growth path of the OECD countries. Instead of trending downward as did the simulated growth rate for China, the model projects that OECD countries will see an increase from a baseline consumption growth rate of 2.5% initially to approximiately 3% along the BGP. I shall first discuss the output growth path of the OECD countries (the North in the model) which then help explains the consumption growth path.

In the theoretical model, the relative number of intermediate firms in the South increases over time, independent of whether the country is an imitator or an innovator. The North's final output production will expand over time through its own innovation and also through importing intermediate inputs from the South. Technically speaking, the North's output growth is a weighted average of the North and South's rates of innovation (or rate of imitation if the South is an imitator). If the South switches from being an imitator to an innovator country at some point in time, then the North's innovation growth follows a U-shaped curve over time, as illustrated in Figure 4.3.4. The reason is that imitation in the South creates a disincentive for the Northern firms to innovate, causing the innovation rate to decline. But once the Southern firms also become innovators, firms in both economies are competing on a level ground. Beyond the point of switchover, however, Southern technology creation slows down, as illustrated by a flatter r_s curve than the r_s^I curve in Figure 4.1. Although Northern firms are no longer threatened by Southern imitation, the increase in the incentive to innovate is offset by smaller increase in Southern intermediate goods used in Northern final outputs production. This is a consequence of a slowdown in Southern technology creation. The Northern rate of innovation may jump slightly, stay flat, or even decline beyond the point of switching. Nevertheless, the Northern rate of innovation eventually picks up over time as a result of increasing demand from the South, which provides incentives to Northern innovation as the size of the Southern economy building up over time. On the other hand, the South's innovation rate remains above the North's, but continues to decline due to the increase in innovation costs over time.

Since the technology base of the South expands faster than that of the North on the transition path, the weight of the North's imported technology in its final output production will keep increasing along the transition path. Initially, the weight on North's domestic technology is much larger than that on the South's technology, so that the North's final output growth is on a declining trend alongside the downward-sloping phase of the U-shaped innovation growth path. After the South switches to become an innovator country, the North's rate of innovation will gradually move to the upward-sloping phase of the U-shaped path. Together with an increasing weight on imported technologies (in which South's rate of innovation is above the North's), North's final output growth rate increases over time as a result. The North's output growth follows a U-shaped path as well.

So, how does this help to explain an upward sloping consumption growth path for the North? Firstly, on the downward-sloping phase of the U-shaped innovation path, fewer resources are allocated to R&D activities, while the North's output growth is faster than its rate of innovation since it is a weighted average of North's and South's rates of imitation. This leads to an increase in resources allocated to consumption. Secondly, although the North will eventually enter the upward-sloping phase of the U-shaped innovation path, since North's output growth will increasingly rely on South's rate of innovation over time, output will continue to grow at a faster pace than its innovation. This implies that relatively less resources will continue to be allocated to R&D than to consumption. Taken together, the consumption growth of the North increases monotonically over time, despite the U-shaped output growth path.

4.5 Counterfactual Experiments: Freer Trade and Stronger Intellectual Property Rights

I conduct numerical exercises to examine the effects of freer trade and stronger intellectual property rights on the per capita consumption and output growth of China and the OECD countries. These counterfactual experiments project the economic path for both economies starting from the initial state.[76]

4.5.1 Freer Trade

The top panel of Table 4.4 shows the results at the initial state, and the bottom panel shows the results along the BGP. The second column shows the per capita consumption growth rates and the per capita GDP ratios under the benchmark case which were discussed in the earlier sections. The third column displays the results under the "freer trade" scenario, in

[76]Transition paths in the counterfactual experiments are generated in the same way as in the benchmark case, which is described in Appendix B.2.

which the iceberg trade cost is assumed to decrease by 30% from the benchmark scenario. This estimate is taken from Novy (2008), where the author estimated that the cost for Japan and Korea had dropped by approximately 30% on average from 1970 to 2000. Note that the decrease in trade cost affects the entry decisions of exporters as well as the Northern vertical MNEs.

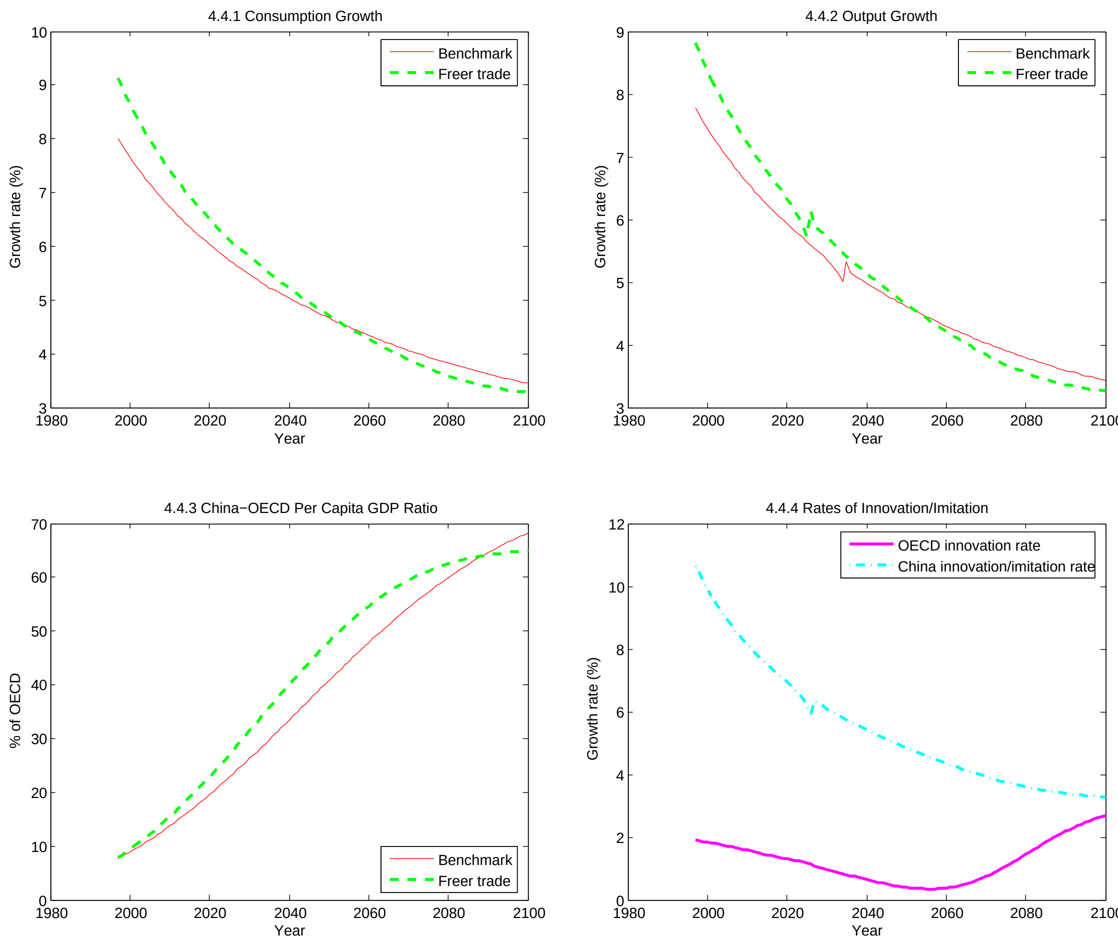
Table 4.4: Counterfactual Experiments - Results

	Benchmark	Freer Trade	Stronger IPR
Initial State			
g_s^c (%)	8.07	9.13	8.06
g_n^c (%)	2.48	2.50	2.48
GDP ratio	7.67	7.91	7.67
Balanced Growth Path			
g_s^c (%)	2.98	3.18	2.98
g_n^c (%)	2.98	3.18	2.98
GDP ratio	76.85	65.59	76.85

Notes: 'Benchmark' column shows the results in which the model is calibrated to match with the data. 'Freer Trade' refers to the scenario where the ice-berg trade cost is decreased by 30%. 'Stronger IPR' refers to the scenario where stronger intellectual property rights are imposed. g_s^c denotes China's per capita consumption growth. g_n^c denotes OECD's per capita consumption growth. GDP ratio refers to China's GDP as a percentage of the OECD's.

Under freer trade conditions, the per capita consumption growth rates for both China and the OECD countries will increase both at the initial state and along the BGP. However, the per capita GDP ratio along the BGP decreases compared with the benchmark case due to a faster speed of convergence. As a graphical illustration, the third panel in Figure 4.4 shows that the per capita GDP ratio grows in a more concave shape along the transition path. In the earlier period, the GDP ratio increases at a faster pace than under the benchmark

Figure 4.4: Counterfactual Experiment - Freer Trade



scenario, but flattens out in the latter period. The reason is that per capita output growth for China, as shown in the second panel of Figure 4.4, has a steeper slope than in the benchmark case, which implies a faster rate of convergence towards the BGP. The per capita consumption growth path for China also has a steeper slope, much like the per capita output growth path. On the other hand, although the decrease in iceberg trade costs has an impact on the OECD's transition path, it is minimal compared with the impact on China.

Notice that China becomes an innovator earlier than in the benchmark case, as shown by the jumps in per capita output growth illustrated in the second panel of Figure 4.4. This has to do with a faster rate of imitation in the earlier period due to an increase in ex-ante profit induced by freer trade, pushing the cost of imitation to increase faster, and hence reaching the switching point sooner. As a result of further trade openness and an earlier switching point for China, the OECD's rate of innovation exhibits a more visible U-shaped path than in the benchmark case, with a strong increase in the latter part of the path leading to a faster convergence towards the BGP, as shown in the fourth panel of Figure 4.4.

4.5.2 Stronger Intellectual Property Rights

In this section we examine the quantitative effects of stronger intellectual property rights. To conduct these counterfactual experiments, I assume an increase in the cost of imitation for Chinese firms has been induced by stronger intellectual property rights set out by the government, such that the projected time of switching to innovation will be shortened by one-third.[77] The last column in Table 4.4 shows that the impact of deterring imitation is minimal.

