The Evolution of the Global Value Chain

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The Evolution of the Global Value Chain

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Production processes are increasingly fragmented geographically, and the performance of production tasks is spread across countries. As multinational production progresses, an intriguing phenomenon arises which is referred to as countries and firms "moving up the global value chain." While many people may have an informal understanding of what it means, testable definitions and examinations of the dynamics are lacking.

My dissertation aims to provide a unified framework to address the meaning and mechanism of the dynamics of global production and value chain. Task-based theoretical models are developed to explore and characterize the dynamics, which arise from learning-by-doing. Using firm-level data, empirical support for the important theoretical predictions is found. The model is further extended to incorporate the innovation effect, which explains the rising phenomenon of reshoring.

Following the first and second chapter for introduction and literature review, in Chapter 3, I develop a dynamic task-based model of multinational production. The technology of producing a final good is modeled as a spectrum of tasks ranked by their degree of technological sophistication. The global value chain of an industry is thus described as a sequence of tasks that may be spread across countries, with each task adding value to the final good. "Moving up the global value chain" is then defined as an upgrading in the set of tasks that a country, an industry, or a firm conducts.

The basic model features the critical role of learning-by-doing in the dynamic production process. Initially, developed countries (the North) offshore simple tasks to developing countries (the South). The South may receive tasks beyond its technological capability. By conducting the "beyond" tasks, the South improves its efficiency on relatively sophisticated tasks. This learning-by-doing effect enables more complex tasks to be offshored in the next period. This process continues until the Southern technological capability matches the set of tasks offshored. Both types of coun-

tries move up the global value chain during this process – the South conducts additional and harder tasks, while the North concentrates on fewer but the most highly sophisticated activities. The evolution of multinational production is characterized by the task offshoring threshold moving up to its steady state, with the movement pace slowing down over time – thus a concave-shaped path. The dynamics of other economic aspects, including wage rates and national welfare, are discussed.

In Chapter 4, I develop the dynamic theory of global production within a monopolistic competition framework. Products are differentiated by variety, with each variety being produced by a multinational firm. Countries and firms move up the global value chain due to firms' learning-by-doing effects, as the Southern subsidiaries engage in a wider range of and more sophisticated tasks, while the Northern counterparts do fewer but more complex activities. The number of varieties increases and displays a converging pattern of growth during the evolution process, and this expansion at the extensive margin is the main source of welfare gains for both countries.

The situation under autarky and the dynamic gains from offshoring are examined. Under monopolistic competition, the South may experience a welfare loss in the short run upon participating in global production. However, in the long run, the learning-by-doing effect will lead the South to be better off than its autarky situation. Meanwhile, the North enjoys a higher level of welfare at the beginning of joining global production, and the gain continues in the long run. Hence, both types of countries get rewarded from offshoring, though their paths are quite different.

The task-based theory predicts that as multinational production evolves, the Southern country's share of value added in total value of industrial output increases over time, while the growth rate declines – thus a concave-shaped path. In Chapter 5, a micro-founded approach is applied to test the dynamics of the value-added ratio (VR) of global production contributed by the South. By using a subsidiary-level dataset on China's multinational operation spanning 10 years, the evolution pattern of industry-level VR is examined. The results show that convergence evidences are present, and the industrial VR dynamics are mainly driven by changes within multinational subsidiaries.

Chapter 6 extends the model to incorporate innovation in developed home countries. Task allocation depends on countries' relative efficiency of conducting tasks. When both countries improve domestic technologies simultaneously – one through learning and the other through innovation, the dynamics of multinational production are determined by the countries' relative speed of technology improvement. Both offshoring expansion and reshoring may occur, where reshoring refers to the phenomenon that previously offshored tasks return to their originating home countries.

Dedication

I wish to dedicate this dissertation to my beloved family, for your continued support and encouragement.

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Chapter 1

Introduction

Currently, global economic activities feature a complex multinational production network with a prominent role played by international task trade, as production processes become increasingly fragmented geographically and the performance of production tasks is spread across the globe. It is not unusual for a final good to have components or technology produced in a high-income country, which are then exported to a lower-income country where final assembly occurs, with the final product exported back to the originating high-income country.

Over time, an intriguing phenomenon arises which is widely referred to as countries and firms "moving up along the value chain of global production." The phrase is used, for instance, (1) in describing the fact that the Brazilian automotive industry, starting with an assembly line built by General Motors, now develops new car models and has become among the world's largest vehicle producers; (2) as the reason why Asian-Tiger economies experienced rapid industrialization and maintained high growth rates for decades after World War II; and (3) as the recipe for OECD countries to stay competitive in the global environment. While many people may have an informal understanding of what "moving up the global value chain" means, testable definitions and examinations of mechanisms of the dynamics involved in this process are lacking. In particular, what is the chain variable? Who is on the chain? Why do countries and firms claim they move up the chain altogether, even if they are at quite different development stages? And how do countries and firms move along the chain?

Exploring these issues, my dissertation aims to provide a unified framework to address the meaning and mechanism of the dynamics of global production. This chapter, as a brief introduction, will provide an overview of the dissertation. After a review of literature in Chapter 2, Chapter 3 introduces the basic task-based model of multinational production, which is briefly outlined here in Section 1.1. Section 1.2 provides an overview of the dynamic theory of global production in monopolistic competition, which is presented in Chapter 4. Section 1.3 overviews the empirical investigation with subsidiary-level data on China's multinational operation. A theoretical extension incorporating innovation into the framework is briefly introduced in Section 1.4.

1.1 A Dynamic Theory of Global Production: A Task-Based Perspective

In Chapter 3 of my dissertation, I develop a unified dynamic task-based theory on global production with the technology for producing a final good modeled as a spectrum of production tasks which are ranked by their degree of technological sophistication. Moving up the global value chain is then given a specific definition as an upgrading in the set of tasks that a country, an industry or a firm conducts. For different countries and firms, the upgrading pattern may vary.

The model features the role of learning-by-doing in the production process, within a perfect competition framework. At the start, developed countries (the North) offshore relatively simple tasks to developing countries (the South). The South acquires certain tasks that are moderately beyond its technological capability. These tasks provide the South with opportunities to improve its production technology through the learning-by-doing effect. This enables the South to carry out the relatively sophisticated tasks more efficiently, which then leads to more complex tasks being offshored in the next period. This self-reinforcing process continues until the technological capability of the South matches the tasks offshored – the long-run steady state. Over time, the Southern coverage of the task spectrum becomes increasingly wide and sophisticated, while the Northern coverage, although narrower over time, concentrates on the tasks involving the highest degree of sophistication.

The movement of global production equilibrium is characterized by the task threshold of offshoring moving toward its steady state, with the movement pace slowing down over time. The evolution of the Southern task scope thus displays a concave-shaped time path, with the steady state being the upper bound. During this process, other aspects of global production also converge to their long-run steady states. The time dynamics of wage rates, output and national welfare levels are examined. Gains from offshoring are also analyzed. The findings indicate that compared with autarky, both the South and the North gain from participating in global production and evolving with offshoring and learning dynamics. While the short-run gain presents for both, the long-run gain at the steady state is mainly for developing countries.

1.2 The Dynamics of Global Value Chain in Monopolistic Competition

Based on the basic model, I further develop the dynamic theory of global production within a monopolistic competition framework in Chapter 4. Products are differentiated by brand, with each brand being produced by a single firm. With offshoring, firms become multinational enterprises (MNEs), with relatively simple tasks being offshored to the Southern subsidiaries initially. When both countries conduct offshorable tasks and with a positive Southern learning effect, more and increasingly sophisticated tasks are reallocated from the North to the South, with the North concentrating on the high-end tasks and non-offshorable activities. Countries and firms move up the global value chain, as the Southern subsidiaries do more and harder tasks, and the Northern counterparts do fewer but more complex tasks. Meanwhile, the number of varieties increases and displays a converging pattern of growth. The expansion at the extensive margin serves as the main source of welfare gains for both countries.

What is interesting here is that with non-offshorable activities being necessary and costly for firms, under certain circumstances, the North may not be participating in any offshorable tasks. Rather, all these tasks are offshored to the South. In this situation, if the Southern subsidiaries have opportunities to learn through conducting tasks beyond their technological capabilities, both countries may be better off over time in terms of consumer welfare.

The autarky situation and dynamic gains from offshoring are examined in this chapter. The gains from offshoring, compared with autarky, can be decomposed into two effects: 1) the variety effect (the extensive margin), with the number of varieties enjoyed by consumers being different from the autarky case, and 2) the consumption effect (the intensive margin), with the per-brand consumption level being changed. The interaction between the two effects determines the national welfare gains from offshoring. It is found that the variety effect is constantly positive for both countries, while the consumption effect is not definitely constantly positive. Combining both effects, different from the situation under perfect competition discussed in the basic model, the developing country here may experience a short-run welfare loss upon participating in global production. However, in the long run, the learning effect will lead the South to be better off than its autarky situation. Meanwhile, the North enjoys a higher welfare level since the beginning of joining global production, and the gain continues in the long-run. Therefore, although both types of countries will be rewarded from joining the multinational production chain, the paths can be quite different.

1.3 Moving Up the Global Value Chain: Evidence from China

A central prediction of the theories is that global production converges to a steady state where no further offshoring occurs. During this evolution process, the national contribution of industrial value-added is dynamically redistributed between countries – the Southern part increases while the Northern part decreases, and the speed of redistribution declines over time. "Moving up the global value chain" thus translates into an increasing Southern share of value added in total value of industrial output over time, while the speed of growth declines gradually.

An empirical approach is thus applied to examine the dynamics of Southern share of total value-added in Chapter 5, and it can be applied to firm-level data from any developing host country. In the approach, multinational subsidiaries in a Southern country are grouped into industries that are considered as multinational industries, and multinational subsidiaries themselves are viewed as collections of tasks. A growth and convergence of the value-added ratio (VR, value-added divided by total value) of multinational industries would support the theoretical predictions on value-added share dynamics.

Subsidiaries are not weightless, and therefore their weights may drive industry-level VR to change even with no VR change within them. To determine whether the VR growth and convergence of multinational industries are essentially driven by those of subsidiaries, I decompose the VR change of each multinational industry into two margins – a within-subsidiary margin and a cross-subsidiary margin, and examine whether each of the two margins, as well as the industry-level VR change itself, is converging. Using this approach, I examine subsidiary-level data on China's multinational operation over ten years (1998-2007). Convergence is found at the industry level, and it is primarily driven by the within-subsidiary margin, which is consistent with the theory.

1.4 Innovation in the Home Country: An Extension

The reshoring phenomenon has been rising recently: production capacities and facilities start returning to developed countries from developing countries where they were previously offshored. One important motivation behind this trend is that developed countries' advantages in production efficiency are able to offset their disadvantages in factor prices. One of the essential reasons here is that the Northern countries keep innovating on production technologies, which outpaces the corresponding improvements taking place in the South. In Chapter 6, I incorporate the important factor of technology improvement – innovation – into the analysis framework of global value chain.

With technology progresses in both countries – innovation in the North and learning in the South, the interaction between the pace of innovation and that of learning determines the organization dynamics of global production. The model provides predictions and explanations for the dynamics of offshoring and reshoring. Both offshoring expansion and reshoring are possible under this enriched framework, depending upon how the countries' relative production efficiency may change over time.

Chapter 2

Review of the Literature

This chapter presents an overview of the existing research on global production and value chain, from the perspective of international trade. The literature has helped shape the theoretical and empirical position developed in this study, and it serves as a lens through which to view this research in a comprehensive contextual framework. Contributions of this research to the literature are thus discussed accordingly in this chapter.

There is a growing literature on multinational production that views global integration as increasingly marked by task trade, and the global chain of production is thus modeled as a collection of offshorable tasks or a continuum of stages of production. Early examples include Dixit and Grossman (1982) and Feenstra and Hanson (1996b, 1997).[1] More recent works further explore issues such as the effects of heterogeneous offshoring costs (e.g., Grossman and Rossi-Hansberg, 2008, 2012), the optimal allocation of ownership rights along the value chain (e.g., Antràs and Chor, 2013), and the influence of technological change on the interdependence of countries participating in the global supply chain (e.g., Costinot et al., 2013).[2] Sharing with this body of literature that global production is considered and analyzed in a task-based framework, I formulate the dynamic theoretical framework of global value chain in this study, in which the location of value added and task trade are endogenously determined. As discussed in the literature, there are various configurations of production processes, such as the "spider" and "snake" described in Baldwin and

[1] Other early related works such as Dornbusch, Fischer, and Samuelson (1977, 1980) have studied trade theories based on a continuum of tradable goods.

[2] Other important task- or stage-based works include Carluccio and Fally (2013), Yi (2003), Baldwin and Venables (2013), and Baldwin and Robert-Nicoud (2014).

Venables (2013), and studies on production-chain issues often assume that tasks and/or stages of production are sequential in nature (e.g., Costinot et al., 2013 and Antràs and Chor, 2013). As models assuming task sequentiality provide sharp insights into the production-chain issues, particularly for the "snake" type of production process, it is desirable that the global production and value chain be understood and interpreted in a generalized way, without depending on any particular pattern of production process. To capture this idea, my models set no specific requirement for the sequence of task- or stage-completion, with tasks being ranked by their degree of technological sophistication in the framework.[3] Thus, the specific organization pattern of a production process is less a concern when using the framework presented in this study to examine and explain value-chain issues.

The theoretical framework presented in this study features the critical role of dynamic learning-by-doing in the production process, and it provides rich descriptions on how global production may evolve and the resulted dynamic effects of this process on various economic aspects. In the existing literature, learning-by-doing has long been viewed as a central driver for growth and upgrading at various economic levels. Since Arrow (1962) incorporated learning-by-doing into the endogenous growth theory, this topic has generated a rich literature in various economic fields. Theoretically, it plays an important role in examining the mechanics of economic growth and development in many fields, including international trade.[4] Empirical studies have also found support for it being an important driver of growth.[5] This study contributes to this body of literature by incorporating learning-by-doing into the task-based production and offshoring models, examining the effects of learning on the dynamics of global production pattern across countries. Particularly, it addresses what countries and firms can do in order to learn and thus move along the global value chain. Understanding these essential factors and the mechanism involved is important, since they are critical in explaining why some countries experience rapid growth and industrialization within

[3] Similar rankings/categorizations of tasks as presented in my model are discussed in Costinot et al. (2011), Oldenski (2012), and Keller and Yeaple (2013), but their studies focus on different issues than those examined in this study.

[4] See, for example, Krugman (1987), Lucas (1988, 1993), Stokey (1988), Young (1991), Matsuyama (1992) and Jovanovic and Nyarko (1996).

[5] See, for example, Bahk and Gort (1993), Irwin and Klenow (1994), and Levitt et al. (2012).

the global production network, while some other otherwise similar countries do not. As mentioned in Young (1991), learning-by-doing could be conceived of as the exploration and actualization of advanced technologies, which may be new to a country. This study largely agrees with this idea – in the models presented in this study, it is by conducting the tasks for which there is a technological gap between countries that the technologically less advanced country can learn and thus improve its production efficiency over time. This improvement further enables the offshoring pattern to evolve gradually. Therefore, the theory fundamentally examines the dynamics of global production through the endogenous exploration of technologies.

Based on the task-based production framework, this study further examines the welfare dynamics of participating in the global production network. There is a long list of studies that have explored the effects of production fragmentation and offshoring on welfare issues. The arguments and results are mixed. Production globalization can bring positive or negative welfare results to countries under different conditions.[6] As indicated in the literature, production fragmentation has different effects on countries' welfare, probably working in opposite directions.[7] In this study, I focus primarily on the *dynamics* of welfare effects – whether countries experience welfare improvement as global production evolves, what the welfare effects are, and how countries' welfare evolution paths may be. These issues are carefully examined within different competition environments and under different other conditions. The discussions contribute to the existing literature in that they present the *evolution* of welfare resulted from learning with production fragmentation and offshoring. They address the question of whether trade in tasks is beneficial for countries dynamically, particularly for developing countries. In this study, evolutions in offshoring naturally translate into world income redistributions. Over time, the national contribution of value-added as well as the national share of world income is dynamically redistributed between the two sets of countries – the Southern

[6] See, for example, Arkolakis et al. (2012), Arkolakis et al. (2013), Burstein and Monge-Naranjo (2009), Lindert and Williamson (2007), Markusen (1984), Markusen and Venables (1998), Ramondo and Rodríguez-Clare (2013), Rodríguez-Clare (2010), Garetto (2013).

[7] For example, in Grossman and Rossi-Hansberg (2008), fragmentation has three main effects on low-skill wages, including the productivity effect, the relative-price effect, and the labor-supply effect. In Rodríguez-Clare (2010), another set of effects – a productivity effect, a terms-of-trade effect, and a world-efficiency effect – is discussed. Depending upon the interactions among separate effects, countries may see different aggregate welfare effects of offshoring.

part increases while the Northern part declines, and the speed of redistribution decreases gradually. Through task trade and with learning, developing countries benefit dynamically while they participate in global production. At the same time, the developed countries can also be better off, but the path is different. Therefore, while classical trade theories such as Ricardian and Heckscher-Ohlin models have argued the static positive gains from openness, and later studies looking at dynamic stories find possible negative effects over time (e.g., Matsuyama, 1992, Redding, 1999 and Stokey, 1991), this research provides a different perspective to understand the welfare dynamics which yields interesting results.

A main prediction from the theoretical models is that when global production converges to its steady state where no further offshoring happens, the Southern value-added portion also converges, and it essentially maps the convergence pattern of task-offshoring during the process. Therefore, the theory offers a convenient prediction as to how the South's share of value added in an industry should behave over time: "moving up the global value chain" translates into an increasing Southern share of value added in total value of industrial output over time, while the speed of moving up declines gradually.

A micro-founded approach is applied in this study to examine the dynamics of the value-added ratio (VR) of global production contributed by the South (i.e., the South's share of value added). By using a dataset on China's multinational subsidiaries spanning 10 years, the evolution pattern of industry-level VR is examined. This practice is related to the broad empirical literature investigating vertical specialization and value-added trade across countries (e.g., Alfaro and Charlton, 2009, Hummels et al., 2001 and Johnson and Noguera, 2012). As documented by these studies, the global production chain has been increasingly sliced up, and vertical specialization is deepening. The work presented here moves one step further – to note the dynamics of Southern contribution during this process. With regard to country choice, there have been many empirical studies examining China's position in the global production network and its change over time. The findings include that the sophistication of China's exports has been rising (e.g., Schott, 2008, Xu and Lu, 2009, Wang and Wei, 2010 and Jarreau and Poncet, 2012) and that the domestic content in China's exports has been increasing (e.g., Koopman et al., 2012 and Kee and Tang, 2013) in recent years. In this study, the results of the empirical examination share the idea with this literature that China has been improving its situation in the global economic environment, but from the perspective of its contribution to the world's production and offshoring network. By further decomposing the aggregate VR change into a within-subsidiary margin and a cross-subsidiary margin, the empirical works further contribute that it is the changes that happen within subsidiaries that mainly drive the overall industry-level VR dynamics.

Chapter 3

A Dynamic Theory of Global Production: A Task-Based Perspective

As noted in Chapter 1, various phenomena have been documented as "moving up the global value chain," however, while we may have a common sense of what the phrase means, questions arise when we attempt to ponder it thoroughly. What is the argument variable of the chain? Who is on the chain? How does a player move along the chain? Why do countries at quite different development stages all claim that they move up the global value chain at the same time? Such questions need to be answered when we try to understand the story better.

This chapter is among the first attempts to provide a unified theoretical framework to address the meaning and mechanism of the dynamics of global production and value chain. It is from the perspective of cross-border task allocation of multinational production. The model introduced in this chapter is task-based, with the global production process being considered as a spectrum of tasks ranked by their degree of technological sophistication. The global production and value chain of an industry is then described as a sequence of tasks that may be fragmented and spread across countries, with each task adding value to the final industrial product.[1] In this basic model, firms operate in a perfectly competitive environment, which provides basic benchmark analyses.

The model features the role of learning-by-doing so that developing countries may improve their production efficiency over time, which then drives the organization pattern of global production to evolve. While countries participating in multinational production typically specialize in different sets of activities, being involved in the global production network provides the participants

[1] Grossman and Rossi-Hansberg (2012) had a similar definition for tasks, while in their model, tasks differ in offshoring cost, and they looked at the static task specialization pattern and related it to relative wages and outputs.

with opportunities to get contact with foreign technologies. This allows them to learn from others with advanced technologies and to accumulate technical experience through conducting activities they specialize in. Over time, this process enables countries to develop capabilities of carrying out more sophisticated activities in a more efficient way.

Typically, multinational operations in developing countries (the South) start from performing tasks that are relatively simple (e.g., assembly and packaging), while those in developed countries (the North) concentrate their efforts on sophisticated activities (e.g., engineering and product design). Due to low factor prices, the Southern operations may acquire activities beyond their technological capability to carry out. The efficiency gap between the South and the North on these "beyond" tasks enables the former to improve on its production technologies by learning from the latter. This learning-by-doing effect thus leads to more sophisticated tasks being relocated from the North to the South. Over time, the Southern coverage of tasks in global production expands, while the Northern coverage, although narrower over time, concentrates on the most sophisticated activities. Thus, both types of countries experience upgrading along the global production chain.

Following discussions on task-offshoring dynamics, this chapter moves on to analyze the welfare dynamics. As global production converges to its long-run steady state, the South becomes increasingly better off, while the North may experience a "hump-shaped" path of welfare dynamics. I further examine the effect of participating in global production on countries' welfare, i.e., whether establishing the global production network is beneficial for different types of countries. Within the perfectly competitive environment, I find that engaging in offshoring benefits both types of countries, with both seeing welfare gains at least in the short run.

The rest of this chapter is organized as follows. In Section 3.1, I introduce the main framework of the basic perfect-competition task-based model of global production. Section 3.2 studies the instantaneous equilibrium of the model and the long-run steady state of multinational production. The dynamics of task offshoring are examined in Section 3.3. Discussions on the dynamics of national welfare are presented in Section 3.4, and the gains from fragmentation and offshoring are analyzed in Section 3.5. Section 3.6 offers concluding remarks.

3.1 Set-up of the Model

Consider a world comprised of two countries: North (N) and South (S). There is one industry supplying a final consumption product Y to both countries, with no trade or shipping cost. Consumer preferences in the two countries are identical. The environment is perfectly competitive. Labor is the sole factor of production, and it is inelastically supplied and immobile across countries. The labor endowment of country i is denoted by L_i, which is constant over time. Time is continuous and indexed by t.

3.1.1 Production

The production of final good Y requires a continuum of tasks to be completed, indexed by $z \in [0, 1]$. The value of z indicates the technological sophistication of tasks – a larger z indicates a more sophisticated task. The production of Y at any time t is expressed as:

$$\ln Y(t) = \int_0^1 \ln x(z,t)dz, \tag{3.1}$$

where $x(z,t)$ is the amount of task z completed at time t. Each task can be carried out in either country with constant returns to scale.

Consider the production technology. For any task z, there is a minimum unit labor requirement for completing it, which is given by

$$\bar{a}(z) = \bar{a}e^{-z}, \tag{3.2}$$

which is a time-invariant and non-increasing function of z.[2]

The North, on one side, has the most efficient technology for carrying out all tasks; i.e., it can conduct any task using the minimum required amount of labor at any time. The South, on the other side, possesses a stock of technologies initially at $t = 0$, but only those for low-sophistication tasks are as good as their Northern corresponding ones. Specifically, the efficiency frontier of technology in the South is denoted by $T(t)$ at time t, with $0 < T(t) \leq 1$. At time $t = 0$, it is the case that

[2] As in Young (1991), this assumption implies that the ultimate productivity of labor is non-decreasing in the technological sophistication of task production.

$0 < T(0) < 1$. For those simple tasks with $z \leq T(0)$, the South's production technologies are as efficient as the North's. For the complicated ones with $z > T(0)$, the Southern technologies are less efficient, and the more sophisticated a task is, the further the South lags behind.[3] Specifically, the Southern unit labor requirement for conducting task z at $t = 0$ is given by

$$a(z,0) = \begin{cases} \bar{a}(z) = \bar{a}e^{-z} & \text{if } z \leq T(0)\,, \\ \bar{a}e^{z-2T(0)} & \text{if } z > T(0)\,. \end{cases} \tag{3.3}$$

3.1.2 Learning-by-Doing

Any task can be conducted in either country. Therefore, offshoring happens out of the cost-minimization incentive – the South conducts tasks offshored from the North, starting from the relatively simple ones, while the North carries out the sophisticated ones. The two countries thus form a multinational production chain. The South may obtain certain offshored tasks beyond its technological efficiency frontier because of its low factor price. By conducting these "beyond" tasks, the South observes the technological gap between the two countries and thus may accumulate experience and improve its own technologies, thereby enhancing its production efficiency. This is the learning-by-doing effect within the South. Furthermore, it is assumed that the learning-by-doing effect is bounded with spillovers across tasks, with the minimum unit labor requirement schedule serving as the learning boundary. Therefore, the South experiences reduction in its unit labor requirement over time:

$$\frac{\partial a(\cdot,t)/\partial t}{a(\cdot,t)} = -\int_0^1 2\beta \left\{1\middle|\frac{a(z,t)}{\bar{a}(z)} > 1\right\} L_S(z,t)\,dz\,, \tag{3.4}$$

where $\left\{1\middle|\frac{a(z,t)}{\bar{a}(z)} > 1\right\}$ is an indicator function whose value equals 1 if the room for learning for task z in the South is not exhausted at time t, and it equals 0 otherwise; $L_S(z,t)$ denotes the amount of labor used for conducting task z in the South at time t; and $\beta > 0$ is a parameter that indicates the learning ability of the South.[4]

[3] The idea of technological distance has appeared in other models of learning. See, for example, Auerswald et al. (2000), Jovanovic and Nyarko (1996), and Mitchell (2000).