In a second experiment, I assume that in addition to increasing the cost of imitation, there is a slightly different innovation cost structure which allows firms in China to innovate more easily, and thereby increasing their willingness to switch and become innovators earlier. One can interpret this as the government providing better economic incentives to encourage innovation, or an improvement in the innovation process.

Table 4.5 shows the results from the re-calibrated version of the model which reflects the new innovation cost structure - I call this the "alternative specification". Specifically, I assume the parameter σ, which controls the cost of innovation in China, is set to 0.1 instead

[77]The parameter ψ^I in the cost of imitation (3.31) is adjusted upward to represent the increase in difficulty to imitate due to stronger intellectual property rights.

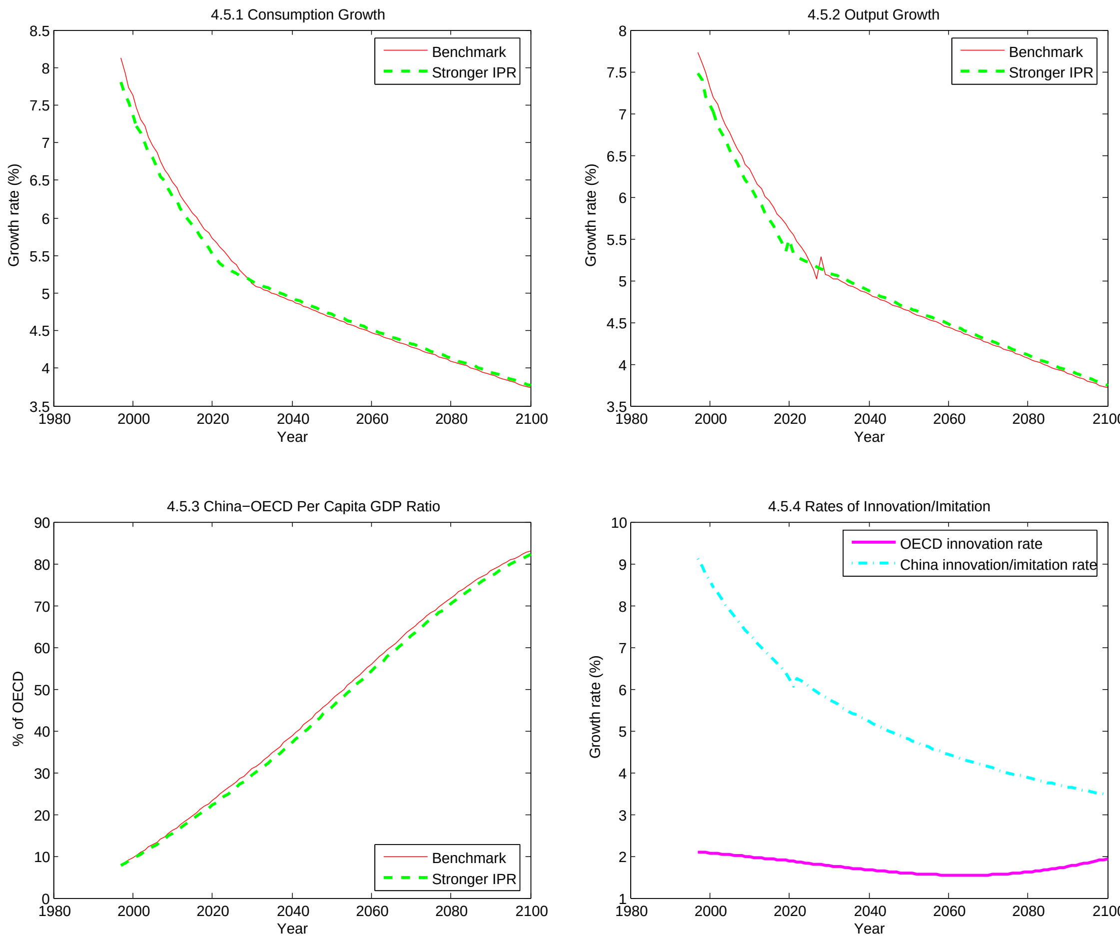
Table 4.5: Alternative Specification - Results

Initial State		
	Benchmark	Stronger IPR
g_s^c (%)	8.07	7.81
g_n^c (%)	2.48	2.49
GDP ratio	7.67	7.53
Balanced Growth Path		
g_s^c (%)	3.32	3.32
g_n^c (%)	3.32	3.32
GDP ratio	89.81	89.81

of 0.188 in the benchmark case. The third column shows that along the transition path, the per capita consumption growth in China will be slower than in the benchmark case at the initial state, due to a slower output growth resulting from less imitation. In contrast, the per capita consumption growth rate in the OECD increases slightly, as per capita output growth and the rate of innovation are both increased when potential entrants find their ex-ante profits increase due to reduced imitation. The per capital GDP ratio decreases, reflecting the decrease in China's per capita output growth and the small increase in the OECD per capita output growth at the initial state.

Figure 4.5 shows China's transition path growth rates and per capita GDP ratio graphically. The per capita GDP ratio in this alternative scenario is slightly below that of the benchmark case, where both the paths of per capita consumption and output growth rates have flattened, with right tails that are slightly above those in the benchmark case. The growth rates and per capita GDP ratio eventually converge to the same BGP values as in the benchmark case, as shown in the bottom panel of Table 4.5. This is because the strength of intellectual property rights only affects the timing of China's switch to becoming an innovator but not the characteristics of both economies along the BGP.

Figure 4.5: Counterfactual Experiment - Stronger IPR (Alternative Specification)



4.5.3 Welfare Analysis

I conduct a welfare analysis based on the welfare measure introduced in Chapter Two, but with slight modification. I compute the welfare gains on both the equilibrium transition path and the BGP for both China and the OECD. Welfare gains along the BGP are measured in exactly the same way as in Chapter Two. Gains along the equilibrium transition path are calculated in a slightly different fashion. Specifically, I solve for $\triangle C_i$ for $i \in \{n, s\}$ in the following equation:

$$\bar{U}_i = \int_0^\infty e^{-\rho t} \frac{(C_{it}^0 + \triangle C_i)^{1-\theta} - 1}{1-\theta} dt \tag{4.8}$$

where $\bar{U}_i$ is the level of lifetime utility attained on the equilibrium transition path for a given scenario. C_{it}^0 denotes the benchmark consumption level at each time period t. $\triangle C_i$ denotes the change in consumption that compensates the benchmark consumption to attain $\bar{U}_i$. The benchmark case here refers to the initial state as described by the data for calibration. The welfare gain is expressed as $\triangle C_i / C_{it}^0 \times 100$.[78] Since there is no population growth, the welfare gains based on aggregate and per capita consumption are the same.

Table 4.6 shows the welfare results from freer trade and stronger intellectual property rights in China from the two specifications. The second column shows that freer trade can create over 10% of welfare gains on the transition path for China, with a smaller gain of 4.5% along the BGP. The reason is that along the transition path, China's rate of innovation (or imitation) is above the rate along the BGP. Hence output and consumption both increase at faster rates than along the BGP growth rate. In other words, welfare gains along the BGP will be smaller once the technological process slows down to reach a steady growth path. The OECD countries, however, will experience a stronger welfare gains in total, where most of the gains come from the BGP consumption. This is because the OECD will gain from cheaper production costs due to increasing intermediate good imports over time. This cost advantage will be maximized along the BGP as the proportion of domestic and imported technologies increases to a stationary value. Moreover, ex-ante profits of firms in the OECD are highest along the BGP when the relative size of China and OECD reaches the highest level. This result, however, depends on the cost parameter γ. If we allow the

[78]One will get the same welfare results for the balanced growth path by using the method here or the one discussed in Chapter Two.

parameter to increase over time to reflect, for instance, scarcity of labour or raw materials, then the welfare results will be affected, but will still support the importance of the trade channel between North and South economies. Nevertheless, ignoring the transitional dynamics can substantially understate the welfare gains.[79]

Table 4.6: Welfare Analysis

	Freer Trade	Stronger IPR (1)	Stronger IPR (2)
China			
Transition	10.25	0.03	2.03
BGP	4.53	0.00	0.00
Total	14.78	0.03	2.03
OECD			
Transition	3.01	0.02	0.18
BGP	18.72	0.00	0.00
Total	21.73	0.02	0.18

Stronger IPR (1) refers to the original specification with $\sigma = 0.188$. Stronger IPR (2) refers to the alternative specification with $\sigma = 0.1$.

Consistent with the results in Tables 4.4 and 4.5, stronger intellectual property rights will have some, though limited, welfare effects, as shown in the last two columns of Table 4.6. These results are in stark contrast to studies in the literature such as Gustaffson and Segerstrom (2011), where stronger intellectual property rights play an important role in improving consumer welfare for both North and South economies. The key difference is that the model here allows the laggard country to endogenously switch from being an imitator to an innovator country, whereas most studies in the literature use frameworks in which the South is constrained not to innovate its own technology even in the long run. A

[79]As discussed in Section 4.3, the sales of Chinese MNEs abroad is negligible at the initial state. Consequently, I cannot project how Chinese MNEs will develop over time, and their impacts are missing along the transition path and BGP results. Nevertheless, the magnitude of gains from trade presented here are comparable to those in Chapter Two.

deterrence on imitation does not alter the resource allocation decisions dramatically within each economy since it mostly affects the earlier part of an equilibrium transition path, depending on the timing of switching, and leaves the rest of the path almost unchanged. As a result, while stronger intellectual property rights may have some impact on both China and the OECD, the effects are limited once a switch in the method of technology creation is being considered.

4.5.4 Balanced Growth Path Dynamics Revisited

To highlight the importance of a switchover in the method of technology creation in the laggard country, I further conduct a quantitative analysis by comparing two balanced growth path equilibria in which a switchover is possible in one equilbrium but not in the other. I gauge the magnitude of possible over-estimations in the growth and welfare gains coming from strong intellectual property rights in the South. The results from this exercise are comparable with the existing literature which is mostly concerned with balanced growth path dynamics.

I first define a baseline scenario where innovation is so costly that switching away from imitation will never occur in China. I compare this scenario to the BGP results where China is an innovator country, with both scenarios using the alternative specification where the σ parameter is set to 0.1. The calibration results from Section 4.3 imply that in the baseline scenario, the world economy will reach the third equilibrium from Proposition 7 in Section 3.4, where the pool of uncopied Northern products is exhausted in every period.

By comparing the results across the two BGP equilibria, the BGP growth rate increases from 2.46% in the baseline scenario to 3.32% in the alternative, as shown in Table 4.7. Moreover, I find that China would enjoy a welfare gain of 6.25% in consumption terms by optimally switching to become an innovator country along the BGP. Since firms from the OECD are no longer threatened by Southern imitation, their average profits are higher, which induces a faster rate of innovation and results in an even larger welfare gain of 15.41% than in the South.

Table 4.7: Balanced Growth Path Comparison

	Initial State	
	Imitation	Innovation
BGP growth (%)	2.46	3.32
Welfare gains (%)		
China	0.00	6.25
OECD	0.00	15.41

The welfare gains are zero in the second column when the baseline scenario is compared to itself.

This quantitative analysis shows that switching from imitation to innovation in the South can account for a large part of welfare gains. Put differently, ignoring the possibility of a switchover in the technology creation process can result in substantial over-estimation of growth and welfare gains from stronger intellectual property rights in the South. The economic impact from deterring imitation can be limited once a switchover in the South is considered.

4.6 Conclusion

This chapter attempts to fill a gap in the existing international growth literature that is concerned mostly with the balanced growth path dynamics when studying policy implications related to trade openness and intellectual property rights. I conduct a quantitative analysis based on a model of endogenous innovation with firm heterogeneity that captures key features of North-South trade and multinational activities, and emphasize both the transitional and balanced growth path dynamics. Using data from China and the OECD countries, I quantify the growth and welfare effects of trade openness and the strengthening of intellectual property rights, with attention to an equilibrium transition path and the balanced growth path.

The simulated model using China and OECD data can match well the per capita consumption growth path of China along the transition path, which is key to the welfare analysis. However, the model faces limitations on predicting the China's per capita output growth due to the slow diminishing return on investment that is unique to China's growth experience. I examine the growth and welfare effects of trade openness and strengthening intellectual property rights by considering the results from both the equilibrium transition path and the balanced growth path. This adds to the existing literature in which many studies are concerned mostly with balanced growth path dynamics when studying policy implications of trade openness and intellectual property rights. Quantitative analysis shows that welfare gains from further trade openness between China and the OECD countries can be significant, where transitional gains account for over two-thirds of the total welfare gain for China.

In contrast to studies in the existing literature, strengthening intellectual property rights in the South has limited growth and welfare effects. This is due to the possibility that the South will optimally switch from an imitator to an innovator, so that stronger intellectual property rights would affect mostly the earlier part of the equilibrium transition path when the South is still an imitator country, while leaving the rest of the path almost unchanged. Further quantitative analysis focusing solely on the balanced growth path dynamics confirm that the over-estimation of growth and welfare gains from stronger intellectual property rights in the existing literature can be significant.

This chapter shows that ignoring the transitional dynamics can lead to biased estimates of growth and welfare impacts of policies. However, since the present model cannot capture the sustainability of high output growth in an emerging economy like China, it will be interesting and important to examine the engine of such a growth experience. Evolutions in factor market and industrial organizational structures have possibly played a large role in sustaining growth over time. Further work can be done to enhance the performance of a North-South model of endogenous innovation by capturing more country-specific features when studying a particular South economy.

Chapter 5

Summary and Conclusions

The global economy has become increasingly integrated through trade, multinational production, and technology diffusion. While the importance of trade has long been observed, the more recent literature also focuses on gains from economic integration using broader measures of international openness. Previous studies suggests that welfare gains from openness can be significant, but the size of these gains remain an open question. The extensive literature that studies the impact from North-South openness also suggests the role of intellectual property rights in generating positive consumer welfare effects, by without accounting for the long-run growth effects nor the possibility of a switchover between imitation and innovation. My dissertation adds to the literature by studying and quantifying the effects of openness to trade and multinational production using a theoretical framework of endogenous innovation with firm heterogeneity. Moreover, I study the policy implications of stronger intellectual property rights in a North-South context, with emphasis on both the equilibrium transition path and the balanced growth path, and the process of technology creation.

In Chapter Two, I study and quantify the long-run effects of openness to trade and multinational production in the context of advanced economies using a model of endogenous innovation with firm heterogeneity. When trade is liberalized, some multinationals find it more profitable to export and forego the cost of maintaining capacities in multiple markets. I examine how this trade-off can have long-run effects on growth and welfare. The model emphasizes the importance of firms' ability to access multiple markets in providing incentives for innovation and highlights the role of international technology spillovers in promoting growth, with special attention towards the difference in quality between the type of technology diffused through trade and multinational production. I find that by fully restricting openness to both trade and horizontal multinational production with other OECD countries, the US would experience a welfare cost that is equivalent to a 39% drop in consumption, with the growth effect accounting for at least 40% of the estimated welfare cost. Allowing for endogenous growth therefore implies that openness has substantial implications for welfare beyond that quantified in previous studies. Moreover, since multinationals tend to use relatively high quality technology, trade liberalization on its own can lead to an adverse effect on economic growth and consumer welfare by reducing the level of multinational production, and consequently lower quality technology is diffused.

In Chapter Three, I extend the theoretical framework from Chapter Two to study economic implications from strengthening intellectual property rights in the North-South context, with particular emphasis on the process of technology creation in which both imitation and innovation are allowed in the South. Firms can form vertical multinational enterprises since intrafirm trade accounts for a substantial part of North-South trade in the data. My theoretical analysis shows that allowing for the possibility that the South may endogenously switch from being an imitator to an innovator is essential for examining the long-run growth effect of stronger intellectual property rights. This adds to the extensive literature where the resulting impact is only temporary. At the same time, the model accounts for endogenous changes in firm distributions that can also affect long-run growth. In particular, the per capita balanced growth path growth rate is the fastest when both the North and the South enforce stronger intellectual property rights. If intellectual property rights protection in the South is weak, the North needs to maintain its absolute advantage in technology creation by sustaining the size of the uncopied pool of ideas. Otherwise, it will fall into a slow-growth balanced growth path.

Chapter Four attempts to fill a gap in the existing growth literature that mostly focusing on balanced growth path dynamics when studying implications from economic policies. Using a calibrated version of the model developed in Chapter Three and based on the data from China and the OECD countries, I quantify the growth and welfare effects of trade openness in the North-South context. I also study the impacts of strengthening intellectual property rights in the South, both along an equilibrium transition path and the balanced growth path. Counterfactual experiments show that welfare gains from further trade openness between China and the OECD countries can be significant, where transitional gain accounts for over two-thirds of the total welfare gain for China. In contrast with the existing growth literature, a deterrence to imitation has limited welfare effects in an model economy where the South can switch from an imitator to become an innovator country. This is because stronger intellectual property rights affect mostly the earlier part of the equilibrium transition path, while leaving the rest of the path almost unchanged. Further quantitative analysis focusing solely on the balanced growth path dynamics confirm that the over-estimation of growth and welfare gains from stronger intellectual property rights in the existing literature can be significant. These together point to a source of potential bias in the welfare estimates in the existing literature.

A number of interesting questions can be examined by extending the models presented in this dissertation. First of all, although three channels of openness: trade, multinational production, and technology diffusion, have been considered in this dissertation, there are other missing channels that can be important. A particularly important channel is financial openness. As suggested by Rajan and Zingales (1998) and Manova (2008), firms rely on both internal and external financing for innovation and for the setup of production facilities. External financing can be done through borrowing from banks and issuance of bonds and stocks, at home or abroad. Aghion, Howitt and Mayer-Foulkes (2005) provide empirical evidence that financially developed countries converge to the same growth rate while others do not. These stylized facts suggest that by extending the model presented in Chapter Two to include credit constraints, the interactions between financial development, openness, and growth can be examined under a unified theoretical framework. For instance, a country can conduct very open trade and multinationals policies, but poor financial development can hinder firms' abilities to serve foreign markets and lower firms' profitability. Consequently, the innovation process slows down, which has an adverse effect on growth and welfare.

A second extension is to examine the role of China as a hub of Asian economies for consumer and capital goods exports. As suggested by Mohommad, Unteroberdoerster, and Vichyanond (2011), a triangular relationship has been developed over the past decade between advanced economies, China, and other Asian economies. China exports final goods to advanced economies, while importing raw materials and intermediate inputs from Asia. The North-South model presented in Chapter Three can be extended to incorporate an extra South country to mimic this vertical global supply chain. Using the extended model, one can study the impacts of trade policies, as well as the potential impacts from rebalancing the global economy. I intend to investigate these issues in my future research.

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Appendix A

Appendix for Chapter 2

A.1 Aggregation

This section of the Appendix presents the aggregation of intermediate goods as inputs of the aggregate production function, which explains the details in Section 2.2.4. Note that the fixed costs to enter different markets that are used below are the versions with scale effect corrections, as presented in Section 2.2.5.