[4] The environment is built upon Young (1991), where a general form of the bounded learning-by-doing function is provided.

The learning function indicates first that the South is not able to learn from tasks that it is not conducting. Secondly, for tasks that the South has already possessed the best technology, carrying them out does not contribute to further efficiency improvement. Furthermore, the efficiency gain from learning decreases in the Southern stock of advanced technology, as the situation $a(z,t) = \bar{a}(z)$ becomes increasingly common when $T(t)$ covers more tasks.

With the initial unit labor requirement schedule of the South and the learning-by-doing effect, the unit labor requirement for conducting a task z in the South at time t follows

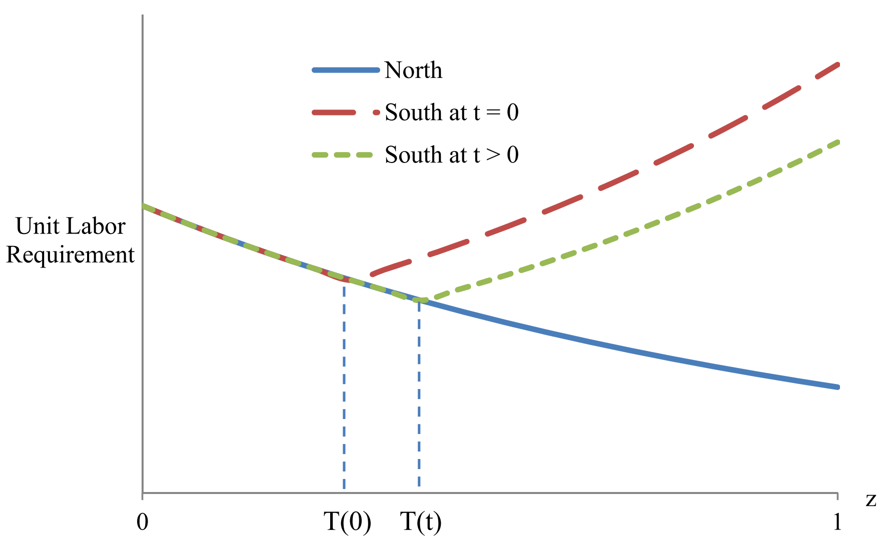
$$a(z,t) = \begin{cases} \bar{a}(z) = \bar{a}e^{-z}\,, & \text{if } z \leq T(t)\,, \\ \bar{a}e^{z-2T(t)}\,, & \text{if } z > T(t)\,, \end{cases} \tag{3.5}$$

where $T(t)$ denotes the technology efficiency frontier of the South at time t. $T(t)$ evolves following

$$\frac{dT(t)}{dt} = \int_{T(t)}^{1} \beta L_S(z,t)dz\,. \tag{3.6}$$

Figure 3.1 shows the evolution of the unit labor requirement in the two countries.

Figure 3.1: Unit Labor Requirement Evolution with Learning-by-Doing in the South



In this basic model with perfectly competitive environment, tasks are undertaken with constant returns to scale. Therefore, firms do not have a substantial role here from the theoretical perspective.

3.2 Instantaneous Equilibrium and Steady State of Multinational Production

3.2.1 Instantaneous Equilibrium

Let $w_i(t)$ denote the wage rate in coutry i at time t. Then the unit cost functions for conducting any task z in the two countries are, respectively,

$$C_S(w_S(t), z) = w_S(t)a(z,t)\,, \tag{3.7}$$

$$C_N(w_N(t), z) = w_N(t)\bar{a}(z)\,. \tag{3.8}$$

As described earlier, a certain range of tasks are offshored to the South, and the offshoring starts from the simplest tasks, since the South has the most advanced technologies for them since the initial time. Thus, the cost conditions (3.7) and (3.8) combine to form a no-arbitrage condition in task offshoring, indicating the pattern of task allocation between the two countries. There exists a threshold task $\bar{z}(t)$ at time t such that $C_S(w_S(t), z) = C_N(w_N(t), z)$ in equilibrium, i.e.,

$$w_S(t)\, a(\bar{z}(t), t) = w_N(t)\, \bar{a}(\bar{z}(t))\,, \tag{3.9}$$

where $\bar{z}(t)$ is the most sophisticated task that is performed in the South. Thus, this threshold task $\bar{z}(t)$ indicates the pattern of multinational production and countries' respective position on the global production chain – the South is at a "lower" position on the chain by carrying out tasks with $z \in [0, \bar{z}(t)]$, while the North is at a "higher" position concentrating on the high-end tasks with $z \in (\bar{z}(t), 1]$. Certainly, one essential condition that enables offshoring is with regard to the factor price: $w_S(t) \leq w_N(t)$. I will show that this condition is fully satisfied in later discussions.

The labor-market clearing conditions for the two countries at time t are given by

$$South: \int_0^{\bar{z}(t)} x_S(z,t)a(z,t)dz = L_S\,, \tag{3.10}$$

$$North: \int_{\bar{z}(t)}^1 x_N(z,t)\bar{a}(z)dz = L_N\,, \tag{3.11}$$

where $x_i(z,t)$ denotes the amount of task z conducted in country i at time t.

With the task-based production function (3.1), each task receives the same share of the world expenditure. The price of each task equals the minimum of its unit completion costs in the two countries. Let $E(t)$ denote the world expenditure on the final product Y at time t, defined as the sum of factor payments in the two economies:

$$E(t) = w_S(t)L_S + w_N(t)L_N\,. \tag{3.12}$$

Then the demand for a task z conducted in country i at time t is given by

$$x_i(z,t) = \frac{E(t)}{C_i(w_i(t),z)}\,,\quad i \in \{N,S\}\,. \tag{3.13}$$

With the unit cost functions (3.7) and (3.8), along with (3.13), the labor-market clearing conditions boil down to

$$\mathit{South}: \int_0^{\bar{z}(t)} \frac{E(t)}{w_S(t)}dz = L_S\,, \tag{3.10$'$}$$

$$\mathit{North}: \int_{\bar{z}(t)}^1 \frac{E(t)}{w_N(t)}dz = L_N\,. \tag{3.11$'$}$$

Therefore, the instantaneous equilibrium of the model at any time t is characterized by the offshoring threshold determination condition (3.9), the labor-market clearing conditions (3.10′) and (3.11′), and the world expenditure function (3.12). One equilibrium equation here can be dropped by Walras' Law, so that one variable can be chosen as numeraire. I thus normalize world expenditure at unity: $E(t) = 1$, and hereby wage rates are measured as a share of the total world factor income.

3.2.2 Steady State

From examining the instantaneous equilibrium conditions described above, it is found that there exists a threshold task z^* such that if it serves as the offshoring threshold under the equilibrium conditions – all tasks with $z \in [0, z^*]$ are offshored to the South, and all tasks with $z \in (z^*, 1]$ are conducted in the North, wage rates in the two countries are equalized. From conditions (3.10′) and (3.11′), this wage-equalization task threshold z^* is solved as

$$z^* = \frac{L_S}{L_S + L_N}\,. \tag{3.14}$$

This task z^* serves as the steady state of offshoring in this basic model.[5] At the steady state, the multinational production organization pattern is stable, with no more offshoring changes happening. Other aspects of the economies, such as wage rates and production of the final good, are also thus stabilized. Particularly, when multinational production arrives at the steady state, all tasks are conducted using the most advanced technologies.

3.3 Transition Dynamics of Task Offshoring

Countries' initial stocks of technology and their factor endowments determine their initial positions on the global production chain, which then further determine their development thereafter. A relatively capable developing country may not see much space for learning thus efficiency improvement by taking part in multinational production, while a factor-abundant country with technologies lagging far behind may find great learning potential and opportunities. In this section, I examine the transition dynamics of task offshoring under different circumstances, i.e., how task-allocation across countries evolves over time with the learning-by-doing effect.

3.3.1 Transition Dynamics of Task Offshoring with an Initially Efficient South

In this situation, the South is relatively capable in terms of production technology initially: $T(0) \geq z^*$. Thus, it is easy to tell that all low-sophistication tasks below z^* will be offshored to the South, in order to fully exploit the cost advantages. All the offshored tasks thus may be conducted using the best technologies. Given the unit labor requirement schedules and the equilibrium conditions, the initial equilibrium is characterized by the following:

$$w_S(0)\,\bar{a}e^{-\bar{z}(0)} = w_N(0)\,\bar{a}e^{-\bar{z}(0)}\,, \tag{3.15}$$

$$\int_0^{\bar{z}(0)} \frac{1}{w_S(0)} dz = L_S\,, \tag{3.16}$$

$$\int_{\bar{z}(0)}^1 \frac{1}{w_N(0)} dz = L_N\,. \tag{3.17}$$

[5] From here on, all notations with the superscript "*" stand for corresponding variables at the long-run steady state.

These conditions indicate that at $t = 0$, the task offshoring threshold, $\bar{z}(0)$, and wage rates are given by, respectively,

$$\bar{z}(0) = z^* = \frac{L_S}{L_S + L_N}\,, \tag{3.18}$$

$$w_S(0) = w_N(0) = w^* = \frac{1}{L_S + L_N}\,. \tag{3.19}$$

Therefore, for all the tasks offshored to the South, the country's technology is as good as the North's – the South does not conduct anything that it is not good at. This implies that there is no learning space for further improvement in the South. From the learning function (3.4), $\frac{\partial a(\cdot,t)/\partial t}{a(\cdot,t)} = 0$. As a consequence, over time, the Southern unit labor requirement schedule keeps the same as that at $t = 0$, and the Southern technology stock does not change over time ($T(t) = T(0),\ \forall t$). Given that production efficiency stays unchanged in both countries, for all following time periods, the equilibrium will also be the same as the initial one:

$$\bar{z}(t) = z^* = \frac{L_S}{L_S + L_N},\ \forall t \tag{3.18$'$}$$

$$w_S(t) = w_N(t) = w^* = \frac{1}{L_S + L_N},\ \forall t. \tag{3.19$'$}$$

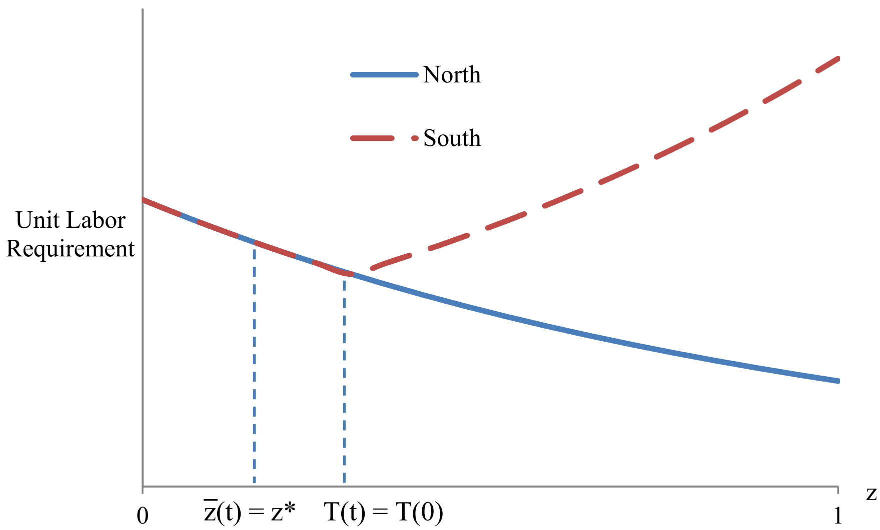
Multinational production in this case thus arrives at its long-run steady state at the beginning. Figure 3.2 displays this essentially static equilibrium situation in this case.

3.3.2 Transition Dynamics of Task Offshoring with Learning-by-Doing

In multinational production, most developing countries have enough labor resource but lack advanced technologies. This situation may be modeled as $T(0) < z^*$. It is the main focus of this basic model, and the task offshoring dynamics in this case are examined in this section.

Given that $T(0) < z^*$, $\bar{z}(0) \in (T(0),\ z^*)$ follows. The reasons are that an offshoring threshold right at $T(0)$ is not cost-minimizing and that without the best technologies for tasks beyond $T(0)$, it is costly to conduct all tasks $[0, z^*]$ in the South in the initial time period. From (3.2), (3.3),

Figure 3.2: Dynamics of Task Offshoring: an Initially Efficient South ($T(0) \geq z^*$)



(3.9), (3.10′) and (3.11′), the initial equilibrium ($t = 0$) then is characterized by

$$w_S(0) \times \bar{a}e^{\bar{z}(0)-2T(0)} = w_N(0) \times \bar{a}e^{-\bar{z}(0)} , \tag{3.20}$$

$$\int_0^{\bar{z}(0)} \frac{1}{w_S(0)} dz = L_S , \tag{3.21}$$

$$\int_{\bar{z}(0)}^1 \frac{1}{w_N(0)} dz = L_N . \tag{3.22}$$

By examining the equilibrium conditions, the initial offshoring threshold, $\bar{z}(0)$, and wage rates are found to be determined by the following conditions:

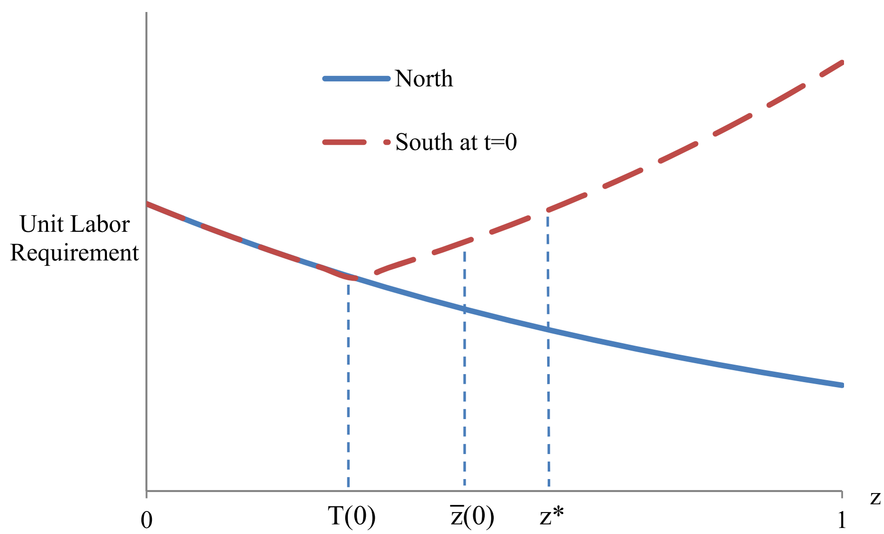
$$e^{2\bar{z}(0)-2T(0)} = \frac{1-\bar{z}(0)}{\bar{z}(0)} \times \frac{L_S}{L_N} , \tag{3.23}$$

$$w_S(0) = \frac{\bar{z}(0)}{L_S} , \tag{3.24}$$

$$w_N(0) = \frac{1-\bar{z}(0)}{L_N} . \tag{3.25}$$

At the equilibrium, with $\bar{z}(0) < z^* = \frac{L_S}{L_S+L_N}$, it is the case that $w_S(0) < \frac{1}{L_S+L_N} < w_N(0)$. The relatively low factor price in the South enables the offshoring to happen, ensuring that the simple tasks for which the South has the best technologies may be offshored. Furthermore, except for these simple tasks, the South also obtains tasks beyond its technological capability to carry out ($\bar{z}(0) > T(0)$). Figure 3.3 shows the initial equilibrium of this situation.

Figure 3.3: Initial Task Offshoring: an Initially Inefficient South ($z^* > T(0)$)



By conducting the "beyond" tasks, the learning-by-doing effect is turned on. From the learning function (3.4), it can be told that $\frac{\partial a(\cdot,t)/\partial t}{a(\cdot,t)} > 0$. The South thus will experience production-efficiency improvement over time, which will further attract more tasks to be offshored. At time t, the instantaneous equilibrium is characterized by

$$e^{2\bar{z}(t)-2T(t)} = \frac{1-\bar{z}(t)}{\bar{z}(t)} \times \frac{L_S}{L_N}\,, \tag{3.26}$$

$$w_S(t) = \frac{\bar{z}(t)}{L_S}\,, \tag{3.27}$$

$$w_N(t) = \frac{1-\bar{z}(t)}{L_N}\,. \tag{3.28}$$

Following the same reasoning as discussed earlier, as long as $T(t) < z^*$, it is always the case that the task-offshoring threshold lies between the Southern technology stock and the long-run steady state: $\bar{z}(t) \in (T(t),\ z^*))$, which enables the South to further accumulate experience and learn. During this process, the Southern wage rate is always lower than the Northern wage level: $w_S(t) < w_N(t)$.

The positive learning-by-doing effect present in the South is reflected by the accumulation of technology there – $T(t)$ evolves according to the technology accumulation path:[6]

$$\frac{dT(t)}{dt} = \beta L_S \times \frac{\bar{z}(t) - T(t)}{\bar{z}(t)}\,. \tag{3.29}$$

[6] See Appendix A.1.1 for the derivation of (3.29).

The learning effect indicates that as long as the South conducts tasks beyond its current technology stock, the country may always learn from what it does, i.e., $\frac{dT(t)}{dt} > 0$ when $\bar{z}(t) > T(t)$.

The learning effect then further pushes the offshoring threshold toward more complicated activities. The production efficiency improvement in the developing country makes more tasks, also the relatively more sophisticated ones, be relocated there from the developed country. Therefore, the South climbs up the global value chain by expanding its task scope and doing increasingly sophisticated tasks as well. This can be seen by examining (3.26):

$$\frac{d\bar{z}(t)}{dt} = \frac{2\bar{z}(t)\,(1-\bar{z}(t))}{1+2\bar{z}(t)\,(1-\bar{z}(t))} \times \frac{dT(t)}{dt}\,, \tag{3.30}$$

which further implies that

$$0 < \frac{d\bar{z}(t)}{dt} < \frac{dT(t)}{dt}\,, \tag{3.31}$$

during the process of Southern learning (i.e., $\frac{dT(t)}{dt} > 0$). At the same time, by increasingly offshoring tasks to the South, the North more and more focuses on the most difficult activities. Although the range of tasks that are performed in the North narrows over time, the average task sophistication increases. Therefore, the developed country also moves up the global value chain in this sense. Moving up the multinational value chain is thus given a specific definition as an upgrading in the set of tasks that a country conducts.

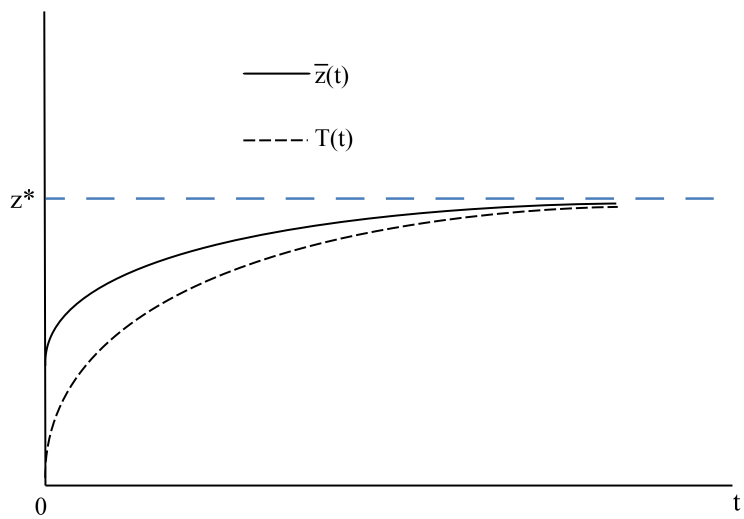
Then the question comes to how strong the learning effect is and whether it diminishes over time. From (3.29), the learning space on "beyond" tasks – the distance between $\bar{z}(t)$ and $T(t)$ relative to the whole range of offshored tasks $\bar{z}(t)$ – largely determines the strength of learning effect. As time passes, the speed of technology accumulation exceeds the speed of offshoring expansion (i.e, $\frac{dT(t)}{dt} > \frac{d\bar{z}(t)}{dt} > 0$), and thus the learning opportunities will be gradually exhausted. This indicates that the offshoring threshold, as well as the technology stock in the South, will evolve over time following a concaved-shaped path:[7]

$$\frac{d^2T(t)}{dt^2} < 0, \text{ and } \frac{d^2\bar{z}(t)}{dt^2} < 0\,. \tag{3.32}$$

[7] See Appendix A.1.1 and Appendix A.1.2 for the derivation.

In the long run, the offshoring threshold, $\bar{z}(t)$, and the Southern technology stock, $T(t)$, converge to the same steady state z^*.[8] Therefore, for all tasks that are offshored to the South, the country will be having the best technologies for them in the long run. All the tasks, no matter conducted in which country, will then be carried out with the best technologies available. Figure 3.4 shows the convergence paths for both the Southern technology stock $T(t)$ and the task offshoring threshold $\bar{z}(t)$.

Figure 3.4: Dynamics of Task Offshoring: an Initially Inefficient South ($z^* > T(0)$)



3.4 Dynamics of National Welfare and Gains from Offshoring

In this section, two important questions are examined: (1) during the process of offshoring evolution, how will the countries' welfare change over time? and (2) do countries gain from production fragmentation and offshoring? For both questions, answers under the first situation – the static equilibrium with a sufficiently efficient South – can be easily understood once the dynamics under the second case are illustrated. Therefore, I will mainly focus on the dynamic case here.

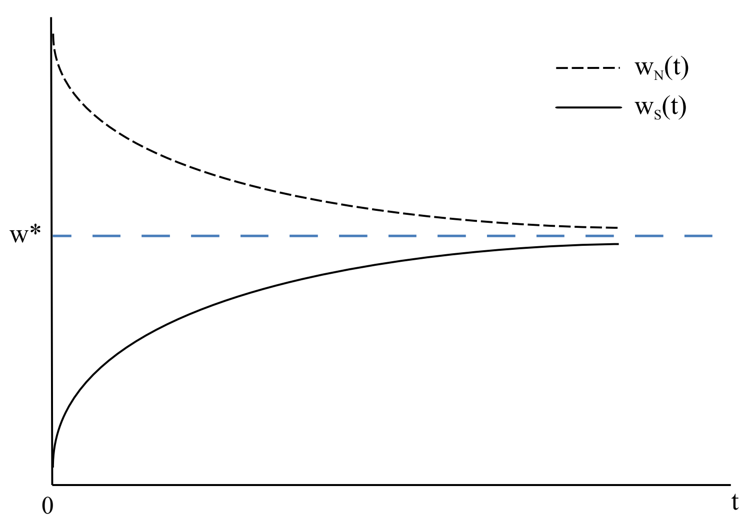
[8] Given (3.26), (3.29) and (3.30), together with the value of z^* shown in (3.14), it is easy to verify that when $\bar{z}(t) = z^*$, both $\frac{dT(t)}{dt}$ and $\frac{d\bar{z}(t)}{dt}$ decrease to 0.

3.4.1 Dynamics of Wage Rates

From the wage determination functions (3.27) and (3.28), it is easy to tell that the dynamics of wage rate in both countries are determined by that of the task offshoring threshold $\bar{z}(t)$. Given the discussions on offshoring dynamics in Section 3.3.2, it is found that wage rate in the South, $w_S(t)$, follows a similar growth path like that of $\bar{z}(t)$ – increasing over time at a decreasing speed. In contrast, the Northern wage rate, $w_N(t)$, decreases over time. What is noteworthy here is that both wage rates are essentially measured as a share of the total world expenditure, which is normalized to unity. Thus, the share of world income that each country takes follows a distinct evolution path.

Before multinational production reaches its long-run steady state, the Southern wage rate is always lower than the Northern wage: $w_S(t) < w_N(t)$, while both are approaching their common steady state, $w^* = \frac{1}{L_S+L_N}$, during the process. Figure 3.5 illustrates the evolution paths of the wage rates in the two countries.