Intermediate good l can be renamed as good a. Only goods with marginal cost $a \leq a_{iit}$ are counted when aggregating the intermediate goods. Equation (2.3) can be rewritten as:

$$\begin{aligned} Y_{it} &= A_i L_i^{1-\alpha} \int_0^{N_{it}} X_{li}^{\alpha} dl \\ &= A_i L_i^{1-\alpha} \Bigg[\int_0^{a_{iit}} X_{ii}(a)^{\alpha} \frac{g_i(a)}{G_i(a_{iit})} N_{ii} da \\ &\quad + \int_{a_{ijt}}^{a_{xjt}} X_{xj}(a)^{\alpha} \frac{g_j(a)}{G_j(a_{xjt}) - G_j(a_{ijt})} N_{xjt} da + \int_0^{a_{ijt}} X_{ij}(a)^{\alpha} \frac{g_j(a)}{G_j(a_{ijt})} N_{ijt} da \Bigg], \end{aligned}$$

where N_{iit} is the number of intermediate goods produced by domestic firms, N_{xjt} is the number of intermediate goods imported, and N_{ijt} is the number of intermediate goods produced by foreign MNEs. Also, $G_i(a_{iit}) = (a_{iit}/a_{i0})^{k_i}$ is the probability of domestic firms making the cut-off. $G_j(a_{xjt}) = (a_{xjt}/a_{j0})^{k_j}$ is the probability of a foreign firm that serves the domestic market either through trade or MNE. $G_j(a_{ijt}) = (a_{ijt}/a_{j0})^{k_j}$ is the probability of a foreign firm becoming a MNE, so that $G_j(a_{xjt}) - G_j(a_{ijt})$ is the probability of a foreign firm exporting to the domestic market. From these probabilities:

$$g_i(a) = \frac{\partial G_i(a)}{\partial a} = \frac{k_i a^{k_i - 1}}{a_{i0}^{k_i}} \qquad \Rightarrow \qquad \frac{g_i(a)}{G_i(a_{iit})} = \frac{k_i a^{k_i - 1}}{a_{iit}^{k_i}}$$

is the density function conditional on surviving, in which firms get a draw a below the cut-off a_{iit}. Similarly,

$$\frac{g_j(a)}{G_j(a_{xjt})} = \frac{k_j a^{k_j - 1}}{a_{xjt}^{k_j}} \qquad , \qquad \frac{g_j(a)}{G_j(a_{ijt})} = \frac{k_j a^{k_j - 1}}{a_{ijt}^{k_j}}.$$

The first equation is the density function conditional on a foreign firm serving the domestic market including both trade and MNE. The second equation is the density function conditional on a foreign firm becoming a MNE.

What the above equations imply is that intermediate goods inputs consist of domestic goods, imported goods, and those that are produced domestically by foreign MNEs. Substitute $X_{sd}(a)$ for $s \in \{i, x, j\}$ and $d \in \{i, j\}$ using equation (2.15), using optimal prices (2.17), and $g_i(a)/G_i(a)$ into the Y_{it} above yield:

$$\begin{aligned} Y_{it} &= A_i^{\frac{1}{1-\alpha}} \alpha^{\frac{2\alpha}{1-\alpha}} L_i \Bigg[\int_0^{a_{iit}} a^{-\frac{\alpha}{1-\alpha}} \frac{k_i a^{k_i - 1}}{a_{iit}^{k_i}} N_{iit} da \\ &\quad + \int_{a_{ijt}}^{a_{xjt}} (\tau a)^{-\frac{\alpha}{1-\alpha}} \frac{k_j a^{k_j - 1}}{a_{xjt}^{k_j} - a_{ijt}^{k_j}} N_{xjt} da + \int_0^{a_{ijt}} a^{-\frac{\alpha}{1-\alpha}} \frac{k_j a^{k_j - 1}}{a_{ijt}^{k_j}} N_{ijt} da \Bigg] \\ &= A_i^{\frac{1}{1-\alpha}} \alpha^{\frac{2\alpha}{1-\alpha}} L_i \Bigg[\int_0^{a_{iit}} a^{1-\epsilon} \frac{k_i a^{k_i - 1}}{a_{iit}^{k_i}} N_{iit} da \\ &\quad + \int_{a_{ijt}}^{a_{xjt}} (\tau a)^{1-\epsilon} \frac{k_j a^{k_j - 1}}{a_{xjt}^{k_j} - a_{ijt}^{k_j}} N_{xjt} da + \int_0^{a_{ijt}} a^{1-\epsilon} \frac{k_j a^{k_j - 1}}{a_{ijt}^{k_j}} N_{ijt} da \Bigg], \end{aligned}$$

where $\epsilon = 1/(1-\alpha)$ so that $-\alpha/(1-\alpha) = 1-\epsilon$. Within the brackets [$\cdot$], the first integral is an index of the average productivity of domestic firms multiply by N_{iit}, the second integral is an index of the average productivity of imported products multiply by N_{xjt}, and the third integral is an index of the average productivity of foreign MNEs multiply by N_{ijt}. These indices of average productivities can be expressed as:

$$\tilde{a}_{iit}^{1-\epsilon} = \frac{k_i}{k_i - \epsilon + 1} a_{iit}^{1-\epsilon} \quad , \quad \tilde{a}_{ijt}^{1-\epsilon} = \frac{k_j}{k_j - \epsilon + 1} a_{ijt}^{1-\epsilon},$$

$$\tilde{a}_{xjt}^{1-\epsilon} = \frac{k_j}{k_j - \epsilon + 1} \left(\frac{a_{xjt}^{k_j - \epsilon + 1} - a_{ijt}^{k_j - \epsilon + 1}}{a_{xjt}^{k_j} - a_{ijt}^{k_j}} \right),$$

where $\tilde{a}_{iit}$ is the average cost of domestic firms, $\tilde{a}_{xjt}$ is the average cost of foreign firms that home country import from, and $\tilde{a}_{ijt}$ is the average cost of foreign MNEs. An index of average productivity of *all* intermediate goods that will become inputs of the final output can be expressed as:

$$\tilde{a}_{it}^{1-\epsilon} = \frac{N_{iit}}{N_{it}} \tilde{a}_{iit}^{1-\epsilon} + \frac{N_{xjt}}{N_{it}} (\tau \tilde{a}_{xjt})^{1-\epsilon} + \frac{N_{ijt}}{N_{it}} \tilde{a}_{ijt}^{1-\epsilon}.$$

Y_{it} therefore becomes:

$$Y_{it} = A_i^{\frac{1}{1-\alpha}} \alpha^{\frac{2\alpha}{1-\alpha}} L_i N_{it} \tilde{a}_{it}^{1-\epsilon}.$$

Knowing that it costs a units of final output to produce one unit of intermediate good, one can derive the total spending on intermediate goods. Using equation (2.15), substitute for the optimal price from (2.17), and replace a with $\tilde{a}_{it}$ yield:

$$X_i(\tilde{a}_{it}) = A_i^{\frac{1}{1-\alpha}} \alpha^{\frac{2}{1-\alpha}} L_i \tilde{a}_{it}^{-\frac{1}{1-\alpha}},$$

where $X_i(\tilde{a}_{it})$ represents intermediate goods produced by an average intermediate good firm that serve country i. One can think of this as the amount of intermediate goods produced by a representative firm with average cost $\tilde{a}_{it}$. To get the total cost of intermediate goods production:

$$\begin{aligned} M_{it} &= \tilde{a}_{it} N_{it} X_i(\tilde{a}_{it}) \\ &= \tilde{a}_{it} A_i^{\frac{1}{1-\alpha}} \alpha^{\frac{2}{1-\alpha}} L_i N_{it} \tilde{a}_{it}^{-\frac{1}{1-\alpha}} \\ &= \alpha^2 Y_{it}. \end{aligned}$$

The total spending on intermediate goods M_{it} turns out to be proportional to final output Y_{it}.

Next, from the final good producer's problem:

$$\begin{aligned} Y_{it} &= w_{it} L_i + \int_0^{N_{it}} p_l X_{li} dl \\ &= w_{it} L_i + \left[\int_0^{a_{iit}} p(a) X_{ii}(a) \frac{g_i(a)}{G_i(a_{iit})} N_{iit} da \right. \\ &\quad \left. + \int_{a_{ijt}}^{a_{xjt}} p(a) X_{xj}(a) \frac{g_j(a)}{G_j(a_{xjt})} N_{ijt} da + \int_0^{a_{ijt}} p(a) X_{ij}(a) \frac{g_j(a)}{G_j(a_{ijt})} N_{ijt} da \right] \\ &= w_{it} L_i + \Big(N_{iit} \tilde{\pi}_{iit} + N_{xjt} \tilde{\pi}_{xjt} + N_{ijt} \tilde{\pi}_{ijt} + N_{iit} F_{ii} + N_{xjt} F_{xj} \\ &\quad + N_{ijt} F_{ij} + \tilde{a}_{it} N_{it} X_i(\tilde{a}_{it}) \Big). \end{aligned}$$

To get from the second to the third line of the equation, one can think of the total revenue generated from selling intermediate goods in country i must equal to the sum of domestic innovators' profits, foreign exporters' and MNEs' profits, the fixed costs that all firms paid to access domestic market, and the total costs of production. Substituting out $\tilde{a}_{it} N_{it} X_i(\tilde{a}_{it})$ yields:

$$Y_{it} - \alpha^2 Y_{it} = w_{it} L_i + N_{iit} \tilde{\pi}_{iit} + N_{xjt} \tilde{\pi}_{xjt} + N_{ijt} \tilde{\pi}_{ijt} + N_{iit} F_{iit} + N_{xjt} F_{xjt} + N_{ijt} F_{ijt}.$$

Using this equation, the budget constraint (2.8) can be further rewritten as:

$$\begin{aligned} R_{it} &= w_{it}L_i + N_{iit}\tilde{\pi}_{iit} + N_{xjt}\tilde{\pi}_{xjt} + N_{ijt}\tilde{\pi}_{ijt} + N_{iit}F_{iit} + N_{xjt}F_{xjt} + N_{ijt}F_{ijt} \\ &\quad +(N_{xit}\tilde{\pi}_{xit} - N_{xjt}\tilde{\pi}_{xjt}) + (N_{jit}\tilde{\pi}_{jit} - N_{ijt}\tilde{\pi}_{ijt}) - C_{it} \\ &= (1-\alpha^2)Y_{it} - C_{it} - NX_{it}, \end{aligned}$$

where

$$NX_{it} = -[(N_{xit}\tilde{\pi}_{xit} - N_{xjt}\tilde{\pi}_{xjt}) + (N_{jit}\tilde{\pi}_{jit} - N_{ijt}\tilde{\pi}_{ijt})].$$

Net exports can be further written as:

$$NX_{it} = -\left[\left(\frac{N_{xit}}{N_{iit}}\tilde{\pi}_{xit} - \frac{N_{xjt}}{N_{iit}}\tilde{\pi}_{xjt}\right) + \left(\frac{N_{jit}}{N_{jjt}}\frac{N_{jjt}}{N_{iit}}\tilde{\pi}_{jit} - \frac{N_{ijt}}{N_{jjt}}\frac{N_{jjt}}{N_{iit}}\tilde{\pi}_{ijt}\right)\right] N_{iit} = \nu_i N_{iit}.$$

A.2 Average Net Profit of Intermediate Good Firms

To derive the average net profit of intermediate goods firms originated from country i, it is necessary to first derive the average net profits from serving at home, from exports, and from foreign market subsidiary.

The average net profit of intermediate goods firms from country i that serve i is given by:

$$\tilde{\pi}_{iit} = \pi_{ii}(\tilde{a}_{iit}) = \left(\frac{1-\alpha}{\alpha}\right)\tilde{a}_{iit}^{-\frac{\alpha}{1-\alpha}} A_i^{\frac{1}{1-\alpha}} \alpha^{\frac{2}{1-\alpha}} L_i - F_{iit}.$$

Substitute for $\tilde{a}_{iit}$, make use of $1-\epsilon = -\alpha/(1-\alpha)$, a_{iit} from zero profit condition (2.20) and the scale-effect-corrected fixed cost yield:

$$\begin{aligned}
\tilde{\pi}_{iit} &= \left(\frac{1-\alpha}{\alpha}\right) A_i^{\frac{1}{1-\alpha}} \alpha^{\frac{2}{1-\alpha}} L_i \tilde{a}_{iit}^{1-\epsilon} - F_{iit} \\
&= \left(\frac{1-\alpha}{\alpha}\right) A_i^{\frac{1}{1-\alpha}} \alpha^{\frac{2}{1-\alpha}} L_i \left(\frac{k_i}{k_i-\epsilon+1}\right) \left[\left(\frac{1-\alpha}{\alpha}\right) \frac{A_i^{\frac{1}{1-\alpha}} \alpha^{\frac{2}{1-\alpha}} L_i}{F_{iit}}\right]^{-1} - F_{iit} \\
&= \left(\frac{k_i}{k_i-\epsilon+1}\right) F_{iit} - F_{iit} \\
&= \left(\frac{\epsilon-1}{k_i-\epsilon+1}\right) r_{it} f_{ii} A_i^{\frac{1}{1-\alpha}} \alpha^{\frac{2}{1-\alpha}} L_i.
\end{aligned}$$

Similarly, substitute for $\tilde{a}_{xit}$, make use of equation (2.20) and the scale-effect-corrected fixed costs, the average net profit from exporting is given by:

$$\begin{aligned}
\tilde{\pi}_{xit} &= \left(\frac{1-\alpha}{\alpha}\right) A_j^{\frac{1}{1-\alpha}} \alpha^{\frac{2}{1-\alpha}} L_j (\tau \tilde{a}_{xit})^{1-\epsilon} - F_{xit} \\
&= \left(\frac{1-\alpha}{\alpha}\right) A_j^{\frac{1}{1-\alpha}} \alpha^{\frac{2}{1-\alpha}} L_j \tau^{1-\epsilon} \times \\
&\quad \frac{k_i}{k_i-\epsilon+1} \frac{f_{xi}^{\frac{k_i-\epsilon+1}{1-\epsilon}} \tau^{-(k_i-\epsilon+1)} - \left(\frac{f_{ji}-f_{xi}}{1-\tau^{1-\epsilon}}\right)^{\frac{k_i-\epsilon+1}{1-\epsilon}}}{f_{xi}^{\frac{k_i}{1-\epsilon}} \tau^{-k_i} - \left(\frac{f_{ji}-f_{xi}}{1-\tau^{1-\epsilon}}\right)^{\frac{k_i}{1-\epsilon}}} \frac{a_{iit}^{1-\epsilon}}{f_{ii}} - F_{xit} \\
&= \left(\frac{k_i}{k_i-\epsilon+1} \tau^{1-\epsilon} \frac{f_{xi}^{\frac{k_i-\epsilon+1}{1-\epsilon}} \tau^{-(k_i-\epsilon+1)} - \left(\frac{f_{ji}-f_{xi}}{1-\tau^{1-\epsilon}}\right)^{\frac{k_i-\epsilon+1}{1-\epsilon}}}{f_{xi}^{\frac{k_i}{1-\epsilon}} \tau^{-k_i} - \left(\frac{f_{ji}-f_{xi}}{1-\tau^{1-\epsilon}}\right)^{\frac{k_i}{1-\epsilon}}} - f_{xi}\right) r_{it} A_i^{\frac{1}{1-\alpha}} \alpha^{\frac{2\alpha}{1-\alpha}} L_i,
\end{aligned}$$

where average productivity of an exporting firm

$$\tilde{a}_{xit}^{1-\epsilon} = \frac{k_i}{k_i-\epsilon+1} \left(\frac{a_{xit}^{k_i-\epsilon+1} - a_{jit}^{k_i-\epsilon+1}}{a_{xit}^{k_i} - a_{jit}^{k_i}}\right)$$

can be found by $\int_{a_{jit}}^{a_{xit}} a^{1-\epsilon}(k_i a^{k_i-1})/(a_{jit}^{k_i} - a_{xit}^{k_i}) da$.

By the same token, substitute for $\tilde{a}_{jit}$, make use of equation (2.21) and the scale-effect-corrected fixed costs, the average net profit from foreign market subsidiary is given by:

$$\begin{aligned}\tilde{\pi}_{jit} &= \left(\frac{1-\alpha}{\alpha}\right) A_j^{\frac{1}{1-\alpha}} \alpha^{\frac{2}{1-\alpha}} L_j \tilde{a}_{jit}^{1-\epsilon} - F_{jit} \\ &= \left(\frac{1-\alpha}{\alpha}\right) A_j^{\frac{1}{1-\alpha}} \alpha^{\frac{2}{1-\alpha}} L_j \frac{k_i}{k_i-\epsilon+1} \left(\frac{f_{ji}-f_{xi}}{f_{ii}(1-\tau^{1-\epsilon})} \frac{A_i^{\frac{1}{1-\alpha}} L_i}{A_j^{\frac{1}{1-\alpha}} L_j}\right) a_{iit}^{1-\epsilon} - F_{jit} \\ &= \left(\left(\frac{k_i}{k_i-\epsilon+1}\right) \frac{f_{ji}-f_{xi}}{1-\tau^{1-\epsilon}} - f_{ji}\right) r_{it} A_i^{\frac{1}{1-\alpha}} \alpha^{\frac{2}{1-\alpha}} L_i,\end{aligned}$$

where average productivity of foreign subsidiary

$$\tilde{a}_{jit} = \left(\frac{k_i}{k_i-\epsilon+1}\right)^{\frac{1}{1-\epsilon}} a_{jit}^{1-\epsilon}$$

can be found by $\int_0^{a_{jit}} a^{1-\epsilon}(k_i a^{k_i-1})/(a_{jit}^{k_i})da$.

Define the average net profit that an average intermediate good firm originated from country i as the average net profit it earns from domestic market i plus the possibility to earn profits from serving foreign market j either through exporting or multinational production. This can be written as:

$$\tilde{\pi}_{it} = \tilde{\pi}_{iit} + \frac{G_i(a_{xit}) - G_i(a_{jit})}{G_i(a_{iit})}\tilde{\pi}_{xit} + \frac{G_i(a_{jit})}{G_i(a_{iit})}\tilde{\pi}_{jit},$$

where $(G_i(a_{xit}) - G_i(a_{jit}))/(G_i(a_{iit}))$ is the probability of a domestic firm exporting, and $G_i(a_{jit})/G_i(a_{iit})$ is the probability of a domestic firm that becomes a MNE to serve abroad. Notice that these probabilities also represent the fractions of all domestic firms that export and engage in multinational production, respectively.

A.3 International Spillovers

The degree of international spillovers is measured by the share of foreign intermediate goods sales in a country's total intermediate goods sales. To derive this, it is necessary to first derive the different components of intermediate goods sales as well as the total sales.