Figure 3.5: Dynamics of Wage Rates with Learning-by-Doing



3.4.2 Dynamics of Output

As offshoring evolves, at any point of time t, the world output amount of the consumer product is[9]

$$Y(t) = \frac{L_N}{\bar{a}(1-\bar{z}(t))} \times e^{\bar{z}(t)^2 - T(t)^2} \times e^{\frac{1}{2}}\,. \tag{3.33}$$

Examining the output function, it is found that the world output displays also a concave-shaped growth path over time:[10]

$$\frac{dY(t)}{dt} = Y(t) \times 2[\bar{z}(t) - T(t)]\frac{dT(t)}{dt} > 0, \text{ when } 0 < T(t) < \bar{z}(t) < 1, \tag{3.34}$$

$$\frac{d^2Y(t)}{dt^2} < 0, \text{ when } 0 < T(t) < \bar{z}(t) < 1\,. \tag{3.35}$$

Therefore, when more and more tasks are reallocated from the North to the South, the total world output grows over time. While the learning space is increasingly exhausted during the process, the growth rate of output declines gradually. In the long run, the output amount converges to its steady state:[11]

$$Y^* = \left(\frac{L_S + L_N}{\bar{a}}\right) e^{\frac{1}{2}}\,. \tag{3.36}$$

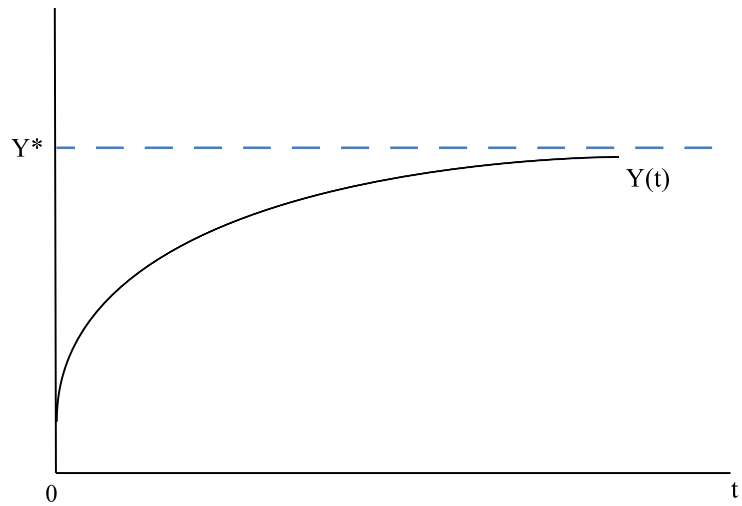
Figure 3.6 shows the growth pattern of output over time.

3.4.3 Dynamics of National Welfare

As discussed in Section 3.4.2, the world output increases over time. As a whole, the world gains as the total consumption level increases. At the same time, wage rates in the two countries show different evolution patterns – the South experiences a positive-sloping path, while the Northern share of world income shrinks. Hence, the question arises as to whether the two countries' respective welfare grows as the learning process continues. Assuming no trade or shipping cost, within the perfectly competitive environment, the consumer price of the final product is the same across countries. The price index of the final good at time t is $P(t) = \frac{1}{Y(t)}$. Then the countries' welfare

[9] See Appendix A.2.1 for the derivation.
[10] See Apeendix A.2.1 for the derivation.
[11] It is easy to obtain the steady state of output with (3.14) and the output expression (3.33).

Figure 3.6: Dynamics of Output with Learning-by-Doing



levels measured by consumption are given by

$$South: \ \omega_S(t) = \frac{w_S(t)L_S}{P(t)} = \bar{z}(t)Y(t)\,, \tag{3.37}$$

$$North: \ \omega_N(t) = \frac{w_N(t)L_N}{P(t)} = (1-\bar{z}(t))Y(t)\,. \tag{3.38}$$

3.4.3.1 Welfare Analysis for the South

For the South, as learning continues, the country keeps getting more tasks to conduct thus obtains an increasing share of world income for consumption. The world output also increases over time. With the two positive effects, the South enjoys a rising welfare over time:

$$\frac{d\omega_S(t)}{dt} = \bar{z}(t)\frac{dY(t)}{dt} + Y(t)\frac{d\bar{z}(t)}{dt} > 0, \text{ when } 0 < T(t) < \bar{z}(t) < 1\,. \tag{3.39}$$

The growth rate of Southern welfare declines as it moves to the long-run steady state:[12]

$$\frac{d^2\omega_S(t)}{dt^2} < 0, \text{ when } 0 < T(t) < \bar{z}(t) < 1\,. \tag{3.40}$$

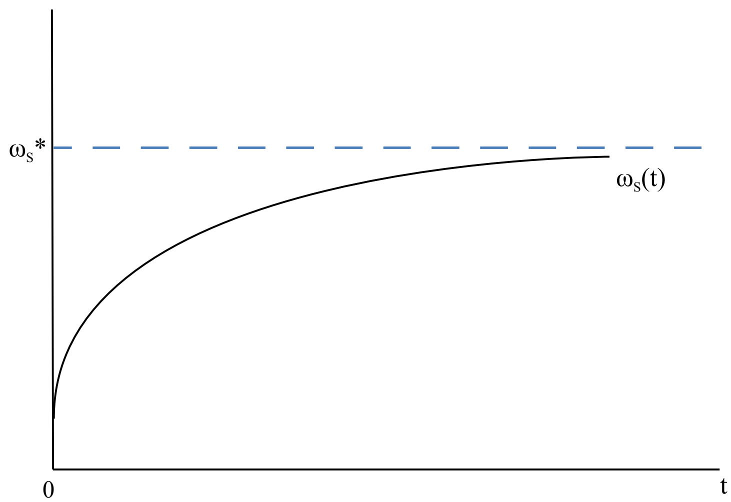
Therefore, as shown in Figure 3.7, the Southern national welfare displays also a concave-

[12] See Appendix A.2.2 for derivation.

shaped growth path, with the steady state reached in the long run, which is[13]

$$\omega_S^* = \left(\frac{L_S}{\bar{a}}\right) e^{\frac{1}{2}} . \tag{3.41}$$

Figure 3.7: Dynamics of Southern Welfare with Learning-by-Doing



3.4.3.2 Welfare Analysis for the North

Different from the case of the South, for the North, although the world output grows over time, the country's share of the world income declines as offshoring deepens. The two forces work in opposite directions. Examining the Northern welfare growth rate, $\frac{d\omega_N(t)}{dt}$, obtained from (3.38), it is found that there exists a cut-off value $\tilde{z}_N$ which is the turning point of the Northern welfare growth. When the offshoring threshold is at $\tilde{z}_N$, $\frac{d\omega_N(t)}{dt} = 0$. When less than $\tilde{z}_N$ tasks are offshored, $\frac{d\omega_N(t)}{dt} > 0$ – the North experiences a growth in welfare while offshoring is at relatively initial stages. When more than $\tilde{z}_N$ tasks are offshored, the North starts to see declines in terms of consumption ($\frac{d\omega_N(t)}{dt} < 0$).[14] Furthermore, it is easy to verify that $\tilde{z}_N < z^*$, and thus the North will experience a welfare decline while multinational production is at the latest stages of approaching its steady state.

[13] It is easy to obtain the steady state value from (3.14), (3.36) and (3.37)

[14] See Appendix A.2.3 for proof.

Intuitively, when close to the steady state, the learning space is almost exhausted – the negative income-share effect thus outweighs the positive productivity effect stemming from learning. At the steady state, the Northern long-run welfare is

$$\omega_N^* = \left(\frac{L_N}{\bar{a}}\right) e^{\frac{1}{2}} \,. \tag{3.42}$$

Comparing the long-run with the initial state of Northern welfare, ω_N^* and $\omega_N(0)$, it is found that

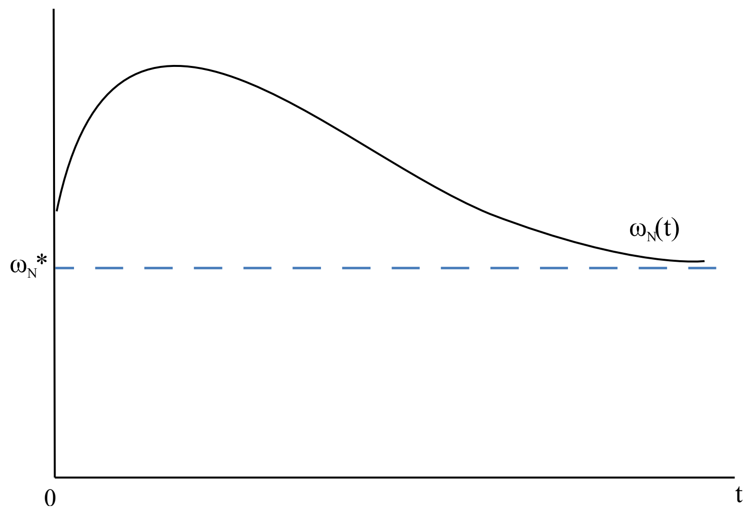
$$\frac{\omega_N^*}{\omega_N(0)} = e^{T(0)^2 - \bar{z}(0)^2} < 1 \,, \tag{3.43}$$

which indicates that the long-run steady-state welfare of the North will actually be lower than its initial state when it just starts offshoring. How big the gap is depends on the initial learning space in the host country. Therefore, in sum, the evolution path of Northern welfare essentially depends on the two countries' relative endowments and the initial technology stocks.

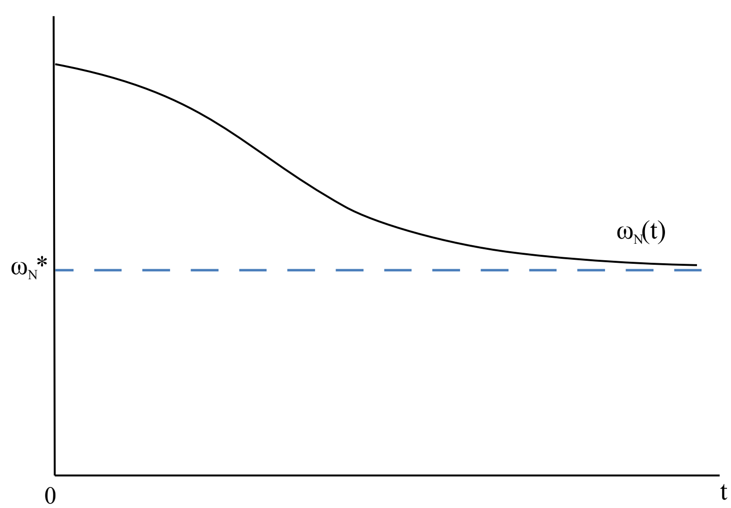
Figure 3.8 illustrates two possible cases of Northern welfare evolution. In Panel A, the initial offshoring threshold $\bar{z}(0) < \tilde{z}_N$. The North thus experiences welfare growth first while the efficiency gain brought by Southern learning outweighs the income effect. The situation will reverse later after more than $\tilde{z}_N$ tasks are offshored. This case is more likely to happen when the South is adequately abundant in labor (a large L_S thus a high $\tilde{z}_N$) and/or has a low technology stock initially (a low $T(0)$ thus a low $\bar{z}(0)$). In Panel B, more than $\tilde{z}_N$ tasks are offshored at the beginning. Over time, the North sees declining welfare until it reaches the steady state. This is more likely the case if the South has a small labor force and/or possesses relatively high stock of technology initially. From the short-run perspective of the North, it may be beneficial to form the multinational production chain when the host country is large and/or lagging far behind in terms of production efficiency, so that the North can enjoy welfare growth at least in the short run. In contrast, from the long-run perspective, it may be better if the South is a "balanced" economy – the technology stock and the factor endowment are balanced, so that the initial offshoring threshold does not deviate too much from the technology stock in the host country.

Figure 3.8: Dynamics of Northern Welfare with Learning-by-Doing

(a) Panel A: A Low Initial Offshoring Threshold: $\bar{z}(0) < \tilde{z}_N$



(b) Panel B: A High Initial Offshoring Threshold: $\bar{z}(0) \geq \tilde{z}_N$



3.5 Gains from Offshoring

An important issue comes to whether countries gain from joining the multinational production chain, i.e., whether engaging in offshoring may benefit final consumers in different countries. In this section, I first present welfare under autarky for the two countries respectively. Then I move on to compare welfare levels under autarky vs. under offshoring, both for the short-run and for the long-run, which leads to the discussions on gains from offshoring. As mentioned earlier, the static case of offshoring can essentially be viewed as a sub-case of the dynamic situation. Therefore, in this section, the main discussions are on the dynamic situation with a positive learning effect.

3.5.1 Welfare under Autarky

Under autarky, both countries have to conduct all tasks to produce the final product according to (3.1). They start with the same situation as $t = 0$ under offshoring – the productivity schedules are given by (3.2) and (3.3), for the North and South, respectively. Without offshoring, countries are not able to get touch with foreign technologies, which indicates that there is no learning opportunity for the South. Therefore, the two economies will stay the same as where they start initially – the time index t can thus be omitted for the autarky case.[15]

With full employment, the amount of task z conducted in a country can be expressed as

$$South:\ x_S^A(z) = \frac{L_S}{a(z,t)}\,, \tag{3.44}$$

$$North:\ x_N^A(z) = \frac{L_N}{\bar{a}(z)}\,. \tag{3.45}$$

This further indicates that the final output level, which is also the real consumption thus implies a country's welfare under autarky, is given by[16]

$$South:\ \omega_S^A = Y_S^A = \frac{L_S}{\bar{a}} \times e^{-[T(0)-1]^2+\frac{1}{2}}\,, \tag{3.46}$$

$$North:\ \omega_N^A = Y_N^A = \frac{L_N}{\bar{a}} \times e^{\frac{1}{2}}\,. \tag{3.47}$$

3.5.2 Gains from Offshoring with Learning-by-Doing

Given the autarky welfare levels, in this section, I discuss the gains from offshoring with the learning-by-doing effect turned on. With learning, the economies evolve over time – the welfare discussions will include both short-run and long-run analyses, i.e., whether countries gain when

[15] The time index will be omitted hereby in this subsection, and the superscript "A" indicates the corresponding variables under autarky.
[16] The equations are easy to obtain given the production function (3.1) and the task amount expressions (3.44) and (3.45).

they just start participating in offshoring and whether they gain when they reach the steady state in the long run.

Initial Gains Comparing the autarky case and the offshoring-with-learning case, it is found that offshoring brings both countries higher welfare levels initially when they just open to form the multinational production chain:[17]

$$\frac{\omega_S(0)}{\omega_S^A} = e^{(\bar{z}(0)-1)^2} > 1\,,\ \ and \tag{3.48}$$

$$\frac{\omega_N(0)}{\omega_N^A} = e^{\bar{z}(0)^2 - T(0)^2} > 1\,. \tag{3.49}$$

This result shows that in the short run, offshoring is beneficial for both countries with advanced technologies and those lagging behind. Under multinational production, countries gain initially from specializing in distinct sets of activities. However, the initial gains may be unbalanced between countries – a large South, thus a high task offshoring threshold $\bar{z}(0)$, brings more welfare gains to the North, than a small South, while a small South will self-benefit more.

Gains in the Long Run As discussed in Section 3.4, the South experiences continuous welfare improvement when offshoring evolves over time. Therefore, it is easy to see that when $t > 0$, the South is always better off than under autarky when multinational production progresses. In the long run, it is the case that

$$\frac{\omega_S^*}{\omega_S^A} = e^{(T(0)-1)^2} > 1 \tag{3.50}$$

For the North, it has been seen that its national welfare may show different possible paths of evolution. Comparing the autarky welfare vs. the welfare under offshoring, it is found that $\omega_N(t) > \omega_N^A$ before the economy reaches the steady state.[18] In the long run, $\omega_N^* = \omega_N^A$. Hence, the consumers in the North are also better off under multinational production during the evolution process. In sum, with the Southern learning effect, both the technologically advanced and less advanced countries may gain. While the short-run gain is positive for both, the long-run gain at

[17] The countries' initial welfare levels under offshoring are from (3.37) and (3.38), together with (3.33), while $t = 0$. The comparison results are then easily obtained by comparing the welfare levels under offshoring vs. under autarky, with condition (3.23) applied.

[18] $\frac{\omega_N(t)}{\omega_N^A} = e^{\bar{z}(t)^2 - T(t)^2} > 1$ before arriving at steady state.

the steady state is mainly for the South.

3.6 Concluding Remarks

A task-based model of multinational production dynamics with learning-by-doing is capable of accounting for the evidences that both the developed and developing economies experience task upgrading over time. To a certain extent, this basic perfect-competition story coincides with the industrialization and growth experience of many countries. The model shows that host countries, although lagging behind in terms of production efficiency, obtain an increasingly wide range of relatively sophisticated activities to carry out over time. They also see increases in their share of world income and consumption. This suggests the progress of foreign-direct-investment-led industrialization observed in many countries. For the developed countries, they increasingly concentrate efforts on the most complicated activities, as also seen in the real world.

The dynamics of welfare in this model show that taking part in multinational production is favorable for both types of participants. Both countries are better off than under autarky since the very beginning when they are engaged in offshoring. This situation continues during the evolution process. In the long run, the South definitely enjoys a better welfare at the steady state than the autarky case, while the North is at least as well off as its autarky level. Therefore, both countries benefit from opening to offshoring.

Certainly, the perfect-competition framework discussed in this chapter provides a convenient environment for analysis, while it leaves out certain factors such as the consideration of final product's varieties. In later chapters, the model under different frameworks will be examined and thus provide additional insights into the dynamics of global value chain.

Chapter 4

The Dynamics of Global Value Chain in Monopolistic Competition

This chapter provides a theory of global value chain dynamics in the monopolistic competition framework. In the model, there is one industry supplying a differentiated final consumer product. Within the industry, there is a continuum of multinational firms, with each producing a single and distinct variety and selling it in both countries. The multinational firms have subsidiaries in both the developed and developing countries, with subsidiaries in different countries specializing in different sets of activities.

Similar like in Chapter 3, the model is task-based, with the technology for producing a final good modeled as a spectrum of production "tasks" that are ranked according to their degree of technological sophistication. This spectrum serves as the basis for global production and value chain analyses, and moving up the global value chain is then given a specific definition as an upgrading in the set of tasks that a country, an industry, or a subsidiary specializes in. For different countries and firms, the task-upgrading pattern may vary.

In the model, the learning-by-doing effect is the main driving force of multinational production evolution. Subsidiaries in developing countries may receive tasks on which they lag behind in terms of technology. By conducting these tasks, the subsidiaries engage in contact with foreign advanced technologies, and further exploration and actualization of those technologies empower efficiency improvement in these subsidiaries over time.

This chapter examines the dynamic welfare effects of participating in global production. As global production converges to the steady state, the South experiences welfare gains constantly along the way. The North, in contrast, may see a long-run welfare level possibly lower than some intermediate level of offshoring. Compared with autarky, the North enjoys positive gains since the initial time when offshoring starts, and it is also better off in the long run, if the steady-state offshoring threshold is within the range of offshorable tasks. The effect of offshoring turns out to be different for the country with technological disadvantages. Engaging in offshoring may have a negative effect for the South initially, wherein the short-term involves pains, but the effect dissipates later while offshoring continues bringing welfare benefits to the country over time. In the long run, the effect is always positive – the South is always better off at the steady state than it is under autarky. Thus, both countries may benefit from joining in global production, but the paths differ.

Different effects contribute to the welfare dynamics. The South and North experience a factor reward increase and decrease, respectively, when global production evolves. At the same time, consumers in both countries enjoy an increasing number of consumption options on the market – the number of varieties available keeps growing along the way. The output dynamics of each variety also contributes to the welfare changes over time. These effects are analyzed and discussed specifically in the chapter.

This chapter is organized as follows. In Section 4.1, I introduce the theoretical environment. Section 4.2 studies the instantaneous equilibrium and the steady state situation in the long run. In Section 4.3, I examine the evolution dynamics of task offshoring under different circumstances. This section also includes discussions of the dynamics of other important economic aspects, such as product variety and national welfare. Section 4.4 discusses the gains from fragmentation and offshoring by comparing national welfare in the state of global production to the state under autarky. Section 4.5 lists the major conclusions.

4.1 Set-up of the Model

Consider a world comprised of two countries: North (N) and South (S). There is an industry supplying a differentiated final consumer product, in which there is a continuum of firms, each producing a single and distinct variety indexed by j and selling it in both countries. Firms are symmetric – the final varieties are only different in the sense that they are under different brand names. Labor is the sole factor of production, and it is inelastically supplied and immobile across countries. The labor endowment of country i is denoted by L_i, which is constant over time. Time is continuous and is indexed by t.

4.1.1 Preference

Consumer preferences are assumed to be identical in the two countries, and the instantaneous preference of a representative consumer at any time t is given by a C.E.S. utility function:

$$U(t) = \left[\int_0^{J(t)} q(j,t)^{\rho} dj \right]^{\frac{1}{\rho}} , \tag{4.1}$$

where $J(t)$ denotes the number of product varieties available and thus also the number of firms at time t; $q(j,t)$ is the consumption of good j at time t; and $0 < \rho < 1$.

This instantaneous utility function implies that the elasticity of substitution between any two varieties within this industry is constant and equals $\sigma = \frac{1}{1-\rho} > 1$. As in Dixit and Stiglitz (1977), the demand for brand j at time t is given by

$$q(j,t) = \frac{E(t)p(j,t)^{-\sigma}}{P(t)^{1-\sigma}} , \tag{4.2}$$

where $E(t)$ stands for the aggregate consumer expenditure at time t; $p(j,t)$ denotes the price of brand j at time t; and $P(t)$ is a price index such that

$$P(t) = \left[\int_0^{J(t)} p(j,t)^{1-\sigma} dj \right]^{\frac{1}{1-\sigma}} . \tag{4.3}$$

4.1.2 Product Market

Facing the constant elasticity demand function derived above, firms choose the same profit maximization markup equal to $\frac{1}{\rho}$. Given the symmetry of firms, the pricing rule is thus given by

$$p(j,t) = p(t) = \frac{c(j,t)}{\rho} = \frac{c(t)}{\rho} , \tag{4.4}$$

where $c(t)$ is the marginal cost of producing any variety j at time t. Assuming no trade or transportation cost, the price of any product is the same across countries.

Firms need to pay a fixed cost during each time period. The fixed cost $f > 0$ is the amount of Northern labor used. It can be viewed as the labor effort needed for conducting the necessary non-offshorable activities. The fixed cost is the same for all firms. This yields the firm profit:

$$\pi(j,t) = \pi(t) = \frac{E(t)}{\sigma}\left(\frac{c(t)}{\rho P(t)}\right)^{1-\sigma} - w_N(t)f\,, \tag{4.5}$$

where $w_N(t)$ is the wage level in the North at time t, and $E(t)$ could be expressed as

$$E(t) = \int_0^{J(t)} p(j,t)q(j,t)dj\,. \tag{4.6}$$

4.1.3 Production

The production of any variety requires the completion of an identical continuum of tasks, indexed by $z \in [0,1]$. The numeric value of z measures the technological sophistication of a task – the larger z is, the more sophisticated the task is. The production technology is identical across all varieties. Given the symmetry of firms, at time t, the production function for any variety j is

$$\ln Y(j,t) = \ln Y(t) = \int_0^1 \ln x(j,z,t)dz\,, \tag{4.7}$$

where $x(j,z,t)$ is the amount of task z that is completed at time t for producing good j. Each task can be located and carried out in either country.

Consider the production technology. For any task z, there is a minimum unit labor requirement, given by

$$\bar{a}(z) = \bar{a}e^{-z}\,, \tag{4.8}$$

where $\bar{a}$ is a positive constant. It is time invariant and non-increasing in z.

The North masters the most advanced technologies for all tasks. Thus, the Northern plants can perform any task using the minimum amount of labor indicated by $\bar{a}(z)$. In contrast, the Southern plants lag behind technologically – they only possess the most efficient technology for a range of low-sophistication tasks, and the situation is identical for all varieties' production. Specifically, initially at $t = 0$, the stock of technologies in the South is denoted by $T(0)$, with $0 < T(0) < 1$. For the relatively simple tasks with $z \leq T(0)$, the South is as efficient as the

North in carrying out these tasks. For the tasks that are relatively difficult to carry out (with $z > T(0)$), the South does not have the best technologies initially; and the more sophisticated a task is, the further the South lags behind the North in terms of production technology. Specifically, the Southern subsidiaries' unit labor requirement schedule at $t = 0$ is given by[1]

$$a(z,0) = \begin{cases} \bar{a}(z) = \bar{a}e^{-z}\,, & \text{if } z \leq T(0), \\ \bar{a}e^{z-2T(0)}\,, & \text{if } z > T(0). \end{cases} \tag{4.9}$$

4.1.4 Learning-by-Doing

Tasks can be completed in the South or in the North. Firms are multinational enterprises in the sense that they have subsidiaries in both countries, performing different sets of tasks. For the South, certain tasks beyond its technological capability may be offshored to the country, which enables subsidiaries there to observe the technological gap between themselves and their Northern counterparts. By conducting these "beyond" tasks, the Southern plants can thus accumulate experience and improve their own technologies, thereby enhancing production efficiency. This is the effect of learning-by-doing in the South. Moreover, the learning-by-doing effect is assumed to be bounded and with spillovers across tasks, with the North serving as the technology frontier and learning boundary. Therefore, the Southern plants experience reduction in the unit labor requirement over time:[2]

$$\frac{\partial a(\cdot,t)/\partial t}{a(\cdot,t)} = -\int_0^1 2\beta \left\{ 1 \middle| \frac{a(z,t)}{\bar{a}(z)} > 1 \right\} L_S(j,z,t)\, dz\,, \tag{4.10}$$

where $\left\{ 1 \middle| \frac{a(z,t)}{\bar{a}(z)} > 1 \right\}$ is an indicator function that equals 1 if the learning room for task z in the South is not exhausted at time t; $L_S(j,z,t)$ denotes the amount of labor used for conducting task z in the Southern subsidiary of brand j at time t; and $\beta > 0$ is a parameter that measures the learning ability of the South.