Domestic firms sales:

$$\begin{aligned} p_{ii}(\tilde{a}_{iit})X_{ii}(\tilde{a}_{iit})N_{iit} &= \frac{\tilde{a}_{iit}}{\alpha} A_i^{\frac{1}{1-\alpha}} \alpha^{\frac{2}{1-\alpha}} L_i \tilde{a_{iit}}^{-\epsilon} N_{iit} \\ &= A_i^{\frac{1}{1-\alpha}} \alpha^{\frac{1+\alpha}{1-\alpha}} L_i \tilde{a_{iit}}^{1-\epsilon} N_{iit}. \end{aligned}$$

Import sales (by substituting out $\tilde{a}_{xjt}$):

$$\begin{aligned} p_{xj}(\tilde{a}_{xjt})X_{xj}(\tilde{a}_{xjt})N_{xjt} &= \frac{\tau \tilde{a}_{xjt}}{\alpha} A_i^{\frac{1}{1-\alpha}} \alpha^{\frac{2}{1-\alpha}} L_i (\tau \tilde{a_{xjt}})^{-\epsilon} N_{xjt} \\ &= A_i^{\frac{1}{1-\alpha}} \alpha^{\frac{1+\alpha}{1-\alpha}} L_i \tau^{1-\epsilon} \frac{k_j}{k_j-\epsilon+1} a_{jjt}^{1-\epsilon} N_{jjt} \left(\frac{A_i^{\frac{1}{1-\alpha}} L_i}{A_j^{\frac{1}{1-\alpha}} L_j} \right)^{\frac{k_j-\epsilon+1}{1-\epsilon}} \\ &\times \left(\left(\frac{f_{jj}}{f_{xj}} \right)^{\frac{k_j-\epsilon+1}{1-\epsilon}} \tau^{-(k_j-\epsilon+1)} - \left(\frac{f_{jj}(1-\tau^{1-\epsilon})}{f_{ji}-f_{xi}} \right)^{\frac{k_j-\epsilon+1}{1-\epsilon}} \right). \end{aligned}$$

Foreign MNEs sales (by substituting out $\tilde{a}_{ijt}$):

$$\begin{aligned} p_{ij}(\tilde{a}_{ijt})X_{ij}(\tilde{a}_{ijt})N_{ijt} &= \frac{\tilde{a}_{ijt}}{\alpha} A_i^{\frac{1}{1-\alpha}} \alpha^{\frac{2}{1-\alpha}} L_i \tilde{a}_{ijt}^{-\epsilon} N_{ijt} \\ &= A_i^{\frac{1}{1-\alpha}} \alpha^{\frac{1+\alpha}{1-\alpha}} L_i N_{jjt} a_{jjt}^{1-\epsilon} \times \\ & \quad \frac{k_j}{k_j-\epsilon+1} \left(\frac{f_{jj}(1-\tau^{1-\epsilon})}{f_{ij}-f_{xj}} \frac{A_i^{\frac{1}{1-\alpha}} L_i}{A_j^{\frac{1}{1-\alpha}} L_j} \right)^{\frac{k_j-\epsilon+1}{1-\epsilon}}. \end{aligned}$$

Total sales in country i = domestic firm sales + import sales + foreign MNEs sales:

$$\begin{aligned} p_i(\tilde{a}_{it})X_i(\tilde{a}_{it})N_{it} &= A_i^{\frac{1}{1-\alpha}} \alpha^{\frac{1+\alpha}{1-\alpha}} L_i \left[N_{iit}\tilde{a}_{iit}^{1-\epsilon} + N_{xjt}(\tau \tilde{a}_{xjt})^{1-\epsilon} + N_{ijt}\tilde{a}_{ijt}^{1-\epsilon} \right] \\ &= A_i^{\frac{1}{1-\alpha}} \alpha^{\frac{1+\alpha}{1-\alpha}} L_i N_{it} \tilde{a}_{it}^{1-\epsilon}. \end{aligned}$$

Notice that the total sales in country i is also equal to αY_{it}, which implies that an α share of final output goes to the sales of intermediate goods. This is also implied by the aggregate production function (2.3).

The degree of international spillovers in country i is given by:

$$\lambda_{it} = \frac{\text{import sales}_t + \text{foreign MNE sales}_t}{\text{total sales}_t}.$$

which can be further expressed as:

$$\lambda_{it} = \frac{\left(\frac{a_{jjt}}{a_{iit}}\right)^{1-\epsilon} \frac{N_{jjt}}{N_{iit}} \cdot \Sigma}{1 + \left(\frac{a_{jjt}}{a_{iit}}\right)^{1-\epsilon} \frac{N_{jjt}}{N_{iit}} \cdot \Sigma}.$$

where

$$\Sigma = \left(\left(\frac{f_{jj}}{f_{xj}}\right)^{\frac{k_j-\epsilon+1}{1-\epsilon}} \tau^{-k_j} + (1-\tau^{1-\epsilon}) \left(\frac{f_{jj}(1-\tau^{1-\epsilon})}{f_{ji}-f_{xi}}\right)^{\frac{k_j-\epsilon+1}{1-\epsilon}} \right) \left(\frac{A_i^{\frac{1}{1-\alpha}} L_i}{A_j^{\frac{1}{1-\alpha}} L_j}\right)^{\frac{k_j-\epsilon+1}{1-\epsilon}}.$$

A.4 Cost of Innovation and Aggregate R&D Expenditure

Since the focus is on the balanced growth path (BGP), I drop the time subscript for the variables that do not change along the BGP. From Section 2.2.5, the stock of knowledge relative to the size of economy is given by:

$$(K_{it}/Y_{it})^{-1} = A_i^{\frac{1}{1-\alpha}} \alpha^{\frac{2\alpha}{1-\alpha}} L_i.$$

Using this fact and h_{it} from equation (2.32), the cost of innovation from equation (2.35) can be rewritten as:

$$\eta_{it} = \left(1 + \lambda_{it} \frac{N_{jjt}}{N_{iit}} \left(\frac{\bar{a}_{xjt}}{\tilde{a}_{iit}}\right)^{1-\epsilon}\right)^{-\phi} \left(\frac{R_{it}}{N_{iit}}\right)^{\phi} f_i^I (A_i^{\frac{1}{1-\alpha}} \alpha^{\frac{2\alpha}{1-\alpha}} L_i)^{1-\phi}.$$

Next, $\dot{N}_{iit} = g_i N_{iit}$, where g_i is the rate of innovation. R&D expenditure from equation

(2.9) can be rewritten as:

$$
\begin{aligned}
R_{it} &= \left(\frac{a_{i0}}{a_{iit}}\right)^{k_i} \eta_{it} \dot{N}_{iit} \\
&= \left(\frac{a_{i0}}{a_{iit}}\right)^{k_i} \left(1 + \lambda_{it} \frac{N_{jjt}}{N_{iit}} \left(\frac{\bar{a}_{xjt}}{\tilde{a}_{iit}}\right)^{1-\epsilon}\right)^{-\phi} \left(\frac{R_{it}}{N_{iit}}\right)^{\phi} f_i^I (A_i^{\frac{1}{1-\alpha}} \alpha^{\frac{2\alpha}{1-\alpha}} L_i)^{1-\phi} g_i N_{iit} \\
&= (f_i^I g_i)^{\frac{1}{1-\phi}} \left(\frac{a_{iit}}{a_{i0}}\right)^{\frac{-k_i}{1-\phi}} \left(1 + \lambda_{it} \frac{N_{jjt}}{N_{iit}} \left(\frac{\bar{a}_{xjt}}{\tilde{a}_{iit}}\right)^{1-\epsilon}\right)^{\frac{-\phi}{1-\phi}} A_i^{\frac{1}{1-\alpha}} \alpha^{\frac{2\alpha}{1-\alpha}} L_i N_{iit} \\
&= \Gamma_i N_{iit}.
\end{aligned}
$$

By substituting out R_{it}, h_{it} becomes:

$$
h_{it} = (f_i^I g_i)^{\frac{-\phi}{1-\phi}} \left(\frac{a_{iit}}{a_{i0}}\right)^{\frac{k_i\phi}{1-\phi}} \left(1 + \lambda_{it} \frac{N_{jjt}}{N_{iit}} \left(\frac{\bar{a}_{xjt}}{\tilde{a}_{iit}}\right)^{1-\epsilon}\right)^{\frac{\phi}{1-\phi}} (A_i^{\frac{1}{1-\alpha}} \alpha^{\frac{2\alpha}{1-\alpha}} L_i)^{-\phi}.
$$

By substituting out h_{it} and η_{it}, the free-entry condition (2.30) becomes:

$$
\begin{aligned}
W_{it} &= \left(\frac{a_{i0}}{a_{iit}}\right)^{k_i} h_{it}^{-1} f_i^I (A_i^{\frac{1}{1-\alpha}} \alpha^{\frac{2\alpha}{1-\alpha}} L_i)^{1-\phi} \\
&= f_i^{I\,\frac{1}{1-\phi}} \left(\frac{a_{iit}}{a_{i0}}\right)^{\frac{-k_i}{1-\phi}} \left(1 + \lambda_{it} \frac{N_{jjt}}{N_{iit}} \left(\frac{\bar{a}_{xjt}}{\tilde{a}_{iit}}\right)^{1-\epsilon}\right)^{\frac{-\phi}{1-\phi}} g_i^{\frac{\phi}{1-\phi}} A_i^{\frac{1}{1-\alpha}} \alpha^{\frac{2\alpha}{1-\alpha}} L_i.
\end{aligned}
$$

Since $\eta_{it} = (a_{iit}/a_{i0})^{k_i} W_{it}$ from free-entry condition (2.30):

$$
\eta_{it} = f_i^{I\,\frac{1}{1-\phi}} \left(\frac{a_{iit}}{a_{i0}}\right)^{\frac{-k_i\phi}{1-\phi}} \left(1 + \lambda_{it} \frac{N_{jjt}}{N_{iit}} \left(\frac{\bar{a}_{xjt}}{\tilde{a}_{iit}}\right)^{1-\epsilon}\right)^{\frac{-\phi}{1-\phi}} g_i^{\frac{\phi}{1-\phi}} A_i^{\frac{1}{1-\alpha}} \alpha^{\frac{2\alpha}{1-\alpha}} L_i.
$$

A.5 The Existence of the Balanced Growth Path

The time subscript is dropped for the variables that do not change along the BGP. From equation (2.36):

$$
g_i = \left(\frac{R_{it}}{N_{iit}}\right)^{1-\phi} \left(1 + \lambda_{it} \frac{N_{jjt}}{N_{iit}} \left(\frac{\bar{a}_{xjt}}{\tilde{a}_{iit}}\right)^{1-\epsilon}\right)^{\phi} (\bar{f}_i^I)^{-1},
$$

which is an increasing and concave function of the ratio N_{jjt}/N_{iit}. I call the above condition (AI). In the (g, N_{jjt}/N_{iit}) space, aggregate innovation (AI) is an upward sloping curve, as shown in Figure 2.1.

Notice that from the AI relationship, a large N_{jjt}/N_{iit} ratio implies a large g_i, while the foreign rate of innovation g_j is small.[80] Since final output is produced using both domestic and foreign intermediate inputs, output growth depends on both countries' rates of innovation. Because the output growth rate is the weighted average between g_i and g_j, country i's output growth must be lower than g_i when the N_{jjt}/N_{iit} ratio is large. The vice-versa is true. Using the final output equation (2.26) and equation (2.38), and by taking logarithm and time derivative yields the condition (YI):[81]

$$\frac{\dot{Y}_{it}}{Y_{it}} = (1 - \Psi)g_i + \Psi g_j,$$

where

$$\Psi = \left(1 + \frac{G_j(a_{xjt})}{G_j(a_{jjt})}\frac{N_{jjt}}{N_{iit}}\right)^{-1} \frac{G_j(a_{xjt})}{G_j(a_{jjt})}\frac{N_{jjt}}{N_{iit}}.$$

First, g_i rises and g_j falls as N_{jjt}/N_{iit} ratio increases. This is based on the AI relationship. Ψ in YI is increasing with N_{jjt}/N_{iit}, which assigns more weight on the decreasing g_j as N_{jjt}/N_{iit} increases. In the (g, N_{jjt}/N_{iit}) space, the YI condition can possibly have an upward sloping section, followed by a downward sloping section. This can be seen by rewriting the YI condition as:

$$\frac{\dot{Y}_{it}}{Y_{it}} = g_i + \Psi(g_j - g_i),$$

[80] A large N_{jjt}/N_{iit} ratio implies a small N_{iit}/N_{jjt} ratio. There are less technologies diffused from domestic to foreign country. Consequently, foreign cost of innovation is high and the foreign rate of innovation g_j is low.

[81] Since a small change in the N_{jjt}/N_{iit} ratio has a small indirect effect on the cut-off costs, the indirect effect on $\tilde{a}_i$ is close to zero.

The output growth rate may increase initially if g_i increases faster than the decline in $\Psi(g_j - g_i)$. Output growth eventually decreases with N_{jjt}/N_{iit} for $\Psi \geq \Psi^*$, where Ψ^* is the point where the increase in g_i is fully offset by the decrease in $g_j - g_i$. Thus implying a downward sloping YI curve for $\Psi \geq \Psi^*$.

A.5.1 A Proof of Proposition 2

Since the AI curve can possibly intersect both the upward and downward sloping sections of YI curve, I focus on the intersection at the downward sloping section only in which the equilibrium is stable. For $N_{jjt}/N_{iit} > (N_{jjt}/N^*_{iit})$, where the asterisk denotes equilibrium, $g_i > g^*$ and $g_j < g^*$ according to the AI relationship. This causes the output growth of country i to drop below its equilibrium value according to the downward-sloping YI curve. However, the cost of innovation η_i is reduced (due to a fall in $\bar{f}_i^I$) due to a large N_{jjt}/N_{iit} ratio which results in a greater degree of international spillovers. As a result, g_i increases as a greater variety of intermediate goods in country i will be developed and produced. As long as the rate of innovation $r_i > r_j$, the N_{jjt}/N_{iit} ratio keeps decreasing. This process continues until $N_{jjt}/N_{iit} = (N_{jjt}/N_{iit})^*$ and $g_i = g_j = g^*$. The vice-versa is true for $N_{jjt}/N_{iit} < (N_{jjt}/N_{iit})^*$.

A.6 Trade Openness and the Quality-Adjusted Spillovers Process

A.6.1 Properties of $\partial lnr/\partial\tau$

Since $r = (a_{ii}/a_{i0})^{k_i}\tilde{\pi}_i/\eta_i$ along the BGP as given by free-entry condition (2.30) and equation (2.37), this implies that:[82]

$$\frac{\partial lnr}{\partial\tau} = \frac{\partial ln\tilde{\pi}_i}{\partial\tau} - \frac{\partial ln\eta_i}{\partial\tau}.$$

First, making use of η_i from Appendix A.4, which involves quality-adjusted spillovers process, the function $ln\eta_i$ is strictly decreasing in τ and is strictly convex, *i.e.* $\partial ln\eta_i/\partial\tau < 0$ and $\partial^2 ln\eta_i/\partial\tau^2 > 0\ \forall\tau$.

Next, if $\partial ln\tilde{\pi}_i/\partial\tau > \partial ln\eta_i/\partial\tau$ for some range of τ, then $\partial lnr/\partial\tau > 0$. An increase in r_i decreases the cut-off cost a_{ii}. Selection drives the least productive domestic firms to exit. For a certain range of τ and depending on other parameters, this selection effect and the entry of new MNEs together can offset the losses from exports sales, *i.e.* $\partial ln\tilde{\pi}_i/\partial\tau$ can be positive or negative. But despite the sign of the first derivative, $\partial^2 ln\tilde{\pi}_i(\tilde{a})/\partial\tau^2 > 0$ for all τ. These properties together imply that $ln\tilde{\pi}_i$ can either be strictly decreasing, or can be first decreasing and then increasing. Since the function is strictly convex, the function becomes increasing once its slope turns positive.

[82]The indirect effect of small changes in τ on r_i through a_{ii} is small.

A.6.2 A Proof of Proposition 3

From the free-entry condition (2.30) and equation (2.37), the sign of $\partial lng/\partial\tau = \partial lnr/\partial\tau$, it suffices to show the changes in $\partial lnr/\partial\tau$ and the existence and uniqueness of the cut-off trade cost τ^*. If τ^* exists, it is unique because both $ln\tilde{\pi}_i$ and $ln\eta_i$ are strictly convex, such that for the functions $\partial ln\tilde{\pi}_i/\partial\tau$ and $\partial ln\eta_i/\partial\tau$, if they ever cross, will only cross once. Based on the properties of $\partial ln\tilde{\pi}_i/\partial\tau$ and $\partial ln\eta_i/\partial\tau$ discussed in Section A.6.1, two results can be established:

1) If $\partial lnr/\partial\tau$ is first negative and then turns into positive, there exists a unique τ^* such that $\partial ln\tilde{\pi}_i/\partial\tau < \partial ln\eta_i/\partial\tau$ for $\tau < \tau^*$, and $\partial ln\tilde{\pi}_i/\partial\tau > \partial ln\eta_i/\partial\tau$ for $\tau > \tau^*$. This also implies that $\partial g/\partial\tau > 0$ for $\tau > \tau^*$, and $\partial g/\partial\tau \leq 0$ for $\tau \leq \tau^*$. The cut-off point τ^* is the point where $\partial lnr(\tau^*)/\partial\tau = 0$.[83]

2) If $\partial lnr/\partial\tau < 0$ for all τ, then τ^* does not exist, *i.e.* $\partial ln\tilde{\pi}_i/\partial\tau < \partial ln\eta_i/\partial\tau$ for all τ, and $\partial g/\partial\tau < 0$.

A.6.3 A Proof of Proposition 4

Since the sign of $\partial lng/\partial\tau = \partial lnr/\partial\tau$, it suffices to show the changes in $\partial lnr/\partial\tau$ and the existence and uniqueness of the cut-off trade cost τ'. Replacing h_i in the cost of innovation η_i in (2.35) by (2.41) yields a $ln\eta_i$ function that is strictly increasing in τ and is strictly convex. However, since $\partial ln\tilde{\pi}_i/\partial\tau$ can be positive or negative, and is strictly convex as discussed in Section A.6.1, two results can be established:

1) If $\partial ln\tilde{\pi}_i/\partial\tau > 0$ for some range of τ, and is large enough to offset $\partial ln\tilde{\eta}_i/\partial\tau$ which is positive $\forall\tau$, there exists a unique τ' such that $\partial ln\tilde{\pi}_i/\partial\tau < \partial ln\eta_i/\partial\tau$ for $\tau < \tau'$, and $\partial ln\tilde{\pi}_i/\partial\tau > \partial ln\eta_i/\partial\tau$ for $\tau > \tau'$. This also implies that $\partial g/\partial\tau < 0$ for $\tau < \tau'$, and

[83] This case can happen whether $\partial ln\tilde{\pi}_i/\partial\tau$ is positive or negative, as long as $\partial lnr/\partial\tau > 0$.

$\partial g/\partial\tau \geq 0$ for $\tau \geq \tau'$. The cut-off point τ' is the point where $\partial lnr(\tau')/\partial\tau = 0$. Moreover, $ln\eta_i$ is strictly increasing in τ without a quality-adjusted technology spillovers process, but the function is strictly decreasing in τ if quality adjustment is accounted for. For a given $ln\tilde{\pi}_i$ function, $\partial lnr/\partial\tau$ must turn positive starting from a smaller τ with quality-adjusted spillovers process than otherwise, *i.e.* $\tau^* < \tau'$.

2) If $\partial ln\tilde{\pi}_i/\partial\tau < 0\ \forall\tau$, or if it is positive for some range of τ, but is smaller than $\partial ln\tilde{\eta}_i/\partial\tau$, then $\partial lnr/\partial\tau < 0$ for all τ and τ' does not exist.

Appendix B

Appendix for Chapter 4

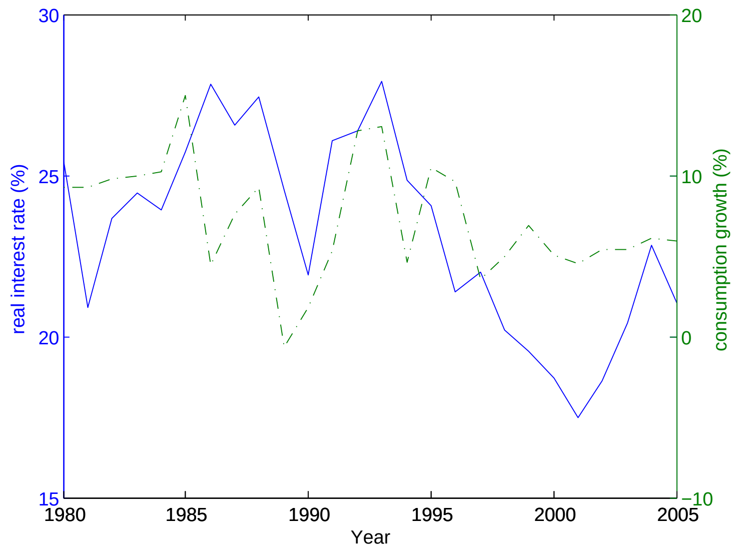
B.1 Parameters Estimation and Calibration

This section of the Appendix describes the estimation of the risk aversion parameter θ_s, and σ^I, the elasticity of innovation cost with respect to relative number of intermediate firms. I also describe below the details of calibrating ψ_s^I, the parameter which controls the level of China's imitation cost.