[1] Given the symmetry of firms, subsidiaries in the same country have the same technologies, and thus the unit labor requirement schedules do not depend on the variety argument j.

[2] The environment here is built upon Young (1991), in which a general functional form of bounded learning-by-doing is provided.

On one hand, the function of learning-by-doing indicates that the Southern plants are not able to learn from the tasks that they do not conduct. On the other hand, for tasks on which learning space has already been exhausted ($a(z,t) = \bar{a}(z)$), carrying them out does not contribute to further efficiency improvement. The learning effect is positive only if the Southern plants perform tasks for which they have not obtained the best techniques.

With the South's initial unit labor requirement schedule and the learning-by-doing effect, the unit labor requirement for completing a task z in the South at time t follows

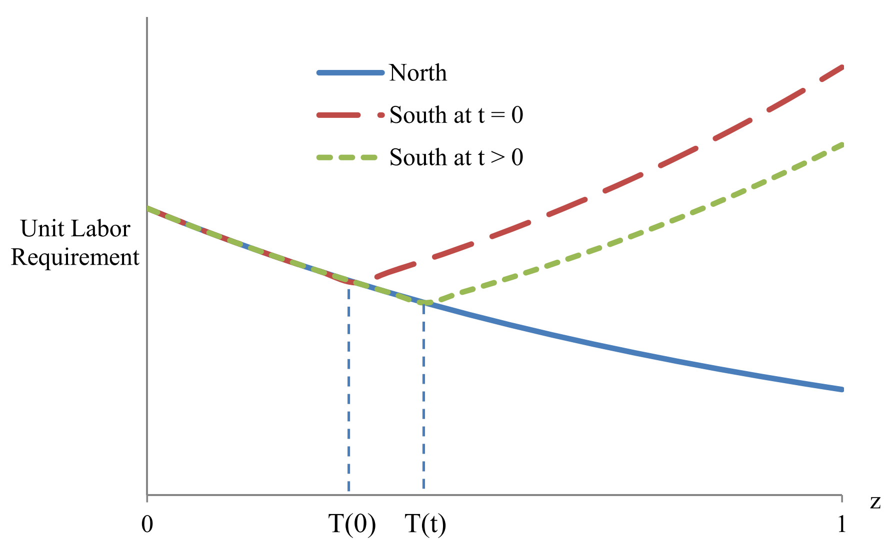
$$a(z,t) = \begin{cases} \bar{a}(z) = \bar{a}e^{-z}\,, & \text{if } z \leq T(t)\ , \\ \bar{a}e^{z-2T(t)}\,, & \text{if } z > T(t)\ , \end{cases} \tag{4.11}$$

where $T(t)$ refers to the technology stock in the South at time t. $T(t)$ evolves according to

$$\frac{dT(t)}{dt} = \int_{T(t)}^{1} \beta L_S(j,z,t)dz\,. \tag{4.12}$$

Figure 4.1 shows the evolution of the unit labor requirement schedule in the South.

Figure 4.1: Unit Labor Requirement Evolution with Learning-by-Doing in the South



A task can be conducted by subsidiaries in the North or in the South, using the corresponding technology indicated by function (4.8) or (4.11), depending on the offshoring pattern prevailing at the time. Each brand establishes only one subsidiary in a country, which completes all tasks allocated to that country by its own brand. There is free entry in the market at all times. The new entrants bring in new distinct brands/varieties, which use the same set of tasks and the identical production function as all already-existing players do. Hence, when a new firm enters the market, it will also use the same offshoring pattern as for the current firms. Free entry draws firms' profit to zero, which then determines the number of varieties present on the market.

4.2 Instantaneous Equilibrium and Steady State of Multinational Production

4.2.1 Instantaneous Equilibrium

Let $w_i(t)$ denote the wage rate prevailing in country i at time t. Then given the symmetry of firms, the cost functions for conducting task z for any brand j in the two countries are, respectively,

$$C_S(w_S(t), j, z) = w_S(t)a(z,t)\,, \tag{4.13}$$

$$C_N(w_N(t), j, z) = w_N(t)\bar{a}(z)\,, \tag{4.14}$$

Under offshoring, certain tasks are allocated to the South. As described earlier, for the range of low-sophistication tasks with $z \leq T(t)$, the Southern plants are as competent in conducting them as their Northern counterparts. However, for the high-end tasks, the South increasingly lags behind. Thus, with consideration of production efficiency, the firms initially offshore relatively simple tasks, with their Southern subsidiaries conducting low-end tasks while the Northern subsidiaries focus on relatively sophisticated activities. Specifically, the cost functions (4.13) and (4.14) combine to form a no-arbitrage condition in task offshoring, indicating the pattern of task allocation between the two countries. There exists a threshold task $\bar{z}(t)$ at time t such that $C_N(w_N(t), j, z) = C_S(w_S(t), j, z)$; or equivalently,

$$w_N(t)\,\bar{a}(\bar{z}(t)) = w_S(t)\,a(\bar{z}(t), t)\,, \tag{4.15}$$

with $\bar{z}(t)$ denoting the most sophisticated task that is conducted in the Southern plants.[3] Thus, for all firms within the industry, tasks with $z \in [0, \bar{z}(t)]$ are allocated to the South, and tasks with

[3] $\bar{z}(t)$ is the same across all plants because firms are symmetric.

$z \in (\bar{z}(t), 1]$ are performed in the North. Given that the value chain of the industry is represented by the whole spectrum of tasks that can be disintegrated and spread over national borders, with each task adding value to the final industrial product, the pattern of task-allocation across countries implied by condition (4.15) indicates countries' respective position on the global value chain – the South is lower than the North. This condition also implies that all firms incur the same marginal cost of production and thus have the same pricing behavior at all times. Certainly, an essential condition that enables offshoring is $w_S(t) \leq w_N(t)$, so that the South has the unit cost advantages in performing those low-end activities. It will be shown later that this condition is always satisfied.

The labor market clearing conditions for the two countries at time t are given by

$$South: \int_0^{\bar{z}(t)} x_S(z,t)a(z,t)dz = L_S\,, \tag{4.16}$$

$$North: \int_{\bar{z}(t)}^1 x_N(z,t)\bar{a}(z)dz + J(t)f = L_N\,, \tag{4.17}$$

where f is the fixed labor cost incurred by every firm in each time period; $J(t)$ is the number of varieties at time t; and $x_i(z,t)$ denotes the total amount of task z conducted by all subsidiaries in country i at time t.

Let $E(t)$ denote the total world expenditure on final products at time t. I0-t is equal to the sum of factor payments in the two countries:

$$E(t) = w_S(t)L_S + w_N(t)L_N\,. \tag{4.18}$$

Given the pricing rule, the demand for a task z conducted in country i at time t is given by

$$x_i(z,t) = \frac{\rho E(t)}{C_i(w_i(t), z)}\,, \quad i \in \{N, S\}\,, \tag{4.19}$$

where $C_i(w_i(t), z)$ is the same across firms.

With the unit cost functions (4.13) and (4.14), along with (4.19), the labor market clearing conditions become

$$South: \int_0^{\bar{z}(t)} \frac{\rho E(t)}{w_S(t)}dz = L_S\,, \tag{4.16$'$}$$

$$North: \int_{\bar{z}(t)}^1 \frac{\rho E(t)}{w_N(t)}dz + J(t)f = L_N\,. \tag{4.17$'$}$$

The free-entry condition drives the firms' profit to zero. Given the symmetry of firms, the zero-profit condition can be simplified to[4]

$$\frac{E(t)}{\sigma J(t)} = w_N(t) f \, . \tag{4.20}$$

Thus, the instantaneous aggregate equilibrium of the model at any time t is characterized by the offshoring threshold determination condition (4.15), the labor market clearing conditions (4.16′) and (4.17′), the world expenditure function (4.18), and the zero-profit condition (4.20). One equilibrium equation here can be dropped by Walras' law, so that one variable can be chosen as the numeraire. I thus normalize the world expenditure at unity, with $E(t) = 1$. Hence, all the wages are measured as shares of the world's total factor income.

4.2.2 Steady State

At the steady state, the task-allocation pattern of global production stays stable. No more tasks are reallocated from one country to the other. Other aspects of the two economies, such as wage rates and the South's technology stock, are also stabilized. By examining the labor market clearing conditions (4.16′) and (4.17′), along with the zero-profit condition (4.20), it is found that there exists a threshold task z^* such that if all tasks with $z \in [0, z^*]$ are offshored to the South and all tasks with $z \in (z^*, 1]$ are retained in the North, the wage rates of the two countries are equalized. Specifically, the time-invariant z^* is solved to be

$$z^* = \frac{L_S}{\rho \, (L_S + L_N)} \, . \tag{4.21}$$

z^* serves as the threshold task of offshoring at the steady state if it is within the range of offshorable tasks ($\frac{L_S}{\rho \, (L_S + L_N)} \leq 1$).[5] If z^* exceeds the range of offshorable tasks, then offshoring will stop when all offshorable tasks have been allocated to the South and the North focuses solely on non-offshorable activities. In this circumstance, the task threshold of offshoring will be $z^{*\prime} = 1$

[4] It is straightforward to obtain (4.20) from examining the profit function (4.5), with considering the aggregate price index expression (4.3) and the pricing rule specified by (4.4).

[5] This condition is more likely to be satisfied if in consumers' eyes, the degree of substitutability among varieties is relatively high.

at steady state. Therefore, the extent of substitutability among varieties in this industry largely determines where the offshoring threshold will be at steady state. Certainly, with learning being the main driving force of technical improvement, if both countries are involved in conducting the offshorable tasks in the long run, the South will be as capable as the North on the tasks it conducts when the steady state is achieved. The unit completion cost of the threshold task of offshoring at the steady state is thus the same in the two countries. The steady state of global production is then featured with equalized wage rates and all tasks being carried out using the best technologies.[6]

4.3 Transition Dynamics

Countries' initial stocks of technology and their factor endowments determine their initial positions on the global value chain, which further indicate the learning opportunities in the global environment. As discussed earlier in the chapter, if a Southern subsidiary conducts tasks at which it is not particularly competent, the learning effect will be positive in the sense that the production efficiency on sophisticated tasks will be improved, through exploring advanced technologies while carrying out the tasks. In contrast, by conducting tasks for which the best technologies have already been in use, plants are not able to obtain further learning opportunities. Therefore, countries' initial positions on the global value chain are important for understanding the transitional dynamics. In this section, I examine the transition dynamics of the model – the movement from an initial situation of task-allocation to the steady state of global production.

Depending upon how far the South lags behind in terms of technology (essentially, where $T(0)$ is) and where the steady state is, there are four possible cases with regard to how global production may evolve over time:

Case I. *Normal Evolution* This is the situation where the steady state stays within the range of offshorable tasks ($0 < z^* \leq 1$) and the initial stock of technology in the South is not adequate for efficiently performing all tasks that could be offshored to the country at the steady state ($T(0) < z^*$).

[6] From here on, all notations with the superscript "$*$" stand for corresponding variables at the long-run steady state.

Under this circumstance, the Southern plants acquire certain tasks that are moderately beyond their technical capabilities. This will provide the South opportunities to learn and improve on the production technology. The positive learning effect will then drive the equilibrium of global production to the steady state, in which both countries participate in offshorable activities.[7]

Case II. *Extreme-end Evolution* In this case, the steady state of global production is $z^{*\prime} = 1$. Namely, at the steady state, all offshorable tasks will be allocated to the South, with the North solely focusing on the non-offshorable activities. With initial Southern technology stock being $0 < T(0) < 1$, the learning effect is positive here as in Case I – the global task allocation evolves to the steady state as the Southern technology improves over time. What is different from Case I is that the evolution path here is not smooth – the actual steady state ($z^{*\prime}$) lies in between the initial equilibrium and the potential steady state ($z^* > 1$), which thus leads to an interruption in the potential evolution path. Once the global production pattern hits the extreme end of offshoring while it evolves to the potential steady state, it will stop progressing further.

Case III. *Static Normal Offshoring* If the South's initial technology stock is sufficiently high ($T(0) \geq z^*$), then global production arrives at the steady state at the initial time $t = 0$. Possessing the best technologies for all tasks conducted in the country, the South will not see opportunities for further learning, which thus leads to a static equilibrium situation.

Case IV. *Static Complete Offshoring* This situation happens when the South is technologically identical with the North ($T(0) = 1$) and the relative labor supply of the South is so large that all offshorable tasks are offshored to the country since the initial time period. Since the variables hit the boundary from the beginning, they will not change further during the following time periods. Certainly, in this case, there is no positive learning effect present in the South.

Among the cases described above, I will mainly focus on Case I, the normal evolution, in this chapter. This case can well illustrate the essential transitional dynamics of global production. The other three cases can then be naturally and easily understood. For instance, Case II is essentially

[7] This case indicates that the South has adequate labor but without enough of an initial stock of technologies, which is the case for most developing countries that currently participate in global production.

a variation of Case I, and it will be discussed briefly later in the section.

4.3.1 Task Dynamics

Given $T(0) < z^* \leq 1$, $\bar{z}(0) \in (T(0), z^*)$ follows. The reasons are that an offshoring threshold at $T(0)$ is not cost-minimizing for any firm and that without the best technologies for tasks beyond $T(0)$, it is costly for the Southern plants to conduct all tasks $[0, z^*]$ compared to the North. By examining (4.15), (4.16′) , (4.17′) and (4.20), together with conditions (4.8) and (4.9), the equilibrium at the initial time of offshoring ($t = 0$) is characterized by

$$e^{2\bar{z}(0)-2T(0)} = \frac{1-\rho\bar{z}(0)}{\rho\bar{z}(0)}\frac{L_S}{L_N}\,, \tag{4.22}$$

$$w_S(0) = \frac{\rho\bar{z}(0)}{L_S}\,, \tag{4.23}$$

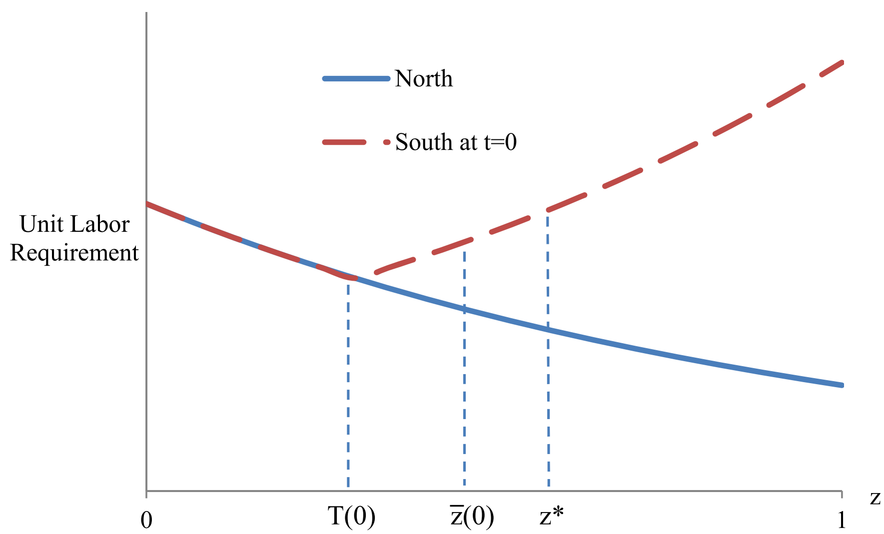
$$w_N(0) = \frac{1-\rho\bar{z}(0)}{L_N}\,, \tag{4.24}$$

$$J(0) = \frac{L_N}{\sigma f\,(1-\rho\bar{z}(0))}\,. \tag{4.25}$$

At equilibrium, with $\bar{z}(0) \in (T(0), z^*)$, the Southern plants receive not only all tasks that they can conduct as efficiently as the North does, but also certain activities beyond their initial technical capability because of the country's abundance of labor. This initial equilibrium is illustrated in Figure 4.2. Furthermore, given $\bar{z}(0) < z^*$, it is the case $w_S(0) < \frac{1}{L_S+L_N} < w_N(0)$. The relatively low wage rate in the South ensures that the low-end activities for which the Southern plants have the best technologies can be offshored.

The situation which involves the South conducting certain tasks that are moderately beyond its capability will turn on the learning-by-doing effect, and thus the production efficiency will improve gradually in the developing country. This effect will further attract more tasks to be

Figure 4.2: Initial Task Offshoring: Normal Evolution ($T(0) < z^* \leq 1$)



offshored. At time t, the instantaneous equilibrium is characterized by

$$e^{2\bar{z}(t)-2T(t)} = \frac{1-\rho\bar{z}(t)}{\rho\bar{z}(t)}\frac{L_S}{L_N}\,, \tag{4.22$'$}$$

$$w_S(t) = \frac{\rho\bar{z}(t)}{L_S}\,, \tag{4.23$'$}$$

$$w_N(t) = \frac{1-\rho\bar{z}(t)}{L_N}\,, \tag{4.24$'$}$$

$$J(t) = \frac{L_N}{\sigma f\,(1-\rho\bar{z}(t))}\,. \tag{4.25$'$}$$

Following the same logic as discussed for the initial equilibrium, as long as $T(t) < z^*$, it is always the case that the offshoring threshold lies between the South's technology stock and the offshoring steady state (i.e., $\bar{z}(t) \in (T(t), z^*)$), which enables the South to learn. During the process, the wage rate in the South is always lower than the Northern wage level (i.e., $w_S(t) < \frac{1}{L_S+L_N} < w_N(t)$).

The positive learning effect in the South is reflected by the accumulation of technology in the country. The technology-stock indicator $T(t)$ evolves over time according to the technology accumulation path:[8]

$$\frac{dT(t)}{dt} = \frac{\beta L_S}{J(t)}\frac{\bar{z}(t)-T(t)}{\bar{z}(t)} = \beta\sigma f\,(1-\rho\bar{z}(t))\,\frac{L_S}{L_N}\frac{\bar{z}(t)-T(t)}{\bar{z}(t)}\,. \tag{4.26}$$

[8] See Appendix B.1.1 for the derivation of (4.26).

The learning effect implies that as long as the Southern plants perform certain tasks beyond their technical capability ($\bar{z}(t) > T(t)$), they can always learn from what they conduct (i.e., $\frac{dT(t)}{dt} > 0$).

This positive learning-by-doing effect pushes the offshoring threshold further, with the Southern coverage of task‘ expanding to include more sophisticated activities. Namely, if the set of tasks undertaken in a plant is viewed as the scope of the plant, then the learning effect will lead to scope expansion in the Southern plants. This can be seen by examining (4.22′):

$$\frac{d\bar{z}(t)}{dt} = \frac{2\bar{z}(t)\,(1-\rho\bar{z}(t))}{1+2\bar{z}(t)\,(1-\rho\bar{z}(t))} \times \frac{dT(t)}{dt}\,, \tag{4.27}$$

which implies

$$0 < \frac{d\bar{z}(t)}{dt} < \frac{dT(t)}{dt}\,, \tag{4.28}$$

as long as the learning room is not exhausted. With learning, the Southern plants are capable of conducting tasks increasingly efficiently for those tasks at which they were not competent before; together with a relatively low wage rate, the South attracts more and harder tasks to be undertaken there. Certainly, while a wider range of low-sophistication tasks are being offshored to the South, the North increasingly focuses on the most difficult activities ($(\bar{z}(t), 1]$). Therefore, both low-income and high-income countries move up the global value chain over time – they both experience upgrading in the sets of tasks that their firms conduct.

As indicated by (4.26), how strong the learning effect is depends upon the relative learning opportunities for the South – for which tasks there is still room for technology improvement, relative to all tasks that are actually offshored (i.e., the distance between $T(t)$ and $\bar{z}(t)$). As time passes, with $\frac{dT(t)}{dt} > \frac{d\bar{z}(t)}{dt}$, the initial learning opportunities are gradually exhausted, which will in turn slow down the pace of learning over time.[9] This further translates into a concave-shaped time path of offshoring evolution. As global production evolves, it is the case that[10]

$$\frac{d^2T(t)}{dt^2} < 0, \text{ and } \frac{d^2\bar{z}(t)}{dt^2} < 0\,. \tag{4.29}$$

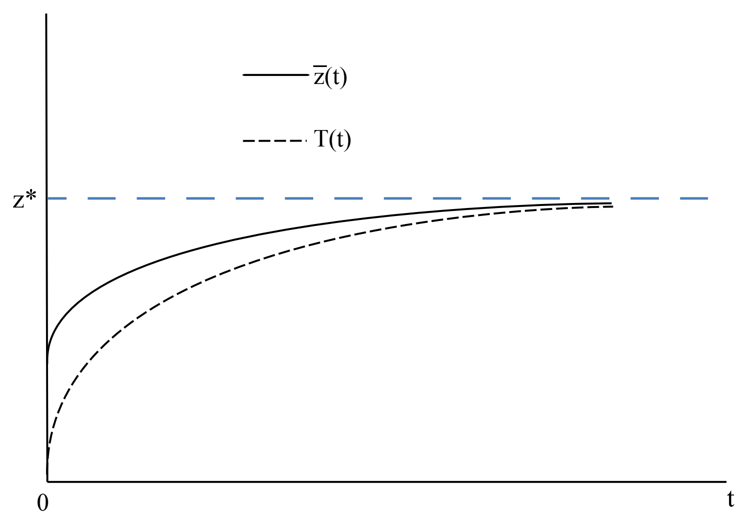
[9] This pattern is not hard to tell from (4.26). The increase in $\bar{z}(t)$ with decrease in $(\bar{z}(t) - T(t))$ leads $\frac{dT(t)}{dt}$ to decline over time.

[10] See Appendix B.1.1 and Appendix B.1.2 for proof.

In the long run, both the technology stock in the South and the offshoring threshold converge to the same steady state, z^*.[11] When they arrive at the steady state, they will not grow further beyond it. With equalized wage rates and both countries possessing the same best technologies for tasks conducted domestically, the pattern of global production is stabilized.

In sum, the dynamics of both the technology stock in the South ($T(t)$) and the task-threshold of offshoring ($\bar{z}(t)$) display concave-shaped growth paths, both converging to the same steady state, which serves as the upper bound. The convergence process is demonstrated in Figure 4.3.

Figure 4.3: Dynamics of Task Offshoring: Normal Evolution ($T(0) < z^* \leq 1$)



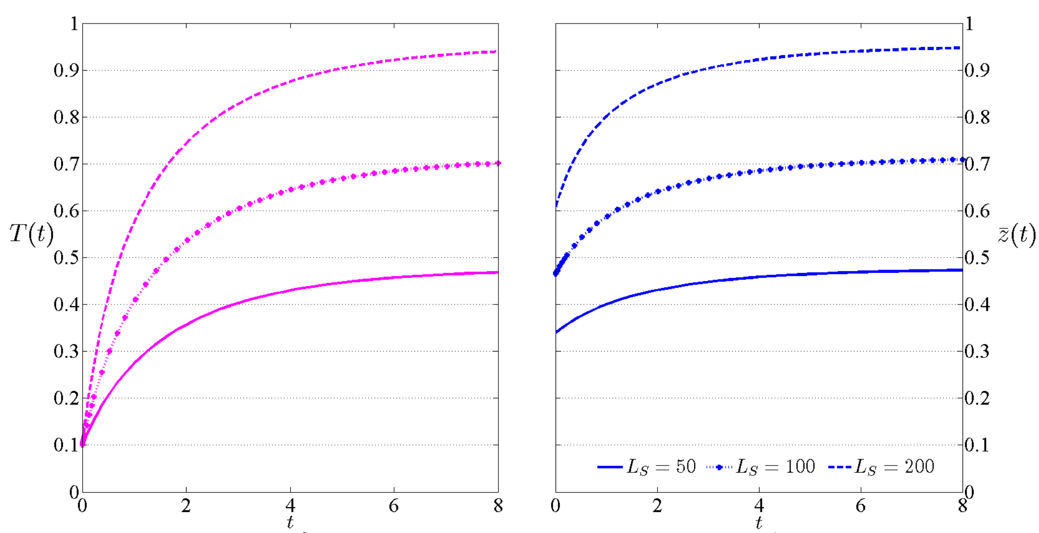
Certainly, factors such as the learning ability of the South (indicated by β), fixed cost (f), variety substitutability of the industry (σ, and thus ρ), and the countries' labor endowments (L_S and L_N) all have influence on the convergence paths. Numerical simulations are performed here to examine how different variables may affect the evolution dynamics of global production. Figure 4.4 demonstrates the results of the numerical simulations. Panel A shows that the size of a country can compensate for its production inefficiency – a larger although technically inefficient country gets a wider range of tasks to carry out, both in the short run and in the long run. Panel B shows the results from variation in the learning ability of the South. It is obvious that a Southern

[11] This can be seen by examining (4.22′) at z^*.

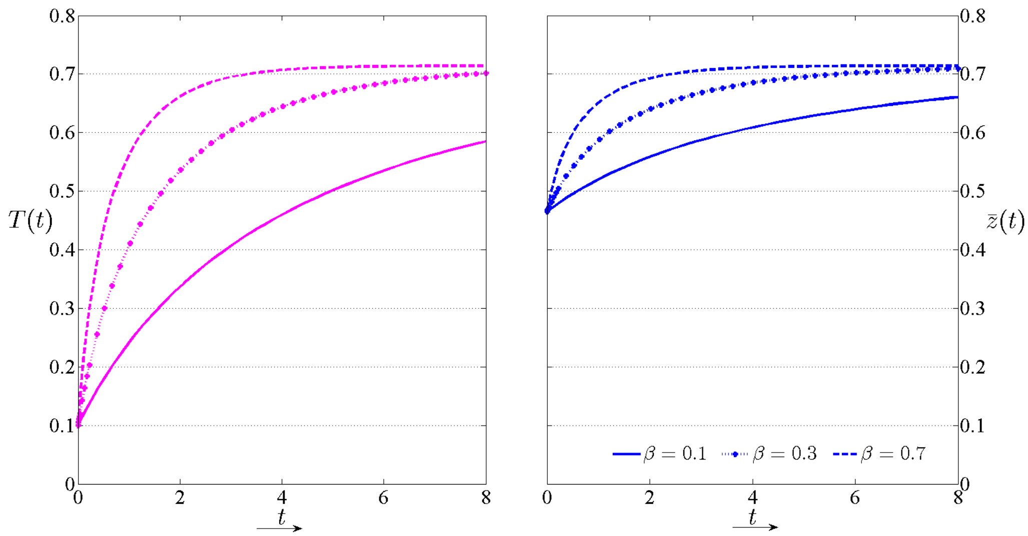
country with strong abilities to explore and actualize advanced technologies converges to its steady state relatively quickly. In Panel C, variety substitutability is the main focus. First, an industry with a higher variety substitutability tends to have less tasks offshored. This is because with high substitutability among varieties, the demand for new ones is low. Therefore, the North will not experience much pressure of bringing in new varieties, which thus allows for more labor in the North to be devoted to current production activities. This leads to a relatively low offshoring threshold. Second, the higher the variety substitutability is, the faster global production converges. Panel D demonstrates how the fixed cost for non-offshorable activities affects the dynamics of offshoring – a higher fixed cost leads to faster convergence. While more efforts are needed for the necessary non-offshorable activities, labor in the North will be transferred to conduct those tasks more quickly as new varieties enter the market, which thus accelerates the offshoring evolution process.

Figure 4.4: Dynamics of Task Offshoring under Normal Evolution ($T(0) < z^* \leq 1$): Simulations

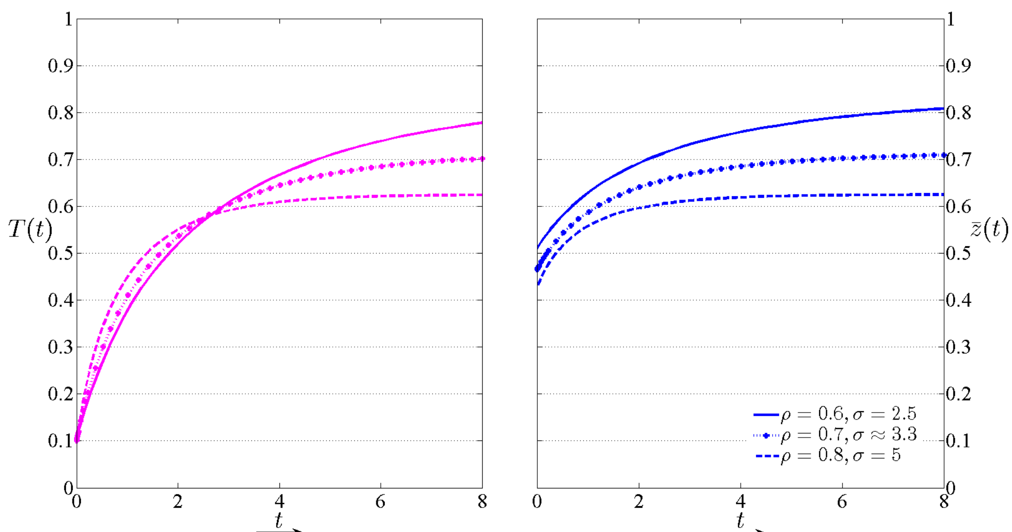
(a) Panel A: Labor Endowment in the South
Note: $L_N = 100$; $\beta = 0.3$; $\rho = 0.7$; $f = 1$; $T(0) = 0.1$



(b) Panel B: Learning Ability
Note: $L_S = 100$; $\text{Ł}_N = 100$; $\rho = 0.7$; $f = 1$; $T(0) = 0.1$



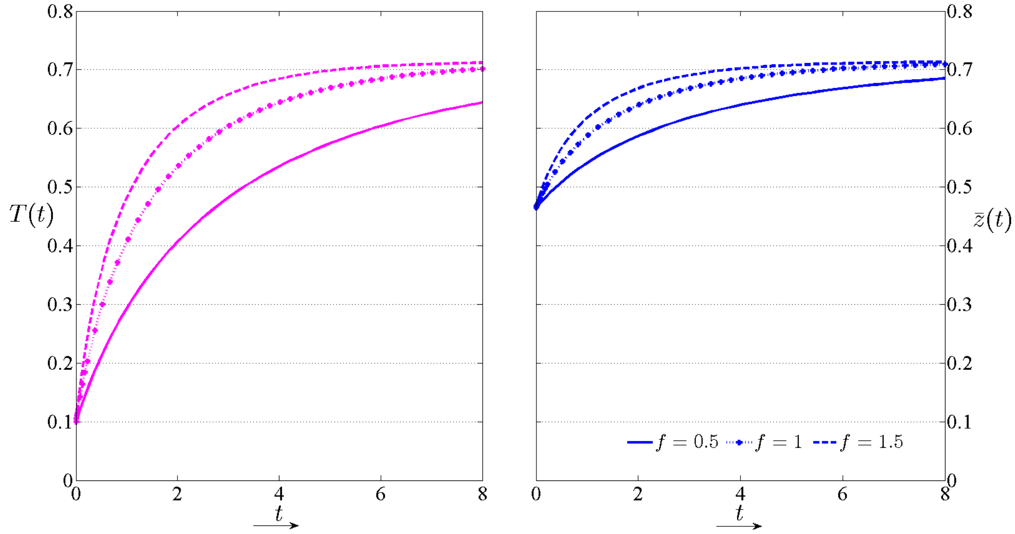
(c) Panel C: Variety Substitutability
Note: $L_S = 100$; $\text{Ł}_N = 100$; $\beta = 0.3$; $f = 1$; $T(0) = 0.1$



4.3.2 Variety Dynamics

Under monopolistic competition, consumers' love for variety provides the market with the incentive to create and maintain different brands. With more and more tasks relocated to the South, the labor in the North that was previously devoted to those offshorable tasks can now

(d) Panel D: Fixed Cost for Branding
Note: $L_S = 100$; $Ł_N = 100$; $\beta = 0.3$; $\rho = 0.7$; $T(0) = 0.1$



switch to conduct the non-offshorable activities. The evolution of offshoring thus brings a change in industrial structure in the country. With more Northern efforts relieved from conducting the offshorable activities, more varieties are brought into the market. This process can be seen by examining the dynamics of variety along the evolution progress.

From (4.25′), it is found that[12]

$$\frac{dJ(t)}{dt} > 0\,, \text{ and } \frac{d^2J(t)}{dt^2} < 0 \tag{4.30}$$

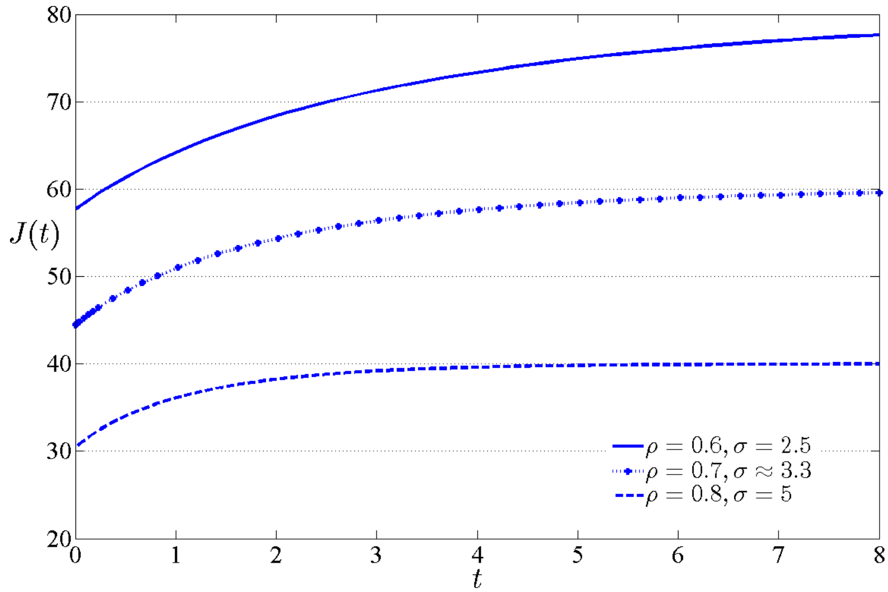
along the way while global production evolves to its steady state, and this indicates a concave-shaped time path for the number of varieties available on the market. In the long run, the number of varieties converges to

$$J^* = \frac{L_S + L_N}{\sigma f}\,. \tag{4.31}$$

Figure 4.5 displays the results from numerical simulations. A higher substitutability among varieties leads to a smaller number of brands on the market both in the short run and in the long run, as well as faster convergence to its steady state.

[12] See Appendix B.2 for proof.

Figure 4.5: Dynamics of Variety: Normal Evolution ($T(0) < z^* \leq 1$)
Note: $L_S = 100;\ L_N = 100;\ \beta = 0.3;\ f = 1;\ T(0) = 0.1$



4.3.3 Dynamics of Factor Income

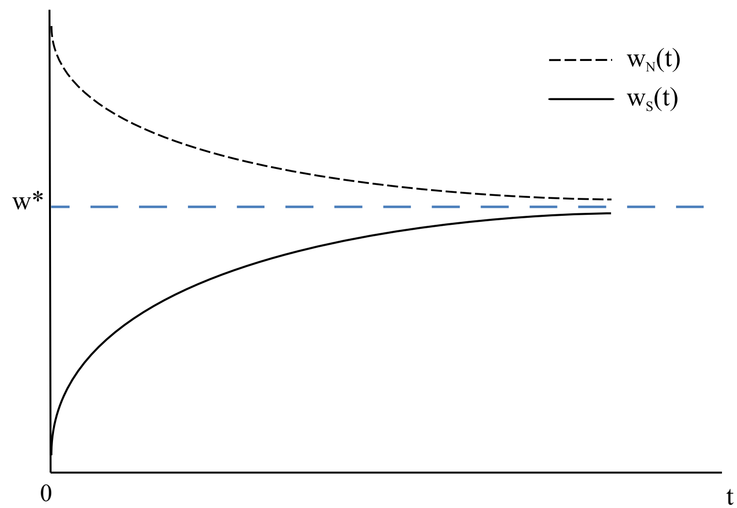
As mentioned in Section 4.3.1, with offshoring, the wage rate in the South continues being lower than that in the North while multinational production evolves. Then how do the wage levels change over time? By examining (4.23′) and (4.24′), it is found that the wage rates in the two countries are closely related to the offshoring threshold. With a constant labor size, the scope of tasks conducted within a country determines the reward rate the workers there can obtain. With technology improvements, even with the same amount of labor, the South can carry out more activities, which is then reflected in the increasing factor price in this country. In contrast, the North experiences a decline in factor price. In the long run, while global production reaches the steady state, the two countries' wage rates are equalized at:

$$w^* = \frac{1}{L_S + L_N}\,, \tag{4.32}$$

which indicates that in the long run, no matter what task a worker performs or which country he or she is in, the wage rate is the same for all. Certainly, this factor-price-equalization condition holds here when the natural steady state is within the range of offshorable tasks ($z^* \leq 1$) and labor flows freely among offshorable and non-offshorable tasks in the North. In the other cases where the potential steady state z^* goes beyond the range of offshorable tasks ($z^* > 1$) so that the actual steady state is at $z^{*\prime} = 1$, the situation is different and will be discussed in later sections.

The wage rate dynamics in the South shows a concave-shaped path, while in the North it displays a convex one, both converging to the steady-state wage rate w^*.[13] Figure 4.6 demonstrates the wage dynamics of the two countries.[14]

Figure 4.6: Dynamics of Wage Rates: Normal Evolution ($T(0) < z^* \leq 1$)



It is clear that although the wage gap between the two countries exists initially in the short run, it diminishes over time as tasks are increasingly offshored. In the long run, under normal offshoring, the wage gap may be closed with factor prices equalized. At the steady state, workers in the South enjoy the same income level as their Northern counterparts, even though they do not master all the most advanced technologies. Hence, what matters most for workers is the actualization of technologies, rather than the potential productivities that are not embodied in real production.

[13] From (4.23′) and (4.24′), $\frac{dw_S(t)}{dt} = \frac{\rho}{L_S}\frac{d\bar{z}(t)}{dt} \geq 0$, $\frac{d^2 w_S(t)}{dt^2} = \frac{\rho}{L_S}\frac{d^2\bar{z}(t)}{dt^2} \leq 0$; $\frac{dw_N(t)}{dt} = -\frac{\rho}{L_N}\frac{d\bar{z}(t)}{dt} \leq 0$, $\frac{d^2 w_N(t)}{dt^2} = -\frac{\rho}{L_N}\frac{d^2\bar{z}(t)}{dt^2} \geq 0$.

[14] Wage rates here are expressed as a share of the world expenditure, since $E(t)$ has been normalized to 1.

4.3.4 Dynamics of National Welfare

Per-Brand Output The evolution of task offshoring naturally translates into the evolution of national welfare of the two countries. Given the utility function (4.1), national welfare depends on both the number of varieties available on the market and the consumption or output volume of each variety. From Section 4.3.2, it is found that the number of varieties keeps growing over time. Now consider the output of each brand. Given the production function (4.7), it is found that the per-brand output at time t is[15]

$$Y(t) = \frac{\rho\sigma f}{\bar{a}} e^{\frac{1}{2}} \times e^{\bar{z}(t)^2 - T(t)^2} . \tag{4.33}$$

Further examination of (4.33) shows that the dynamics of per-brand output may not display a monotonic growth pattern over time. There exists a threshold task $\tilde{z}_y$ such that if less than $\tilde{z}_y$ tasks are offshored to the South (i.e., the offshoring threshold $\bar{z}(t) < \tilde{z}_y$), the per-brand output increases ($\frac{dY(t)}{dt} > 0$); and if more than $\tilde{z}_y$ tasks are offshored (i.e., the offshoring threshold $\bar{z}(t) > \tilde{z}_y$), the per-brand output experiences declines over time. Moreover, the threshold $\tilde{z}_y$ is below the offshoring steady state z^*, which implies that when global production gets close to its steady state, the output of each individual brand will see a decline pattern.[16] Results from numerical simulations are presented in Figure 4.7. It is obvious from the results that the further the South lags behind the North initially in terms of technology, the more likely that the per-brand output will experience an increase in the short run.

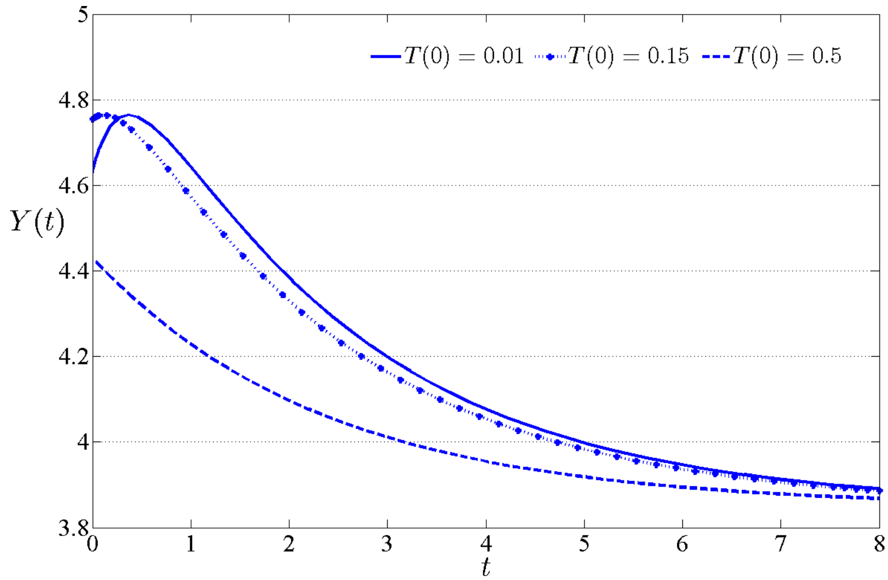
In the long run, the per-brand output always converges to its steady state:

$$Y^* = \frac{\rho\sigma f}{\bar{a}} e^{\frac{1}{2}} , \tag{4.34}$$

which implies that a higher substitutability among varieties will lead to a higher steady state of per-brand output. It is interesting to find that as global production evolves, $Y(t) \geq Y^*$. This indicates an effect of crowding-out with technology improvement and free-entry: the number of variety grows continuously, but at the same time, each individual variety's output may decline.

[15] See Appendix B.3.1 for the derivation of (4.33).
[16] See Appendix B.3.2 for proof.

Figure 4.7: Dynamics of Per-Brand Output: Normal Evolution ($T(0) < z^* \leq 1$)
Note: $L_S = 100$; $Ł_N = 100$; $\beta = 0.3$; $\rho = 0.7$; $f = 1$; $\bar{a} = 1$



This reflects the interaction between consumers' love for variety and the utility gains they enjoy from production efficiency enhancement. Firms can produce more output because of the internal technology improvement, but they also face mounting external competition pressure stemming from new entrants that keep coming into the market. The interaction among these forces determines the evolution path of the per-brand production.

The instantaneous utility function (4.1) indicates that the welfare of a representative consumer in a country can be expressed as

$$U_i(t) = \left[\int_0^{J(t)} q_i(j,t)^\rho dj \right]^{\frac{1}{\rho}} = L_i w_i(t) Y(t) J(t)^{\frac{1}{\rho}} \,,\, i \in \{N,\, S\} \,, \tag{4.35}$$

where $U_i(t)$ represents the welfare level of the representative consumer in country i at time t, and $q_i(j,t)$ denotes the consumption amount of variety j in country i at time t. The national welfare of a country thus is determined by three effects: (1) the income effect, which is indicated by the aggregate national income indicator, $L_i w_i(t)$; (2) the per-variety output effect, represented by $Y(t)$; and (3) the variety effect, which is given by the last term, $J(t)^{\frac{1}{\rho}}$.

With conditions (4.23′), (4.24′), (4.25′), and (4.33), the two countries' consumer welfares are, respectively,

$$U_S(t) = \rho \times \left(\frac{L_N}{\sigma f}\right)^{\frac{1}{\rho}} \times \frac{\rho\sigma f}{\bar{a}} \times e^{\frac{1}{2}} \times \left[\bar{z}(t)\left(1-\rho\bar{z}(t)\right)^{-\frac{1}{\rho}} e^{\bar{z}(t)^2 - T(t)^2}\right], \tag{4.36}$$

and

$$U_N(t) = \left(\frac{L_N}{\sigma f}\right)^{\frac{1}{\rho}} \times \frac{\rho\sigma f}{\bar{a}} \times e^{\frac{1}{2}} \times \left[\left(1-\rho\bar{z}(t)\right)^{1-\frac{1}{\rho}} e^{\bar{z}(t)^2 - T(t)^2}\right]. \tag{4.37}$$

Dynamics of welfare in the South Examining the South's consumer welfare indicated by (4.36), it is found that the utility level enjoyed by Southern consumers keeps increasing since the initial time $t = 0$ (i.e., $\frac{dU_S(t)}{dt} > 0$), until global production reaches the steady state.[17] Therefore, for the South, although the world output of each brand may experience a decline over time, the other two effects, i.e., the income effect and the variety effect, are positive and dominate the evolution.[18] With increasing income and a growing number of varieties, the South keeps enjoying welfare improvements while taking more and more production tasks. In the long run, the national welfare of the South reaches its steady state:

$$U_S^* = \frac{L_S}{L_S + L_N} \times \left(\frac{L_S + L_N}{\sigma f}\right)^{\frac{1}{\rho}} \times \frac{\rho\sigma f}{\bar{a}} \times e^{\frac{1}{2}}. \tag{4.38}$$

Dynamics of welfare in the North For the North, the situation is different. Among the three effects, the national income decreases for the North, which can be seen from (4.24′). The per-variety output also decreases when global production gets close to the steady state. The only effect that keeps experiencing positive growth is the number of varieties. By examining (4.37), it is found that the national welfare of the North may be non-monotonic over time. There is a threshold $\tilde{z}_{UN}$ that serves as a stationary point. If the offshoring threshold ($\bar{z}(t)$) is right at $\tilde{z}_{UN}$, it is the case that $\frac{dU_N(t)}{dt} = 0$. When less than $\tilde{z}_{UN}$ tasks are allocated to the Southern plants for completion ($\bar{z}(t) < \tilde{z}_{UN}$), the consumers in the North experience growth in their utility ($\frac{dU_N(t)}{dt} > 0$). In contrast, when more than $\tilde{z}_{UN}$ tasks are offshored ($\bar{z}(t) > \tilde{z}_{UN}$), the Northern welfare declines over time ($\frac{dU_N(t)}{dt} < 0$). This stationary point is further found to be higher than $\tilde{z}_y$.[19]

[17] See Appendix B.4.1 for proof.
[18] This could be seen from conditions (4.23′), (4.28) and (4.30).
[19] See Appendix B.4.2 for proof.

Therefore, after the per-brand output reaches the peak amount and when it starts to decline, the consumers in the North can still enjoy an increasing utility for an extended period of time, during which the variety effect dominates the other two, while both the national income and the production of each variety decrease. Consequently, Northern consumers' utility has two possible different evolution paths. In the first case, the South initially receives relatively few tasks, with $\bar{z}(0) < \tilde{z}_{UN}$. The variety effect, possibly with a positive output effect, is significant so that the Northern consumers get increasingly better off in the short run. This trend is reversed after more than $\tilde{z}_{UN}$ tasks are offshored. The other possible path happens when the Southern plants obtain a relatively large range of activities initially beyond $\tilde{z}_{UN}$, which will lead the North to experience persistent declines in welfare until the steady state is reached. No matter which path is realized, the steady-state level of Northern welfare is

$$U_N^* = \frac{L_N}{L_S + L_N} \times \left(\frac{L_S + L_N}{\sigma f} \right)^{\frac{1}{\rho}} \times \frac{\rho \sigma f}{\bar{a}} \times e^{\frac{1}{2}} \tag{4.39}$$

in the long run. Compared with the initial level $U_N(0)$, the long-run steady-state welfare U_N^* is not necessarily higher or lower. The interaction among the three effects, as well as the initial situation, determines where the final case is.

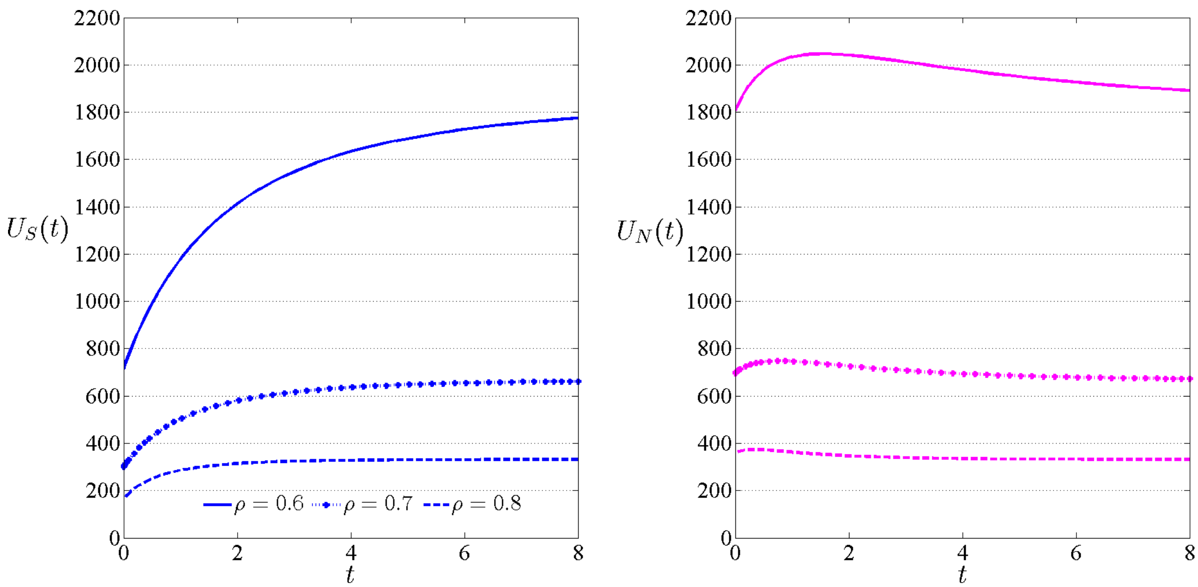
Figure 4.8 displays results from simulations with different parameter values. Panel A displays how the variety substitutability may affect the two countries' welfare dynamics. For both countries, the lower the substitutability is, the higher the long-run welfares are at the steady state. This implies that consumers' love for variety is important in the sense that it can strengthen and enlarge the variety effect on national welfare, which is always positive for both countries among the three. Panel B shows the situations with different relative Southern labor endowments. The results show that a larger South engaging in offshoring can bring both countries higher welfares. Thus, for technologically advanced countries, it is to their benefit to cooperate with developing countries with relatively large factor supplies. Compared with small ones, a large developing host country has more resources that can be devoted to learning in global production,[20] which empowers a

[20] Consider that the offshoring threshold at the steady state is relatively high.