B.1.1 Estimating θ_s and σ^I

To estimate θ_s, I first re-arrange the Euler equation (3.3) to become $\theta_s = (r_{st} - \rho)/g_{st}^c$, where $g_{st}^c = \dot{C}_{st}/C_{st}$. I construct a series of θ_s's using the per capita consumption growth data from World Bank's World Development Indicators for the period between 1980 and 2008, together with the estimates of the real return on capital from Bai et al. (2006). I then take the average of the series to get an $\tilde{\theta}_s$ estimate. Figure B.1 illustrates a close relationship between China's per capital consumption growth and its real interest rate.

Figure B.1: Consumption Growth and Real Interest Rate in China



To estimate σ^I, I make use of equations (3.29) and (3.35), and free-entry condition (3.37) from Chapter Three, which can be written as:

$$r^I_{st} = \frac{\tilde{\pi}_{st}}{\zeta \hat{N}_t^{\sigma^I}} + \sigma^I \frac{\dot{\hat{N}}_t}{\hat{N}_t}$$

where $\zeta = \psi^I_s A_s^{\frac{1}{1-\alpha}} \alpha^{\frac{2\alpha}{1-\alpha}} L_s$. $\dot{\hat{N}}_t/\hat{N}_t$ can be further written as $g^I_{st} - g_{nt}$, the difference between China and OECD rates of imitation and innovation. I then estimate the equation using non-linear least squares, where I treat $\tilde{\pi}_{st}$ as a constant for simplicity. The data for real return on capital r^I_{st} is from Bai et al. (2006), and I proxy $\hat{N}_t$ with China-OECD per capita GDP ratio.

Alternative, I estimate $V_{st} = \zeta \hat{N}_t^{\sigma^I}$ using non-linear least squares estimation, where I proxy V_{st} with the data on the total firm value in China from the China Industrial Economy Statistical Yearbook for the period between 1999 and 2008. The σ^I estimate is very close to the estimate from the first method described above.

B.1.2 Calibrating ψ_s^I

I calibrate ψ_s^I, the parameter that controls the level of China's imitation cost over time, to match the average per capita consumption growth rate of 8.07% for the period from 1980 to 1997. Recall that from the Euler equation (3.3) in Chapter Three, consumption growth is a function of real interest rate r_{st}, which in turn is a function of $\dot{V}_{st}/V_{st}$ and other parameters where their calibration targets are shown in Table 4.2. This leaves us with the calibration strategy for $\dot{V}_{st}/V_{st}$ still to be discussed. Since it is equivalent to $g_{st}^I - g_{nt}$ in the model, we first need to find out what the average g_{st}^I and g_{nt} should be for the given period. Note that by knowing the rate of imitation g_{st}^I, it will also determine the probability of imitation ϕ, which will in turn be used for calibrating the parameters listed in Table 4.2.

Since final output production makes use of domestic and foreign intermediate inputs, the per capital output growth in China and the OECD can be expressed as weighted averages of technology growth in the North and in the South:

$$\begin{aligned} \frac{\dot{Y}_{st}}{Y_{st}} &= (1-\beta_s)g_{st}^I + \beta_s g_{nt} \\ \frac{\dot{Y}_{nt}}{Y_{nt}} &= (1-\beta_n)g_{nt} + \beta_n g_{st}^I \end{aligned}$$

I proxy the weight β_s and β_n by the sum of import and inward MNE sales shares of GDP for China and the OECD, respectively. Together with the average per capital output growth rates of China and OECD for the given period, I can solve for the two equations and the two unknowns to find out the values of g_{st}^I and g_{nt}, which represent the average rates of imitation and innovation in China and the OECD, respectively, for the given period.

B.2 Algorithm to Solve for the Transition Path

The transition path for the North-South economy is simulated using an algorithm in which a balanced growth path is assumed to be attained in the future. Then, by using the Euler equations from the Households' problems of the two economies, a transition path is generated in backward fashion until the state variable $\hat{N}$ has reached its value implied by the baseline data described in Table 4.1 to 4.3, or the "initial state" of the economy. I also simulate the path for the period prior to the "initial period" to compare the simulated data and the actual data. I shall further describe the steps to solve for the model as follows.

First of all, I calibrate the parameters of the model to their respective targets from the China and OECD data described in Tables 4.1 to 4.3. Second, since consumption growth rates across economies are equal along the BGP as discussed in Section 3.3.1, I find the balanced growth path (BGP) attainable in the long-run by equating the Euler equations for China and OECD countries to solve for the equilibrium the relative number of intermediate firms $\hat{N}^*$. After solving for the BGP growth rate g^*, we can calculate China's output (Y_s^*), consumption (C_s^*), net exports (NX_s^*), and R&D (R_s^*) as a ratio of N_{ss}^* along the BGP, and similarly for the OECD macroeconomic variables. Note that although these macroeconomic variables continue to grow along the BGP at the rate of g, the variables are constant once expressed as a ratio of N_{ii}^* for $i \in \{n, s\}$ along the BGP.

Next, I solve for the switching point of the Chinese economy from being an imitator to become an innovator country, which I denote $\hat{N}_{switch}$. I equate the costs of imitation and innovation given by equations (3.31) and (3.32), respectively, which I assume to be equal to the constant cost of innovation given by equation (3.29) for the OECD countries at the point of switching.

Once we know the values of growth rates and macroeconomic variables that characterize the BGP, as well as the point of switching for China, we can solve for the transition path in backward fashion. For the simplicity of calculating the transition path numerically, I discretize the time t so that each period stands for a year. I also discretize $\hat{N}_t$ up to 5 decimal points. The procedure for backward solving is as follows:

1. Start with the BGP $\hat{N}^*$ and treat $\hat{N}^*$ as $\hat{N}_t$. Also, the probability of imitation ϕ is equal to 0 because the economy is now at a point in which both countries are innovators, and the cost of innovation for China η_{st} is given by equation (3.32).

2. Knowing $\hat{N}_t$, pick $\hat{N}_{t-1}$ that is one unit smaller (e.g. 0.00001 smaller than $\hat{N}_t$ if steps are discretized with precision of 5 decimal points).

3. Find $g_{s,t-1} - g_{n,t-1} = \frac{\hat{N}_t - \hat{N}_{t-1}}{\hat{N}_{t-1}}$.

4. Given $\hat{N}_{t-1}$ find $(Y_s/N_{ss})_{t-1}$, $(NX_s/N_{ss})_{t-1}$, $r_{s,t-1}$, and consumption growth $g^c_{s,t-1}$.

5. From step (3), $g_{s,t-1} - g_{n,t-1}$ is known but $g_{s,t-1}$ and $g_{n,t-1}$ are not known separately. Since we know $(C_s/N_{ss})_t$ from time t ahead of time $t-1$, we can make use of the following:

$$\begin{aligned} \frac{C_{s,t}}{N_{ss,t}} &= \frac{C_{s,t-1}}{N_{ss,t-1}} \times (1 + g^c_{s,t-1} - g_{s,t-1}) \\ &= \frac{Y_{s,t-1}}{N_{ss,t}} - \frac{M_{s,t-1}}{N_{ss,t-1}} - \frac{NX_{s,t-1}}{N_{ss,t-1}} - \frac{R_{s,t-1}}{N_{ss,t-1}} \end{aligned}$$

   where $(R_s/N_{ss})_{t-1} = g_{s,t-1}V_{s,t-1}$. Solve for $g_{s,t-1}$ given all other variables are known at $t-1$.

6. Knowing $g_{s,t-1}$, we find $g_{n,t-1}$ using information from step (3). Once g_n is known we can solve for $(Y_n/N_{nn})_{t-1}$, $(NX_n/N_{nn})_{t-1}$, $r_{n,t-1}$, and consumption growth $g^c_{n,t-1}$.

7. Since we know $(C_n/N_{nn})_{t-1}$, $(C_n/N_{nn})_t$, and $g^c_{n,t-1}$, we can make use of the following to imply an alternative g'_n:

$$\frac{C_{n,t}}{N_{nn,t}} = \frac{C_{n,t-1}}{N_{nn,t-1}} \times (1 + g^c_{n,t-1} - g'_n)$$

8. If $g_{s,t-1} - g'_n > g_{s,t-1} - g_{n,t-1}$, repeat steps (2) to (7). If $g_{s,t-1} - g'_n = g_{s,t-1} - g_{n,t-1}$, treat the optimal $\hat{N}_{t-1}$ as the new $\hat{N}_t$, and go back to step (2) to find the new optimal $\hat{N}_{t-1}$ as the procedure is stepping backward in time.

9. Repeat the above procedure until reaching the switching point $\hat{N}_{switch}$ where China becomes an innovator from an imitator country. At the switching point and the time backward, use equation (3.30) where the probability of imitation $\phi > 0$ for Northern firms serving the South, and the imitation cost function η^I_{st} given by equation (3.31) instead of η_{st}.

10. Once $\hat{N}$ reached $\hat{N}_0$, stop the simulation.

To simulate the path prior to $\hat{N}_0$, *i.e.* for the period from 1980 to 1997, we can perform the same algorithm as above. The simulation now starts at $t = 0$ and stops at $t = -18$ (*i.e.* back to 1980).