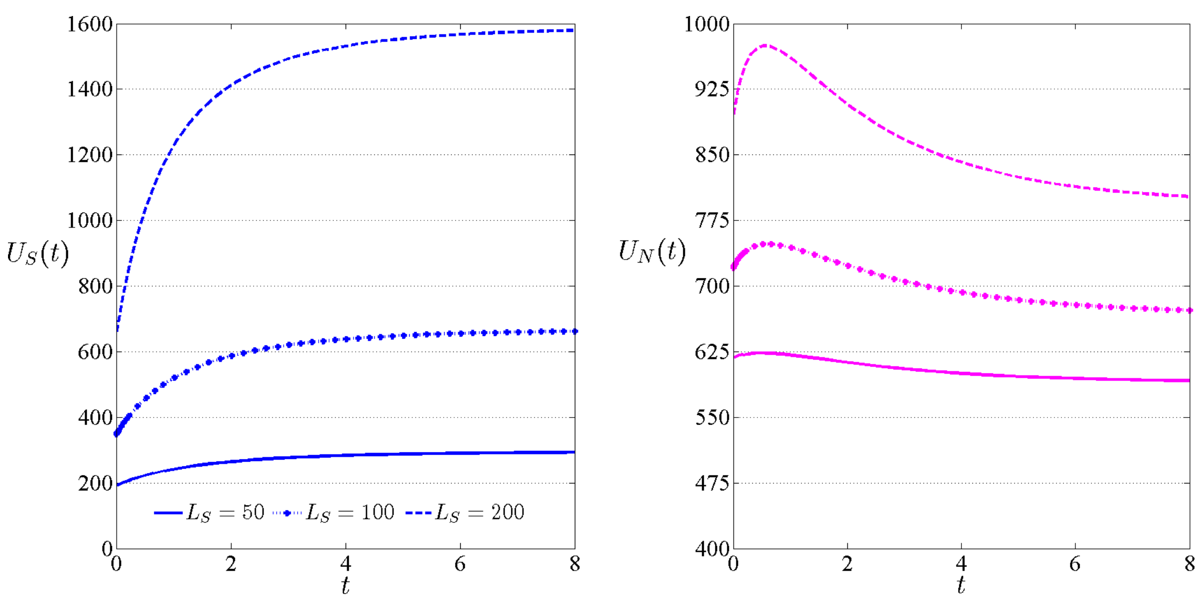
bigger improvement in technologies. This will lead to more products and varieties being produced and thus to a higher national welfare.

Figure 4.8: Dynamics of National Welfare under Normal Evolution ($T(0) < z^* \leq 1$): Simulations

(a) Panel A: Variety Substitutability
Note: $L_S = 100$; $L_N = 100$; $\beta = 0.3$; $f = 1$; $T(0) = 0.01$; $\bar{a} = 1$



(b) Panel B: Size of the South
Note: $L_N = 100$; $\beta = 0.3$; $\rho = 0.7$; $f = 1$; $T(0) = 0.1$; $\bar{a} = 1$



4.3.5 Extreme-End Evolution

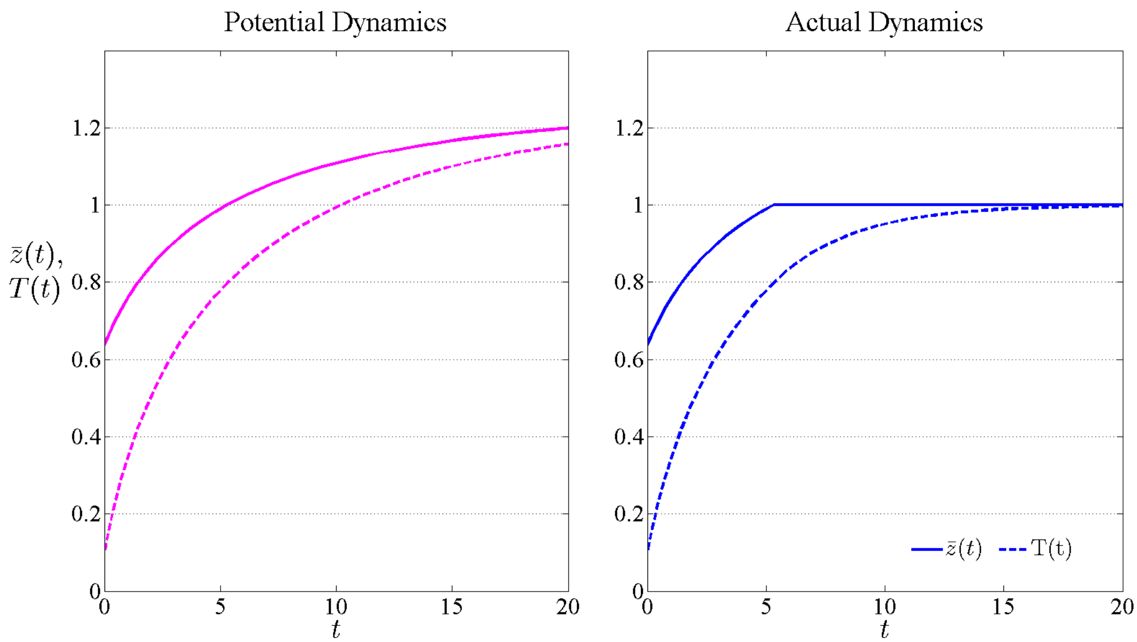
In the case of extreme-end evolution, the potential steady state z^* is beyond the range of offshorable tasks ($z^* > 1$), which thus leads the actual steady state of global production to be $z^{*\prime} = 1$ in the long run. The most sophisticated offshorable task serves as the upper bound of offshoring, where global production saturates. Therefore, all offshorable tasks will be offshored to the South in the long run under this circumstance – theoretically, a situation that may happen if the South is sufficiently abundant in production factors relative to the North. The North will then focus solely on the non-offshorable activities.

Task Offshoring Dynamics The dynamics of variables are essentially variations of the normal-evolution situation. With both the South's initial technology stock $T(0)$ and the initial offshoring threshold $\bar{z}(0)$ within the task range $(0, 1)$, all aspects of the two economies behave as if the steady state is z^* at the beginning. Thus, the dynamics of task offshoring at first displays a pattern of convergence similar to the corresponding one discussed in the normal-evolution case. Once all offshorable tasks have been allocated to the South ($\bar{z}(t_z) = 1$), further offshoring will not happen. However, the South's technical capability will continue improving for some time, until it matches the range of tasks offshored ($T(t^{*\prime}) = 1, \text{with } t^{*\prime} > t_z$). The evolution paths of task offshoring and technology stock are shown in Figure 4.9. The left panel displays the potential dynamics if the offshorable tasks' range could go beyond $z = 1$. The right panel shows the actual dynamics of the technology stock $T(t)$ and the offshoring threshold $\bar{z}(t)$ over time. Offshoring stops progressing when the offshoring threshold reaches the upper bound. After that, the South's technological capability continues improving, although the speed of learning is lower compared with the potential case.[21] The actual steady state will be arrived at when the technology stock in the South matches the offshoring pattern ($T^{*\prime} = z^{*\prime} = 1$).

Factor Price and Number of Varieties Consider other variables characterizing the economies, such as the wage rates and the number of varieties. At first, before the South obtains all offshorable activities to conduct ($\bar{z}(t) < 1$), they all follow the same corresponding paths of

[21] This can be understood by examining equation (4.26).

Figure 4.9: Task Dynamics under Extreme-End Evolution ($z^* > 1,\ z^{*\prime} = 1$)
Note: $L_N = 100\,; L_S = 100\,; \beta = 0.3\,; \rho = 0.4\,; f = 1\,; T(0) = 0.1$



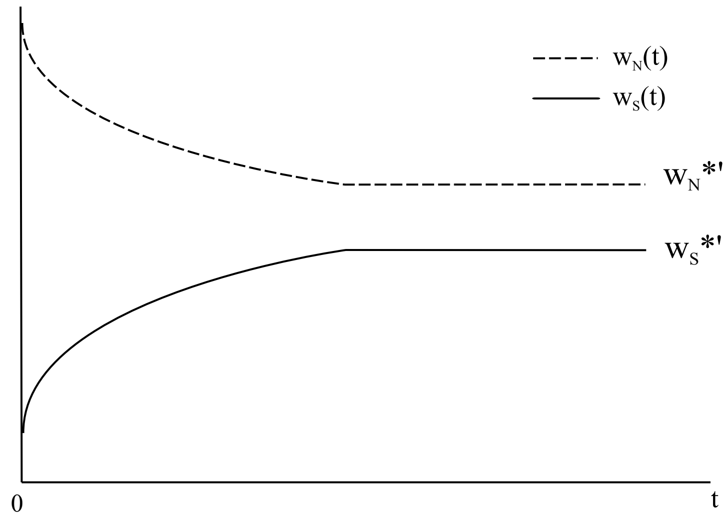
evolution as what they would experience if the task range could go beyond $z = 1$. Then when all offshorable tasks are moved to the South, the wage rates in the two countries stop changing. Thus, their evolution paths are not smooth – the time when offshoring hits its upper limit is a singular point when the wage rates reach their bounds and also their final steady states. Given that $z^{*\prime} = 1$, the factor prices in the long run are $w_S^{*\prime} = \frac{\rho}{L_S}$ and $w_N^{*\prime} = \frac{1-\rho}{L_N}$ respectively, with $w_S^{*\prime} < w_N^{*\prime}$.[22] Therefore, the factor-price-equalization condition is not achieved in this case. For the number of varieties, the situation is similar. It stops growing once all offshorable tasks are allocated to the Southern plants. With all Northern efforts solely spent on non-offshorable activities, the total number of varieties on the market is given by $J^{*\prime} = \frac{L_N}{f}$ in the long run. Figure 4.10 presents the evolution paths for wage rates and for the number of varieties.

Output and Welfares Production efficiency is the key factor determining output and thus national welfare levels. After the offshoring threshold stops moving further, the learning effect continues being positive in the South for some time, but is weaker than it would be if there was no

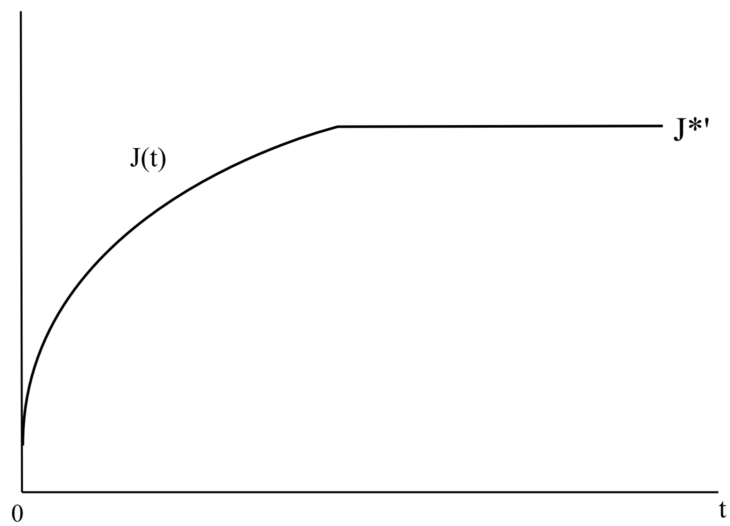
[22] Consider that $z^* = \frac{L_S}{\rho(L_S+L_N)} > 1$ in this case.

Figure 4.10: Dynamics of Wage Rates and Number of Varieties under Extreme-End Evolution ($z^* > 1,\ z^{*\prime} = 1$)

(a) Panel A: Dynamics of Wage Rates



(b) Panel B: Dynamics of Number of Variety



compulsory limit on offshoring. This weaker-than-potential learning effect keeps driving production aspects of the economies to their long-run steady states. In Section 4.3.4, it has been shown that the growth path of per-variety output may be non-monotonic. The situation is similar under the circumstance here. When both countries participate in offshorable activities ($\bar{z}(t) < 1$), the growth path of the per-variety output is the same as if it is moving towards the potential steady state z^*, and it may or may not show positive growth in the short-run. When all offshorable tasks have been allocated to the South ($\bar{z}(t) = 1$), the per-brand output starts to be described by[23]

$$Y(t)' = \frac{L_S f}{L_N \bar{a}} \times e^{-(T(t)-1)^2 + \frac{1}{2}} , \tag{4.40}$$

which increases over time while the South improves its technology.[24] In the long run, it converges to its steady state

$$Y^{*\prime} = \frac{L_S f}{L_N \bar{a}} e^{\frac{1}{2}} , \tag{4.41}$$

when the South has possessed the most advanced technologies for all tasks. Compared with the normal-evolution case, if the South takes all offshorable production responsibilities, in the long run, there will be more brands on the market($J^{*\prime} > J^*$), while less of each is supplied ($Y^{*\prime} < Y^*$).

With regard to national welfare, before the offshoring threshold $\bar{z}(t)$ reaches the most sophisticated offshorable task, like in the normal-evolution case, the South experiences positive growth since the very beginning of engaging in global production, while the North may see different possible patterns of growth over time. However, during the period of time when all tasks have been offshored and the South is still learning ($\bar{z}(t) = 1$ and $T(t) < 1$), both countries will experience welfare growth. Specifically, with the per-brand output expression derived above, during this time period, the national welfares of the two countries are, respectively,

$$U_S(t)' = \rho \times \left(\frac{L_N}{f}\right)^{\frac{1}{\rho}-1} \times \frac{L_S}{\bar{a}} \times e^{-(T(t)-1)^2 + \frac{1}{2}} , \tag{4.42}$$

and

$$U_N(t)' = (1-\rho) \times \left(\frac{L_N}{f}\right)^{\frac{1}{\rho}-1} \times \frac{L_S}{\bar{a}} \times e^{-(T(t)-1)^2 + \frac{1}{2}} . \tag{4.43}$$

Both of them will be increasing monotonically while $T(t) < 1$ and $\frac{dT(t)}{dt} > 0$. When the South's technology stock covers the most sophisticated task, the welfares converge to their steady states:

$$U_S^{\star\prime} = \rho \left(\frac{L_N}{f}\right)^{\frac{1}{\rho}-1} \frac{L_S}{\bar{a}} e^{\frac{1}{2}} , \tag{4.44}$$

[23] See Appendix B.5.1 for derivation of (4.40).
[24] See Appendix B.5.2 for proof.

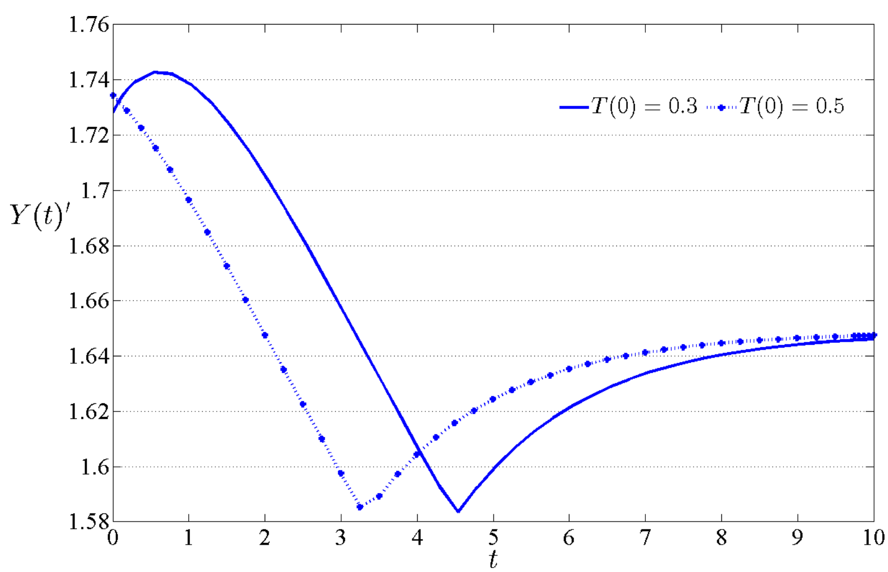
and

$$U_N^{\star\prime} = (1-\rho)\left(\frac{L_N}{f}\right)^{\frac{1}{\rho}-1}\frac{L_S}{\bar{a}}e^{\frac{1}{2}}\,. \tag{4.45}$$

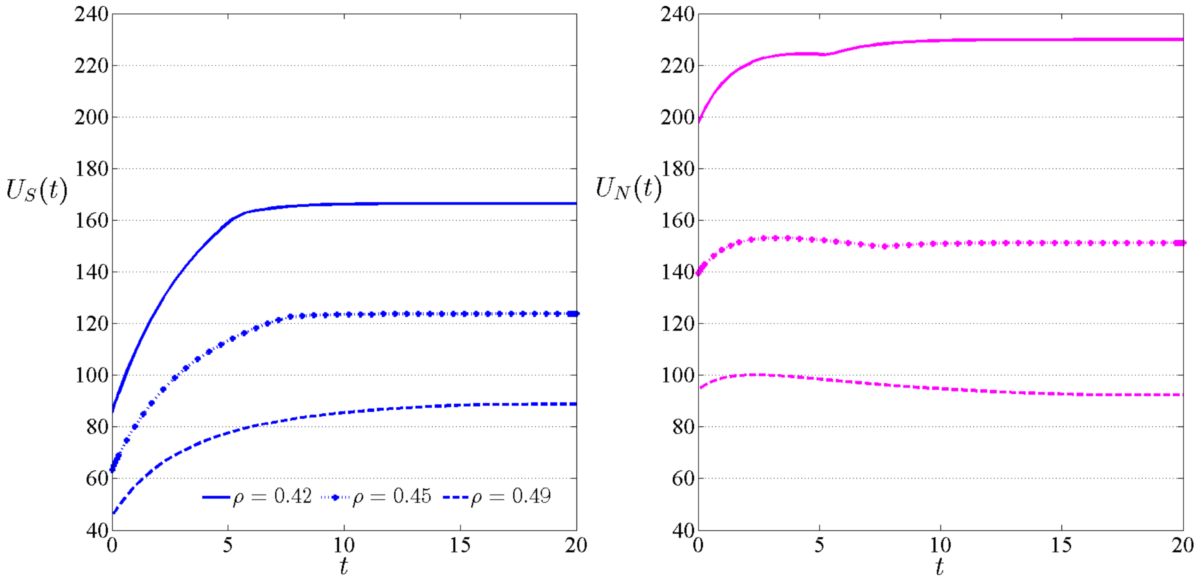
With the discussion above and in Section 4.3.4, it is found that during the process of evolving, the South continues seeing welfare improvement, although the speed of improvement may decrease. For the North, the overall path of welfare development may be non-monotonic. Numerical simulations are performed for per-brand output as well as for national welfares. The results are shown in Figure 4.11. Panel A displays the simulation results for the per-brand output. After all manufacturing tasks are offshored to the South, the learning effect stimulates another round of output growth. For the national welfare results displayed in Panel B, the South sees positive increases in national utility during the whole evolution process. For the North, although the initial growth pattern is uncertain, after all manufacturing tasks are taken by the South, the country will also experience positive growth – the learning effect will benefit both countries by increasing the output of each brand.

Figure 4.11: Dynamics of Output and Welfares under Extreme-End Evolution ($z^* > 1,\ z^{*\prime} = 1$)

(a) Panel A: Dynamics of Per-Brand Output
Note: $L_S = 100;\ L_N = 100;\ \beta = 0.3;\ \rho = 0.4;\ f = 1;\ \bar{a} = 1$



(b) Panel B: Dynamics of National Welfares
Note: $L_S = 10;\ L_N = 10;\ \beta = 0.3;\ f = 1;\ T(0) = 0.3;\ \bar{a} = 1$



4.3.6 Static Equilibrium Cases

Except for the dynamic situations where countries see evolutions of their multinational operations, there are two other static equilibrium possibilities: Case III – static normal offshoring, in which the South's initial technology stock is sufficiently high so that global production reaches its normal steady state $z^* \in (0, 1)$ at the initial time $t = 0$; and Case IV – static complete offshoring, where since the very beginning, the South is essentially the same as the North in terms of technology ($T(0) = 1$), and the factor endowment of the South is abundant so that all offshorable tasks are moved to the South since $t = 0$.

The static normal offshoring situation is likely to happen if the South is technically capable and relatively small in size, so that $T(0) \geq z^*$. When this situation prevails, there will be no room for the South to learn, as the country is not working on any activity at which it is not already skilled. Therefore, the world equilibrium stays at z^* since $t = 0$, with all other aspects of the two economies at their steady states since the initial time.

The other static case is essentially a multinational production situation with two countries equally advanced in terms of technology on conducting the offshorable activities. The South is relatively large such that $z^* > 1$ and $\bar{z}(0) = 1$. If this is the case, then the country with abundant factor endowment will be specializing in offshorable tasks, while the other one puts all efforts on the non-offshorable activities. Learning is not present here as both countries already possess the best technologies since the beginning. Therefore, this pattern of specialization will hold as long as factor supplies remain stable. The two economies are at the steady states characterized by $z^{*\prime} = 1$.

4.4 Gains from Offshoring

The discussion so far focuses on the time dynamics of offshoring evolution. It has been shown that compared with the initial situation when the two countries start engaging in offshoring, the South becomes increasingly better off over time, while the North may or may not see a higher welfare level at the long-run steady state. Then the question becomes whether the countries should participate in global production by offshoring or accepting offshored activities, or they should remain closed and supply all products domestically.

4.4.1 Equilibrium under Autarky

The consumer preferences are still identical in the two countries under autarky, described by the same C.E.S. function (4.1). The production of goods, as well as the two countries' production technologies, is also the same as defined in Section 4.1.3. Namely, the two economies start with the situations under autarky the same as under offshoring. Under autarky, countries do not have information about each other, and thus they are not able to acknowledge their technological differences in production. Without seeing the gap, the South does not have incentives to learn, though it conducts all the activities under this circumstance. Therefore, under autarky, there is no production efficiency improvement over time like what we have seen under offshoring. Since countries' behaviors do not change over time, the time index t can be omitted here.

In autarky, both countries have to conduct all activities on the task range $[0, 1]$ to produce the final goods, and both of them also need to pay the fixed costs, which are assumed to be the same (f), to make the products viewable on the market. Let E_i^A denote the national expenditure on final products in country i under autarky, defined as the sum of factor payments in that country:

$$E_i^A = w_i^A L_i \, , \; i \in \{N, \, S\} \, , \tag{4.46}$$

where w_i^A denotes the autarky wage rate of country i.

Assume that the fixed cost is the same across countries: $f_S = f_N = f$. The labor market clearing conditions for the two economies under autarky are given by

$$\begin{aligned} \textit{South}: \; & \int_0^1 x_S^A(z) a(z,0) dz + J_S^A f = L_S \, , \\ \textit{North}: \; & \int_0^1 x_N^A(z) \bar{a}(z) dz + J_N^A f = L_N \, , \end{aligned}$$

where $x_i^A(z)$ denotes the total amount of task z conducted in country i by all firms there, and J_i^A denotes the number of brands on the market in country i, both under autarky. The task demands can be expressed as:

$$\begin{aligned} x_S^A(z) &= \frac{\rho E_S^A}{w_S^A a(z,0)} = \frac{\rho L_S}{a(z,0)} \, , \\ x_N^A(z) &= \frac{\rho E_N^A}{w_N^A \bar{a}(z)} = \frac{\rho L_N}{\bar{a}(z)} \, . \end{aligned}$$

With the task demands, the labor market clearing conditions become:

$$\textit{South}: \; \int_0^1 \rho L_S dz + J_S^A f = L_S \, , \tag{4.47}$$

$$\textit{North}: \; \int_0^1 \rho L_N dz + J_N^A f = L_N \, . \tag{4.48}$$

The numbers of varieties in the two domestic markets thus are:

$$J_i^A = \frac{L_i}{\sigma f} \, , \; i \in \{N, \, S\} \, . \tag{4.49}$$

Given the production function (4.7), together with the task demand expressions, technology specifications (4.8) and (4.9), and condition (4.49), the per-brand outputs under autarky are found to be

$$Y_S^A = \frac{\rho \sigma f}{\bar{a}} \times e^{-(T(0)-1)^2 + \frac{1}{2}} \, , \tag{4.50}$$

and

$$Y_N^A = \frac{\rho\sigma f}{\bar{a}} \times e^{\frac{1}{2}} \,. \tag{4.51}$$

Together with the number of varieties J_i^A, this implies that the national utility levels of the two countries are, respectively,

$$U_S^A = \left(\frac{L_S}{\sigma f}\right)^{\frac{1}{\rho}} \times \frac{\rho\sigma f}{\bar{a}} \times e^{-(T(0)-1)^2+\frac{1}{2}} \,, \tag{4.52}$$

and

$$U_N^A = \left(\frac{L_N}{\sigma f}\right)^{\frac{1}{\rho}} \times \frac{\rho\sigma f}{\bar{a}} \times e^{\frac{1}{2}} \,, \tag{4.53}$$

which remain constant over time.

4.4.2 Gains from Normal Offshoring

Under normal offshoring, global production is characterized by the participation of both countries in offshorable tasks, in the short run as well as in the long run. During the process of normal evolution, the national welfares are given by (4.36) and (4.37).

Gains of the South For the South, comparing the welfare under offshoring and the welfare under autarky, it is found that

$$\frac{U_S(t)}{U_S^A} = \left[\frac{L_N}{L_S} \times \frac{1}{1-\rho\bar{z}(t)}\right]^{\frac{1}{\rho}} \times \left[\rho\bar{z}(t) \times e^{\bar{z}(t)^2-T(t)^2} \times e^{(T(0)-1)^2}\right] \,. \tag{4.54}$$

Countries' welfare levels essentially depend on the number of varieties available on the market and the consumption or output of each product. The first term of the equation above indicates the *variety effect* (the extensive margin), while the second implies the *output (or consumption) effect* (the intensive margin).

When the South opens to offshoring, the Southern labor that was working on non-offshorable tasks is withdrawn and reassigned to conduct the offshored activities. Therefore, the number of goods available is no longer totally determined within the country, while the North takes over certain responsibilities. This international shift of non-offshorable efforts brings uncertainty with regard to whether the developing country can enjoy more variety options initially when countries start to engage in global production. During the initial stages when offshoring starts, the South may or may not be able to obtain the same number of varieties as they could under autarky. Then as time elapses, the situation improves. While more and more tasks are reallocated to the South which enables more Northern efforts to be put on non-offshorable activities, both countries' consumers can enjoy more variety options over time. In the long run, it is found that $\frac{J^*}{J_S^A} = \frac{L_S+L_N}{L_S} > 1$, which indicates that with offshoring and learning, the Southern consumers will enjoy more varieties than they could under autarky. By participating in global production, the South not only obtains better technologies, but also enjoys more options for consumption. This variety effect contributes to the long-run welfare gain of the country.

Concerning the output effect, it is not definite that the South can enjoy more consumption on each brand at the initial time when it starts producing for the whole world. The output also depends on the North's conditions. In the long run, the output effect indicated by the second term of (4.54) turns out to be indefinite as well.[25]

Combining the two effects, both the variety and the output effects, it is found that

$$\frac{U_S^*}{U_S^A} = \left[\frac{L_S + L_N}{L_S}\right]^{\frac{1}{\rho}-1} \times e^{(T(0)-1)^2} > 1\,. \tag{4.55}$$

Therefore, although the gain from engaging in global production is not definite for the South in the short run, it will certainly benefit the South in the long run. This is different from the offshoring case under perfect competition discussed in Chapter 3, where the South sees gains in both the short run and the long run. By accepting offshored activities and by learning in the process of conducting them, the South under monopolistic competition may experience short-run pains, but it will end up enjoying more consumption choices, which dominates the other welfare effect.

Gains of the North Consider the situation for the North. By comparing (4.37) and (4.53), it is the case that

$$\frac{U_N(t)}{U_N^A} = \left[\frac{1}{1-\rho\bar{z}(t)}\right]^{\frac{1}{\rho}} \times \left[(1-\rho\bar{z}(t)) \times e^{\bar{z}(t)^2 - T(t)^2}\right] > 1\,, \tag{4.56}$$

[25] When the global economy reaches the steady state z^*, the second term becomes: $\rho z^* \times e^{(T(0)-1)^2} = \frac{L_S}{L_S+L_N} \times e^{(T(0)-1)^2}$, which is not necessarily greater or less than 1.

which is greater than 1 since the initial time of offshoring ($t = 0$). The first term in the equation is the variety effect for the North, while the second indicates the consumption or output effect.

By relocating low-sophistication tasks to the South, the North is able to produce more varieties since the very beginning of offshoring. Thus, the variety effect is positive initially and will continue strengthening over time as more and more production tasks are offshored. The other one, the per-brand consumption effect, is not deterministic for the North, but it is dominated by the variety effect, which then leads to the situation where the North overall is better off than under autarky since the start of engaging in global production. In the long run, the utility comparison shows that the North ultimately benefits from offshoring:

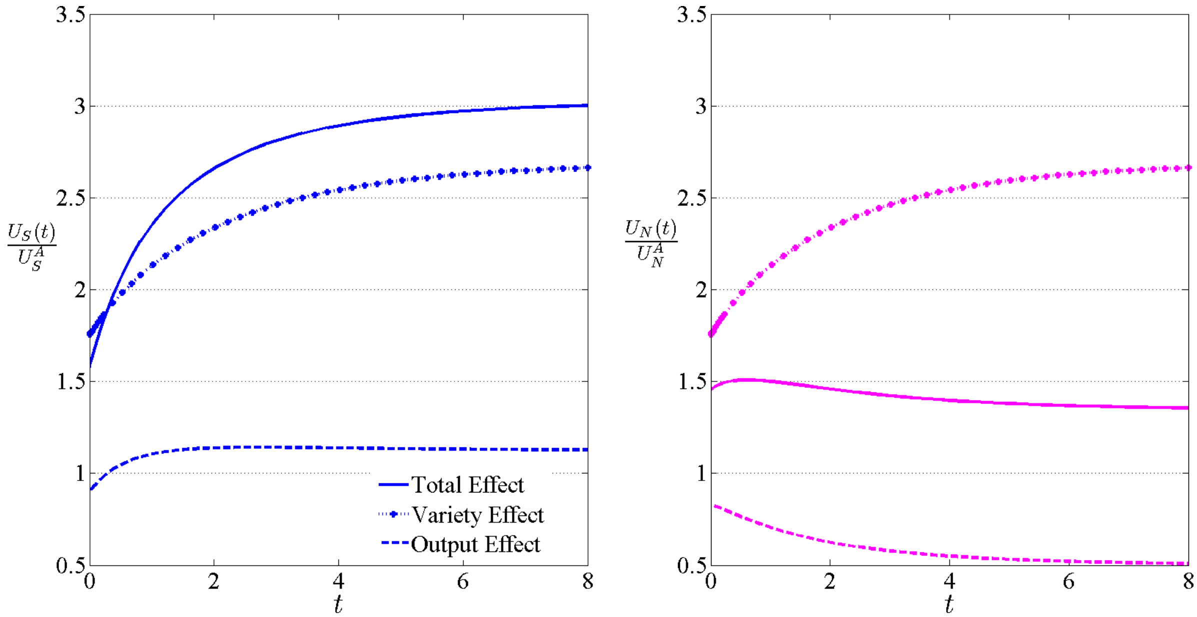
$$\frac{U_N^*}{U_N^A} = \left[\frac{L_S + L_N}{L_N}\right]^{\frac{1}{\rho}-1} > 1. \tag{4.57}$$

In sum, from the analyses above, participating in global production is beneficial for both countries. Even if they may experience short-term challenges when they initially join in the global production network and/or during the process in which they are evolving to the steady state, they both will ultimately see positive gains and rewards from offshoring. The results from simulations clearly demonstrate this pattern, and are shown in Figure 4.12. In the simulation, although both countries initially experience a cut in per-brand consumption when they join in global production, they do see welfare gains in the long run compared with autarky. This also further confirms that for the static normal offshoring case, although learning is not present, both countries can still earn positive gains by forming a multinational production network.

4.4.3 Gains from Extreme-End Offshoring

In the case of extreme-end offshoring, in the long run, all offshorable tasks are ultimately allocated to the South. During the process of evolution, as discussed in the previous section, the South may experience short-run challenges while the North is always better off compared with the autarky situation. Consider the long-run welfare at the steady state. By comparing (4.44) and

Figure 4.12: Welfare Gains from Offshoring: Normal Evolution
Note: $L_S = 100$; $L_N = 100$; $\beta = 0.3$; $\rho = 0.7$; $f = 1$; $T(0) = 0.1$; $\bar{a} = 1$



(4.52), as well as (4.45) and (4.53), it is the case that

$$\frac{U_S^{*\prime}}{U_S^A} = \left(\frac{L_N}{L_S} \times \frac{1}{1-\rho} \right)^{\frac{1}{\rho}-1} \times e^{(T(0)-1)^2}, \tag{4.58}$$

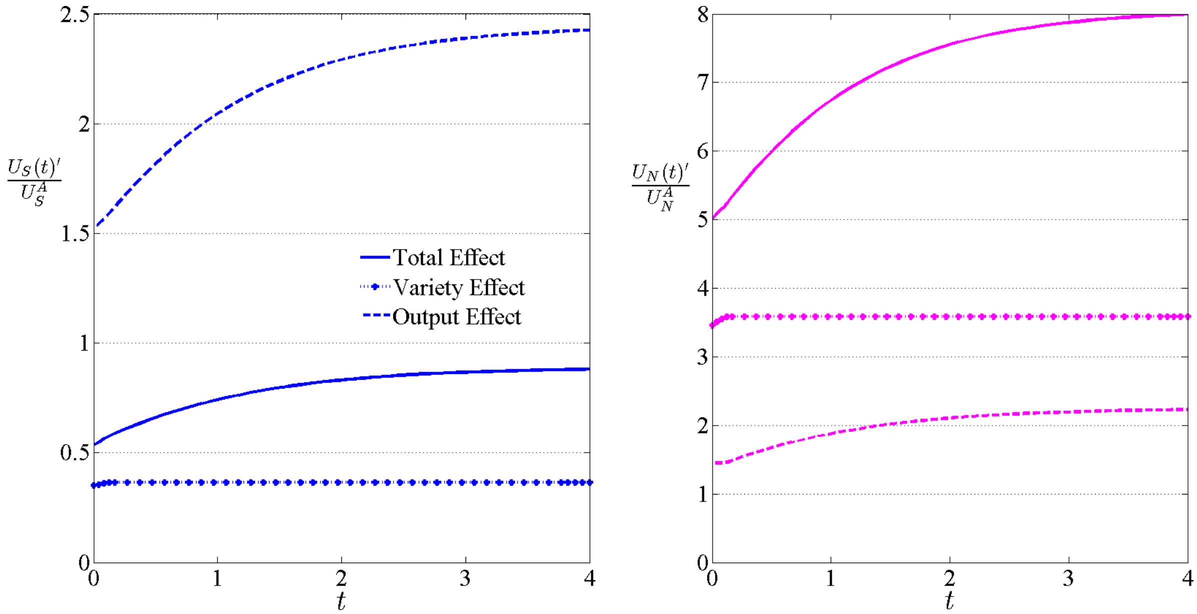
and

$$\frac{U_N^{*\prime}}{U_N^A} = \frac{L_S}{L_N} \times \frac{1}{\rho} \times (1-\rho)^{2-\frac{1}{\rho}}. \tag{4.59}$$

Close examinations show that on one side, there is no deterministic relationship between $U_S^{*\prime}$ and U_S^A, which implies that with extreme-end offshoring, although all offshorable tasks are ultimately moved to the South, the country does not necessarily gain from producing for the whole world. The main reason is that the variety effect is found not to be necessarily significant in the long run in this case.[26] On the other side, the North does see welfare gains from offshoring in the long run ($\frac{U_N^{*\prime}}{U_N^A} > 1$).[27] Figure 4.13 displays the results of the simulations, which clearly show the patterns discussed here.

[26] $\frac{J^{*\prime}}{J_S^A} = \sigma \times \frac{L_N}{L_S}$, which is not necessarily greater than 1 here.
[27] See Appendix B.6 for proof.

Figure 4.13: Welfare Gains from Offshoring: Complete Offshoring
Note: $L_S = 10$; $L_N = 4$; $\beta = 0.2$; $\rho = 0.4$; $f = 1$; $T(0) = 0.3$; $\bar{a} = 1$



4.5 Concluding Remarks

Given the basic model introduced in Chapter 3, this chapter examines the global production dynamics within a monopolistic competition environment. The model provides rich descriptions on various economic aspects. First, both countries move up the global production and value chain through learning-by-doing in the South, with subsidiaries in the South conducting more and harder tasks and subsidiaries in the North increasingly concentrating on the most sophisticated activities and the non-offshorable responsibilities. It is also possible that all offshorable tasks are moved to the technologically less-advanced country under this framework.

Secondly, the offshoring dynamics that occur through learning give rise to changes in other aspects of the global economy, such as factor prices and number of varieties on the market. While consumers will enjoy more and more consumption options as more firms join the competition, the output of each firm may not display a monotonic increasing pattern. Considering also the factor price effects, the welfare dynamics can be quite different for countries.

Welfare analysis is thus an important issue that this chapter looks at. Different from the situation under perfect competition, under normal offshoring here, the South does *not* necessarily gain in the short run by accepting offshoring. It may be the case that the developing country experiences a short-run pain by participating in global production – it gives up its authority on variety-determination and hands it over to the developed country by agreeing to produce for Northern brands, and this may lead to a welfare loss for the South during the initial stages of offshoring. In the long run, however, the learning effect will lead the South to be better off than its autarky situation. Meanwhile, the North enjoys a higher welfare level since the beginning of offshoring, and it continues in the long run. Thus, although both parties are rewarded by forming the multinational production chain, their paths of welfare dynamics can be quite different. What is noteworthy here is the complete-offshoring situation, where all offshorable responsibilities are taken over by the South. In this case, the South may not gain even in the long run, while the North always benefits.

Chapter 5

Moving Up the Global Value Chain: Evidence from China

As presented in Chapter 3 and 4, the global value chain of an industry is described as a sequence of tasks that may be fragmented and spread across countries, with each task adding value to the final product. Countries' respective contributions to the final product can thus be associated with the sets of tasks they carry out. A central prediction of the theories presented is that multinational production converges to a steady state where no further offshoring happens. During this evolution process, the national contribution of value-added as well as the national share of world income is dynamically redistributed between countries – the Southern part increases while the Northern part decreases, and the speed of redistribution declines over time. In fact, the convergence of the Southern value-added portion essentially and exactly maps the convergence pattern of task-offshoring. Therefore, the theory offers a convenient prediction as to how the South's share of value-added in an industry should behave over time: "moving up the global value chain" translates into an increasing Southern share of value added in total value of industrial output over time, while the speed of moving up declines gradually.

In this chapter, a micro-founded approach is applied to empirically examine the dynamics of the value-added ratio (VR) of global production contributed by the South (i.e. the host country's share of value added). By using a dataset on China's multinational operations spanning 10 years, the evolution pattern of industry-level VR is examined. The VR change of multinational operation is analyzed at the industry level, and the aggregate VR change is further decomposed into a within-subsidiary margin and a cross-subsidiary margin, with convergence testing pursued for these two margins respectively. The results show that convergence evidences are present, and the industrial VR dynamics are mainly driven by changes within subsidiaries.

The rest of the chapter is organized as follows. In Section 5.1, I review the theoretical predictions on VRs of multinational production. Section 5.2 discusses the empirical approach. Data description is presented in Section 5.3, and empirical results are presented in Section 5.4. I give a brief conclusion summary for this chapter in Section 5.5.

5.1 Review of the Theoretical Prediction

The evolution process of multinational production involves a shift of value added in the final industrial product from the North to the South. According to the monopolistic competition model presented in Chapter 4, the final output value of an industry within global production is given by

$$J(t)p(j,t)Y(j,t) = w_S(t)L_S + w_N(t)L_N \,, \tag{5.1}$$

with all tasks contributing value to the final product. Within the final industrial output value, the contribution shares of the two countries are, respectively,

$$\mathrm{VR}_N(t) = \frac{w_N(t)L_N}{p(j,t)Y(j,t)J(t)} = 1 - \rho\bar{z}(t) \,, \tag{5.2}$$

and

$$\mathrm{VR}_S(t) = \frac{w_S(t)L_S}{p(j,t)Y(j,t)J(t)} = \rho\bar{z}(t) \,, \tag{5.3}$$

which are defined as the value-added ratios (VR) hereafter. The growth pattern of the Southern value-added portion VR_S thus essentially and exactly maps the convergence pattern of task-offshoring in multinational production. As analyzed in Chapter 4, under normal offshoring, the task offshoring threshold $\bar{z}(t)$ grows and converges to its steady state z^* over time. Even in the case of extreme-end evolution, it goes through the convergence process first until it hits the upper limit of offshorable activities. Therefore, the theory actually provides a central prediction on VR_S – it increases over time at a decreasing rate.[1] "Moving up the value chain" thus translates into

[1] In the prefect competition model, the South's contribution of value-added displays the same pattern.

an increase in the South's share of value added in the total value of industrial output (VR_S) over time, and the rate of this increase declines gradually. This is the critical theoretical prediction and a testable hypothesis as to how the VR_S should behave over time. By considering each industry as a random draw of the representative industry presented in the model, I can thus test the theory and its prediction with regard to the dynamics of VR_S.

5.2 Empirical Approach

5.2.1 Data on Multinational Operations: the Usage

For a given Southern country that hosts multinational operations, the rest of the world is treated as a whole as an aggregate North. The investigation will mainly focus on the multinational subsidiaries in the host country. The main reason for focusing on multinational subsidiaries is that they are the closest approximations of global production operations examined in the theory. On one hand, in reality, although both vertical and horizontal offshoring patterns are present, a common acknowledgment is that multinational subsidiaries in a developing host country generally only conduct some of the production tasks, rather than replicating the whole complete production processes. Therefore, multinational subsidiaries provide a reasonable base for the empirical investigation of the theoretical model. On the other hand, certainly, domestic and local firms in a host country may also be involved in the global production network in some way, but distinguishing them is difficult, and their operations in fact may be mixed in many circumstances. Multinational subsidiaries thus serve as a better representation than local firms for global production in the South.

By focusing on multinational subsidiaries, local firms in a host country can serve as a countercheck. For domestic firms that are not multinational subsidiaries, the value-added ratios constructed from their performance data are not expected to follow the same convergence pattern of VR_S. Thus, examining local firms as a counter group can help to check whether the findings based on multinational subsidiaries represent a nation-wide trend or are specific to global production.

Multinational subsidiaries are aggregated at the industry level to form multinational industries (MIs), which closely approximate the concept of industry in the theory. It is not required that an MI in the South involves the very last task of producing final end-consumer products. For example, an MI may be defined as a "screen" industry while the very final consumer products are cellphones. Thus, an MI is an industry of multinational production where the industrial products come out in a given host country. The VR_S of an MI is thus computed as

$$\text{VR}_{S,i}(t) = \frac{\sum_{j\in\Omega_i(t)} p_j(t)y_j(t) - \sum_{j\in\Omega_i(t)} M_j(t)}{\sum_{j\in\Omega_i(t)} p_j(t)y_j(t)}, \tag{5.4}$$

where i and j are industry and firm indicators, respectively; $\Omega_i(t)$ is the set of subsidiaries in industry i in the host country; $p_j(t)y_j(t)$ stands for the value of output; and $M_j(t)$ denotes the value of intermediate inputs. Here, $M_i(t) = \sum_{j\in\Omega_i(t)} M_j(t)$ covers intermediate inputs from both domestic and foreign sources, since they are not different as non-value-added entities for the Southern MIs. The labor concept in the theory should be viewed as a composite factor of production in reality, which essentially contains all efforts that are used in production. VR_S will serve as the base variable in the empirical investigation.

5.2.2 Convergence of VR_S

Using panel data of MIs over a certain period of time, the convergence dynamics of VR_S can be examined (VR for short hereafter). Specifically, given the theoretical discussions, the convergence pattern of VR can essentially be characterized by

$$\Delta\text{VR}_{i,\tau} = \psi_1\text{VR}_{i,0} + \psi_2\beta_i + \psi_3\tau + \eta' X_{i,\tau} + \epsilon_{i,\tau}, \tag{5.5}$$

where β_i is the learning-ability indicator, τ is a time indicator starting from 1 for the first time period covered in the data, $X_{i,\tau}$ is a vector of control variables and $\epsilon_{i,\tau}$ is the error term. The theory predicts that $\psi_1 < 0$, $\psi_2 > 0$, and $\psi_3 < 0$. The specification (5.5) may be affected by the tendency of VR to mechanically revert to its mean. A negative shock at $\tau = 0$ may not have a persistent effect in following periods, which may lead to a spurious convergence captured by the regression. To address this concern, VR_i from different initial years are used for robustness checks.

5.2.3 Two Margins of Changes

In the theory, the convergence of task offshoring stems from the learning effect occurring at the firm level, which drives the progress of the whole industry. To investigate this idea, I decompose changes in VR into two margins: (1) the within-subsidiary margin, which captures the changes within subsidiaries with constant relative subsidiary sizes, and (2) the cross-subsidiary margin, i.e., the change in relative subsidiary size with subsidiaries' VR constant. An empirical pattern consistent with the theory is that the VR convergence of MIs is mainly driven by the first margin. The decomposition method is as follows:

$$\Delta \mathrm{VR}_{i,\tau} = \sum_{j\in\Omega_i} \Delta \mathrm{VR}_{j,\tau}\left(\frac{\lambda_{j,\tau}+\lambda_{j,\tau-1}}{2}\right) + \sum_{j\in\Omega_i} \Delta\lambda_{j,\tau}\left(\frac{\mathrm{VR}_{j,\tau}+\mathrm{VR}_{j,\tau-1}}{2}\right) , \quad (5.6)$$

where $\lambda_{j,\tau} = \frac{y_{j,\tau}}{y_{i,\tau}}$. The first term is the within-subsidiary margin, and the second is the cross-subsidiary margin. Both margins are examined using the regression (5.5).

The empirical approach can be applied to data on a Southern host country's multinational operations. It is desirable that the host country meets the following conditions: (1) being a host country for multinational production operations in multiple industries for a reasonably long time span, (2) regularly and consistently reporting subsidiary-level data that are representative of the multinational operations, and (3) reporting corresponding data with information on industrial classification, value-added, value of output and other industrial characteristics. It is ideal to use data on developing host countries that have abundant production factors and that host relatively large volumes of multinational operations – according to the theory, such countries are relatively far from their steady states in global production and thus the patterns can be easily detected. In the following section, I provide an empirical investigation using this approach with data from China on multinational operations there.

5.3 Data Description

The dataset used covers the population of large- and medium-sized industrial enterprises in China with annual revenues of five million RMB or more[2] , for a 10-year time span between 1998-2007. It is from the Annual Survey of Industrial Firms (ASIF) conducted by the National Bureau of Statistics of China, which is the main source of the industrial section of the China Statistical Yearbooks. Firms covered in ASIF account for more than 90 percent of the total industrial output and more than 70 percent of the industrial workforce of China.[3] The ASIF reports different types of firms such as state, private, and foreign firms. The foreign classification is further categorized by source of fund and ownership. Firms categorized as wholly foreign-owned (non-HMT[4]) enterprises are drawn from ASIF and defined as multinational subsidiaries here. Table 5.1 presents the summary statistics for multinational subsidiaries. During the 10 years covered, there were significant growths in multinational operations as indicated by the statistics. Their share of output in the whole manufacturing sector of China almost quadrupled from 1998 to 2007; the share of export almost tripled; and their mean VR rose from 0.265 to 0.301, a 13.6% increase over the 10 years.

Table 5.1: Summary Statistics of Multinational Subsidiaries

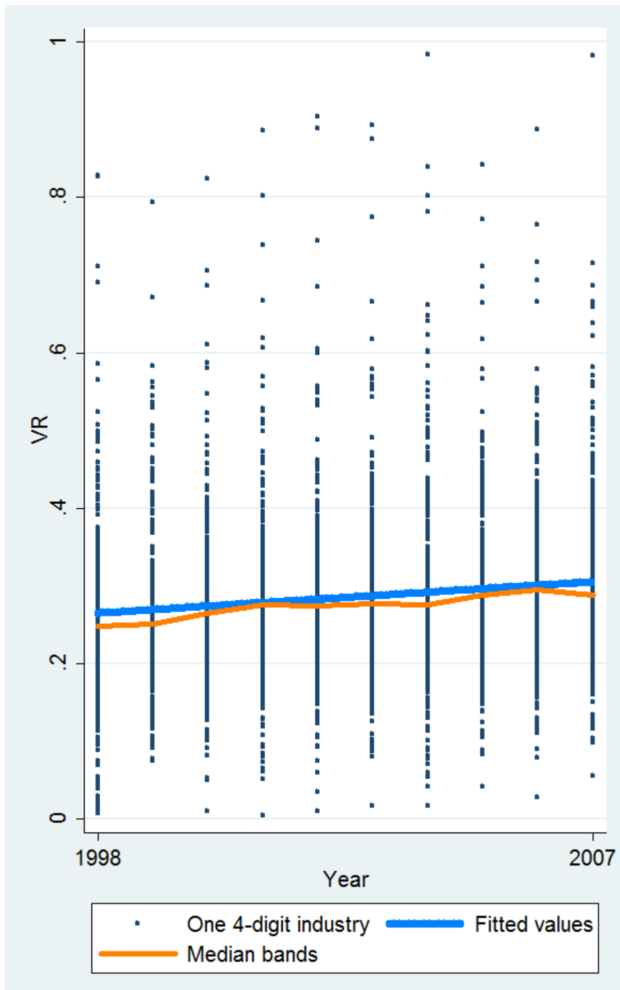
Year	Output			Value-Added			VA/Output Ratio		Export		
	Mean	S.D.	Share	Mean	S.D.	Share	Mean	S.D.	Mean	S.D.	Share
1998	79.64	516.92	3.13	18.51	119.90	2.47	0.265	0.161	50.36	250.83	12.30
1999	89.55	517.03	3.74	21.55	114.33	3.00	0.266	0.145	55.19	266.47	14.45
2000	109.30	650.07	4.60	27.66	177.61	3.88	0.277	0.15	65.09	305.54	16.00
2001	112.25	745.81	5.29	28.53	217.11	4.52	0.281	0.146	65.45	435.58	18.10
2002	129.44	961.53	6.34	32.03	253.44	5.23	0.283	0.151	79.82	703.03	21.55
2003	152.86	1,150	7.64	35.53	172.59	6.02	0.288	0.148	91.83	1,010	24.16
2004	143.79	1,160	9.49	32.67	218.91	7.61	0.286	0.169	90.00	980	29.51
2005	180.09	1,560	9.93	44.75	291.42	8.53	0.298	0.163	100.17	920	28.93
2006	208.53	1,770	10.68	52.40	353.12	9.27	0.304	0.163	121.08	1,550	32.01
2007	232.32	2010	11.05	54.551	292.73	9.21	0.301	0.16	133.39	1870	33.7

Nominal values are in current price RMB and the unit is 1 million.
Columns labeled "Share" refer to the share within the whole manufacturing sector of China.

[2] It approximately equals US$600,000 for the time period covered.
[3] See Brandt et al. (2012) for a more detailed and comprehensive discussion.
[4] HMT stands for Hong Kong, Macau, and Taiwan.

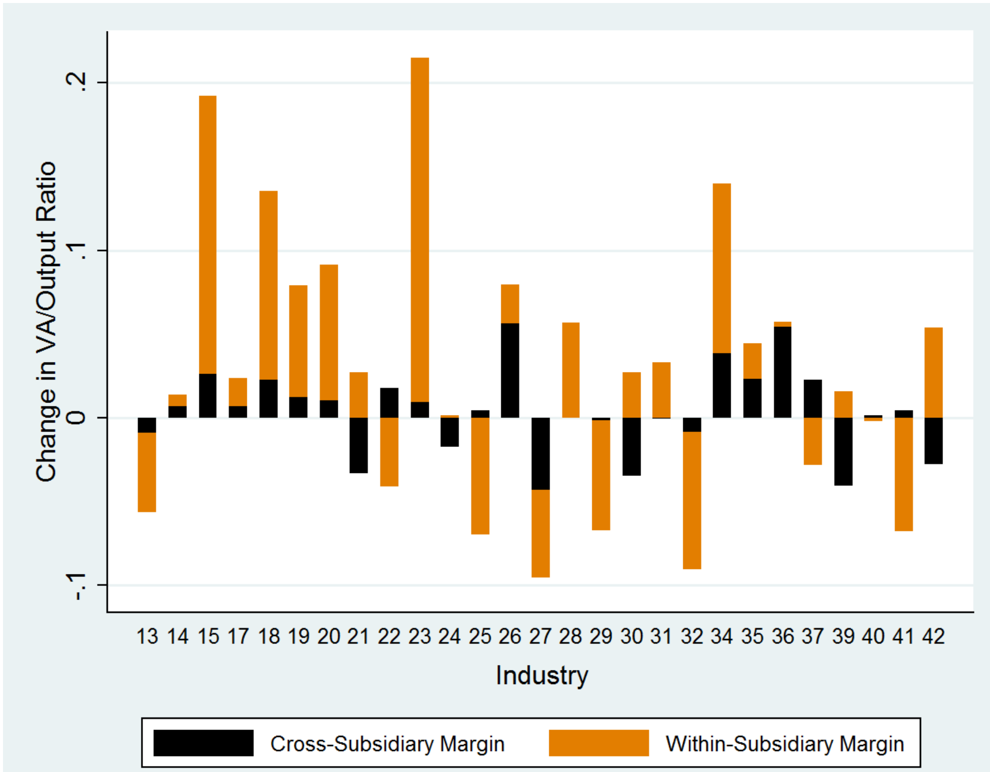
Figure 5.1 plots the trend of VR during the time span covered, with all four-digit industries pooled together. It can be told from the graph that the Chinese multinational operations experienced positive overall growth trend during the ten years.

Figure 5.1: Value-Added/Output Ratio Growth in China: Multinational Operations



With regard to the components of VR changes, the decomposition method (5.6) is applied to identify the within-subsidiary margin and the cross-subsidiary margin. The decomposition can be performed at any aggregate level of industry and for any time span. Figure 5.2 demonstrates the decomposition results of the VR changes at the two-digit industry level over the 10 years covered. From the figure, the within-subsidiary margin appears to be the main source of VR changes.

Figure 5.2: Decomposition of ΔVR: Two-Digit Industries, 10-Year Change
Note: See Table 5.3 for industry classification and description.



The decomposition is further conducted at the four-digit industry level and with a two-year time span. Table 5.2 presents a snapshot of the average change in VR over time and the two margins obtained from decomposition. The within-subsidiary margin dominates the cross-subsidiary margin and appears to be the main source of overall industrial VR change in all years here. In the following section, further investigations are performed using regression analyses.

5.4 Empirical Results

Given industry i and year τ, the dependent variable in (5.5) can be the total change in $\text{VR}_{i,\tau}$, the within-subsidiary margin $\sum_{j\in\Omega_i} \Delta\text{VR}_{j,\tau}\left(\frac{\lambda_{j,\tau}+\lambda_{j,\tau-1}}{2}\right)$, or the cross-subsidiary margin $\sum_{j\in\Omega_i} \Delta\lambda_{j,\tau}\left(\frac{\text{VR}_{j,\tau}+\text{VR}_{j,\tau-1}}{2}\right)$. Table 5.3 provides summary descriptive statistics for the two-digit manufacturing industries. The control variables included in regression include capital intensity

Table 5.2: Change in VR and the Two Margins, Four-digit Industries

Year	ΔVR		Within-Subsidiary Margin		Cross-Subsidiary Margin	
	Mean	S.D.	Mean	S.D.	Mean	S.D.
1999	0.0116	0.130	0.0119	0.129	-0.00035	0.0188
2000	0.0094	0.112	0.0101	0.111	-0.00071	0.0171
2001	0.0058	0.102	0.0045	0.104	0.00128	0.0145
2002	0.0090	0.111	0.0089	0.110	0.00009	0.0154
2003	0.0093	0.106	0.0111	0.105	-0.00183	0.0151
2004	-0.0084	0.108	-0.0090	0.108	0.00068	0.0184
2005	0.0052	0.106	0.0069	0.104	-0.00164	0.0189
2006	0.0147	0.090	0.0136	0.089	0.00106	0.0150
2007	-0.0043	0.085	-0.0034	0.082	-0.00091	0.0195

(K/L), measured as the value of fixed asset per worker, and the skill intensity indicator, calculated as the share of employees with the highest completed education equal to or above the level of junior college. Training intensity, measured as the ratio of employee-training expense to total value of output, is included to approximate an industry's learning ability.

Table 5.3: Industry Description

Industry code	Description	Capital Intensity (K/L)	Training intensity	Skill Intensity
		(1,000 RMB per Person)	(Employee Training Expense/Output)	(Share of Employees with Education $\geq$ Junior College)
13	Processing of Farm and Sideline Food	91.67	0.00028	0.124
14	Manufacture of Food Products	89.07	0.00043	0.138
15	Manufacture of Beverages	149.90	0.00044	0.194
17	Manufacture of Textiles	67.97	0.00035	0.061
18	Manufacture of Wearing Apparel, Footwear, Hats and Caps	23.23	0.00036	0.049
19	Manufacture of Leather, Fur, Feather (Down) and Related Products	34.72	0.00030	0.054
20	Processing of Wood; Manufacture of Products of Wood, Bamboo, Rattan, Palm Coir and Articles of Straw	74.90	0.00032	0.092
21	Manufacture of Furniture	51.22	0.00040	0.066
22	Manufacture of Paper and Paper Products	116.1	0.00036	0.112
23	Printing and Reproduction of Recorded Media	125.60	0.00069	0.170
24	Manufacture of Sport and Recreational Goods (Sports Goods, Toys, Musical Instruments and Stationery Goods)	38.90	0.00038	0.078
25	Manufacture of Coke and Refined Petroleum Products; Manufacture of Nuclear Fuel Products	257.00	0.00042	0.202
26	Manufacture of Chemical Material and Chemical Products	161.90	0.00040	0.180
27	Manufacture of Pharmaceuticals and Medicinal Chemical Products	120.70	0.00061	0.270
28	Manufacture of Chemical Fiber	231.20	0.00026	0.172
29	Manufacture of Rubber Products	70.46	0.00035	0.087
30	Manufacture of Plastics Products	86.59	0.00031	0.093
31	Manufacture of Other Non-metallic Mineral Products	80.47	0.00044	0.102
32	Ferrous Metal Foundries and Presses	193.30	0.00027	0.136

Table 5.3 Continued

Industry code	Description	Capital Intensity (K/L) (1,000 RMB per Person)	Training intensity (Employee Training Expense/Output)	Skill Intensity (Share of Employees with Education ≥ Junior College)
33	Non-ferrous Metal Foundries and Presses	135.40	0.00029	0.156
34	Manufacture of Fabricated Metal Products (except machinery and equipment)	72.63	0.00044	0.104
35	Manufacture of General Purpose Machinery and Equipment n.e.c.	68.22	0.00054	0.161
36	Manufacture of Special Purpose Machinery	63.73	0.00063	0.195
37	Manufacture of Transport Equipment	89.14	0.00088	0.184
39	Manufacture of Electrical Equipment	74.74	0.00041	0.154
40	Manufacture of Computer and Electronic Products	120.7	0.00034	0.285
41	Manufacture of Special Instruments and Office Machinery	63.38	0.00068	0.252
42	Manufacture of Art Products; Other Manufacturing	45.43	0.00049	0.093
43	Waste Collection, Treatment and Disposal Activities; Materials Recovery	92.30	0.00019	0.121

Table 5.4 reports the regression results from (5.5) with the overall two-year change in VR at the four-digit industry level as the dependent variable. Column (1) displays the baseline results, with only the explanatory variables included. The results are in line with the theory predictions. VR change is larger when the initial VR is lower; it decreases over time; and it is higher in industries with higher training intensities. In Column (2), a control variable – capital intensity – is included into the regression. The results display similar pattern as in the baseline case, and industries with higher capital intensities tend to show higher growth in VR. Skill intensity is further included as another control variable with results presented in Column (3). Again, results are consistent with the theoretical predictions.

Table 5.4: Overall ΔVR of Multinational Operation

	(1) Full Sample	(2) Full Sample	(3) Full Sample	(4) High K/L Industries	(5) Low K/L Industries	(6) Skill-Intensive Industries	(7) Non Skill-Intensive Industries
Initial VR	-0.0760***	-0.0744***	-0.0743***	-0.0694***	-0.0654***	-0.0711***	-0.0771***
	(0.0144)	(0.0142)	(0.0143)	(0.0200)	(0.0201)	(0.0201)	(0.0228)
Year Trend	-0.00119*	-0.00120**	-0.00120**	-0.00238***	-0.000046	-0.00200**	-0.000454
(τ)	(0.000608)	(0.000607)	(0.000608)	(0.000899)	(0.000822)	(0.000945)	(0.000787)
Training	23.32***	24.30***	24.54***	34.92**	16.62**	29.23***	18.40
Intensity (β)	(7.506)	(7.345)	(7.369)	(16.09)	(6.706)	(9.075)	(14.44)
Capital		35.99*	37.57*	43.35**	88.07	26.46	109.6
Intensity		(19.57)	(20.68)	(21.18)	(190.4)	(21.79)	(77.33)
Skill			-0.00339	-0.00707	-0.0206	-0.00973	-0.164
Intensity			(0.0176)	(0.0202)	(0.0360)	(0.0222)	(0.119)
Constant	0.0215***	0.0176***	0.0178***	0.0178*	0.0132	0.0211**	0.0260**
	(0.00542)	(0.00553)	(0.00548)	(0.0106)	(0.00993)	(0.0101)	(0.0112)
Observations	2,485	2,485	2,485	1,246	1,239	1,192	1,293
R-squared	0.014	0.015	0.015	0.024	0.012	0.018	0.018

Dependent variable is the two-year change in value-added/output ratio (ΔVR).
The regression is at the level of (4-digit industry × year) level. 2-digit industry dummies are included.
Robust standard errors in parentheses.
*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

In Columns (4) and (5), VR changes are divided into two groups of industries with high and low capital-labor intensities, respectively.[5] The coefficient of time trend τ is insignificant for the group of industries with low capital intensities, which confirms that capital-intensive industries tend

[5] The groups are defined based on their capital intensities: industries in the high- (low-) intensity group are with capital-labor intensities above (below) the median of the measure.

to have a more significant time-convergence pattern in VR growth. Column (6) and (7) present results from regressions dividing industries into groups with different levels of skill intensity.[6] For the highly skill-intensive industries, their growth rate in VR declines faster as time passes than the non-skill-intensive industries. At the same time, training intensity appears to have a more significant positive influence on the VR growth of skill-intensive sectors. In all the regressions, industry-dummies are included to address the issue that there may be industry-specific and non-time variant characteristics that affect the VR changes over time.[7]

Table 5.5 examines the within-subsidiary margin of VR change, which is obtained from the decomposition specified in (5.6). The regression results are similar as in Table 5.4. The within-

Table 5.5: Within-Subsidiary Margin of ΔVR, Multinational Operation

	(1) Full Sample	(2) Full Sample	(3) Full Sample	(4) High K/L Industries	(5) Low K/L Industries	(6) Skill-Intensive Industries	(7) Non Skill-Intensive Industries
Initial VR	-0.0690***	-0.0666***	-0.0665***	-0.0629***	-0.0563***	-0.0626***	-0.0670***
	(0.0143)	(0.0140)	(0.0141)	(0.0198)	(0.0196)	(0.0198)	(0.0215)
Year Trend	-0.00108*	-0.00110*	-0.00110*	-0.00225**	0.00003	-0.00196**	-0.000302
(τ)	(0.000601)	(0.000601)	(0.000601)	(0.000900)	(0.000801)	(0.000930)	(0.000780)
Training	22.61***	24.02***	24.35***	32.85**	17.00**	28.29***	23.02
Intensity (β)	(7.678)	(7.430)	(7.380)	(15.72)	(6.572)	(8.914)	(15.21)
Capital		51.97***	54.12***	57.54***	99.76	49.20**	119.3
Intensity		(18.69)	(19.76)	(20.26)	(182.1)	(21.60)	(79.26)
Skill			-0.00460	0.000622	-0.0368	-0.00487	-0.154
Intensity			(0.0170)	(0.0200)	(0.0362)	(0.0218)	(0.121)
Constant	0.0198***	0.0142**	0.0145***	0.0138	0.0117	0.0159	0.0199*
	(0.00545)	(0.00558)	(0.00556)	(0.0104)	(0.00985)	(0.0102)	(0.0114)
Observations	2,485	2,485	2,485	1,246	1,239	1,192	1,293
R-squared	0.013	0.014	0.014	0.023	0.012	0.017	0.016

Dependent variable is the within-subsidiary margin obtained from the decomposition of the two-year change in value-added/output ratio (ΔVR).
The regression is at the level of (4-digit industry × year) level. 2-digit industry dummies are included.
Robust standard errors in parentheses.
*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

subsidiary margin displays similar convergence patterns as the overall change in VR, consistent with the theoretical predictions. The magnitude and the significance level of the coefficient estimates

[6] The groups are defined based on their skill intensities: industries in the skill-intensive (non skill-intensive) group are with skill intensities above (below) the median of the measure.

[7] As in the theory presented in Chapter 4, there are time-invariant and industry-specific characteristics that affect the development of task-offshoring over time (i.e., $\frac{d\bar{z}(t)}{dt}$ depends also on parameters such as ρ).

are quite close to those of overall VR changes, and the convergence patterns are more significant in highly capital-intensive industries and skill-intensive industries.

Table 5.6 shows the regression results for the cross-subsidiary margin from the decomposition. With regard to the cross-subsidiary margin, it does not show the similar convergence pattern as

Table 5.6: Cross-Subsidiary Margin of ΔVR, Multinational Operation

	(1) Full Sample	(2) Full Sample	(3) Full Sample	(4) High K/L Industries	(5) Low K/L Industries	(6) Skill-Intensive Industries	(7) Non Skill-Intensive Industries
Initial VR	-0.00703**	-0.00776**	-0.00780**	-0.00651	-0.00903	-0.00844*	-0.0101*
	(0.00357)	(0.00342)	(0.00342)	(0.00416)	(0.00668)	(0.00479)	(0.00570)
Year Trend	-0.000108	-0.000102	-0.000102	-0.000128	-0.000077	-0.000039	-0.000152
(τ)	(0.000129)	(0.000128)	(0.000128)	(0.000196)	(0.000167)	(0.000190)	(0.000176)
Training	0.712	0.278	0.190	2.074	-0.378	0.937	-4.623
Intensity (β)	(1.784)	(1.728)	(1.822)	(3.084)	(2.809)	(1.913)	(6.671)
Capital		-15.98***	-16.54***	-14.19*	-11.69	-22.74***	-9.719
Intensity		(5.789)	(5.905)	(7.214)	(47.15)	(6.635)	(13.94)
Skill			0.00120	-0.00769	0.0162*	-0.00486	-0.0102
Intensity			(0.00385)	(0.00516)	(0.00927)	(0.00403)	(0.0231)
Constant	0.00165	0.00340**	0.00332**	0.00401	0.00154	0.00521**	0.00609**
	(0.00126)	(0.00140)	(0.00141)	(0.00267)	(0.00267)	(0.00254)	(0.00255)
Observations	2,485	2,485	2,485	1,246	1,239	1,192	1,293
R-squared	0.011	0.014	0.014	0.017	0.019	0.019	0.028

Dependent variable is the cross-subsidiary margin obtained from the decomposition of the two-year change in value-added/output ratio (ΔVR).
The regression is at the level of (4-digit industry × year) level. 2-digit industry dummies are included.
Robust standard errors in parentheses.
*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

of the overall VR change and of the within-subsidiary margin. The cross-subsidiary margin still decreases in initial VR, while other coefficient estimates of the explanatory variables do not show the convergence trend. The magnitude, as well as the significance level, of the estimates is much smaller than those in Table 5.4 and Table 5.5. It is interesting to see that capital intensity tends to have a negative effect on cross-subsidiary margin, while the effect is positive for both within-subsidiary margin and the overall VR change. This may imply that the more capital-intensive an industry is, the more likely it is the case that the VR growth mainly occurs within subsidiaries.

Comparing the results in Table 5.4 – 5.6, it is found that the within-subsidiary change dominates the cross-subsidiary change and serves as the main driving force of the overall convergence of VR of multinational operations. The explanatory power of the independent variables for ΔVR primarily comes from their explanatory capabilities in addressing the within-subsidiary margin. This result is consistent with the theory presented in Chapter 4 in the sense that the growth of industrial VR mainly stems from the within-firm developments. This trend is even more significant in more capital-intensive industries. Furthermore, the tables report the constant terms from the regressions. For overall ΔVR and the within-subsidiary margin regressions, the constant estimates are positive, with most of them are also statistically significant. They are also much larger in magnitude than those for the cross-subsidiary margin. This indicates that there is a positive VR development over time which is primarily driven by the within-firm changes.

Specification (5.5) may be affected by the tendency of VR to mechanically revert to its mean, which may lead to spurious convergence pattern being captured by the results. To address this issue, regressions are re-conducted with different initial years, i.e., the time trend index τ starts from other initial years other than 1998, which is the earliest year covered in the dataset and also the initial year used in the regressions above. The reason is that shocks might hit an industry and make the VR fluctuate for a short time, but it would not constantly and consistently hit it in the same manner for years. Table 5.7 presents the results, using 1999, 2001, 2003 and 2005 as the initial year, respectively. The results show that the convergence pattern displayed are similar to those in the previous main regressions. This confirms that the results are not due to or significantly affected by shocks.

In the main regressions shown earlier, skill intensity is measured by the share of employees with the highest completed education at the junior college level or above. Table 5.8 then displays the estimation results with skill intensity approximated by different measures. The two alternatives are the shares of employees with at least college education and with graduate degrees, respectively. It is seen from the table that the convergence patterns as shown by the estimations are the same as in the main regressions. The main coefficients' estimates are quite similar to the main results.

Since the concentration of discussion is mainly on multinational operation, domestic and local industrial operations can thus serve as groups for counter-checks. Table 5.9 replicates the

Table 5.7: ΔVR and its Two Margins, Multinational Operations, Various Initial Years

Dependent Variables	(1) ΔVR	(2) Within-Subsid. Margin	(3) Cross-Subsid. Margin	(4) ΔVR	(5) Within-Subsid. Margin	(6) Cross-Subsid. Margin
	Initial VR: Year 1999			Initial VR: Year 2001		
Initial VR	-0.107***	-0.106***	-0.00137	-0.105***	-0.0996***	-0.00507
	(0.0160)	(0.0157)	(0.00338)	(0.0227)	(0.0220)	(0.00526)
Year Trend	-0.00112	-0.00102	-0.000100	-0.00206*	-0.00198*	-0.000081
(τ)	(0.000710)	(0.000704)	(0.000139)	(0.00111)	(0.00110)	(0.00022)
Training	23.93**	25.17**	-1.246	20.48*	21.76*	-1.285
Intensity (β)	(9.697)	(9.757)	(1.658)	(11.98)	(12.29)	(2.116)
Capital	21.17	35.48	-14.31**	-3.462	16.59	-20.05***
Intensity (K/L)	(26.35)	(24.07)	(6.341)	(27.81)	(26.61)	(7.549)
Skill	-0.0425	-0.0439*	0.00140	-0.0162	-0.0178	0.00163
Intensity	(0.0269)	(0.0254)	(0.00432)	(0.0307)	(0.0288)	(0.00483)
Constant	0.0350***	0.0329***	0.00210	0.0401***	0.0366***	0.00351
	(0.00709)	(0.00699)	(0.00143)	(0.0105)	(0.0106)	(0.0022)
R-squared	0.020	0.020	0.013	0.020	0.020	0.013
	Initial VR: Year 2003			Initial VR: Year 2005		
Initial VR	-0.133***	-0.128***	-0.00497	-0.258***	-0.250***	-0.00867
	(0.0313)	(0.0297)	(0.00532)	(0.0424)	(0.0420)	(0.00659)
Year Trend	0.000147	0.000396	-0.000249	-0.0196***	-0.0177***	-0.00195
(τ)	(0.00218)	(0.00212)	(0.000449)	(0.00656)	(0.00645)	(0.00125)
Training	15.17	13.03	2.135	36.61***	37.82***	-1.217
Intensity (β)	(14.88)	(15.81)	(2.791)	(7.839)	(7.689)	(1.048)
Capital	47.10	57.83*	-10.73	-3.093	18.70	-21.79**
Intensity (K/L)	(35.39)	(31.14)	(11.67)	(34.89)	(34.69)	(10.27)
Skill	-0.00782	-0.00308	-0.00474	0.0511	0.0417	0.00944
Intensity	(0.0329)	(0.0313)	(0.00682)	(0.0373)	(0.0376)	(0.00661)
Constant	0.0298	0.0259	0.00389	0.224***	0.204***	0.0203*
	(0.0196)	(0.0192)	(0.00374)	(0.0557)	(0.0545)	(0.0105)
R-Squared	0.034	0.034	0.019	0.121	0.116	0.036

Specification is the same as column (3) in Tables 5.4 – 5.6.
The regression is at the level of (4-digit industry × year) level. 2-digit industry dummies are included.
Robust standard errors in parentheses.
*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

primary regressions on the domestically-funded and the HMT-owned counterparts of MIs. They are conceptual industries consisting of only domestically-funded and HMT-owned enterprises respectively. The results are quite different from those for multinational operations. The domestic production does not show a similar convergence pattern, either for the total change in VR or the within- and cross-firm margins. Particularly, the coefficient estimates on employee training intensity are negative, which is the opposite of the case of MIs. For HMT-owned operations, the situation is similar. Except for the initial VR, no other explanatory variable shows significant explanatory

Table 5.8: ΔVR and its Two Margins, Multinational Operations, Skill Intensity Measures

	(1)	(2)	(3)	(4)	(5)	(6)
	Skill Intensity: Share of Employees with Education $\geq$ College			Skill Intensity: Share of Employees with Education $\geq$ Graduate		
Dependent Variables	ΔVR	Within-Subsid. Margin	Cross-Subsid. Margin	ΔVR	Within-Subsid. Margin	Cross-Subsid. Margin
Initial VR	-0.0740*** (0.0143)	-0.0662*** (0.0141)	-0.00774** (0.00342)	-0.0740*** (0.0143)	-0.0663*** (0.0141)	-0.00770** (0.00344)
Year Trend (τ)	-0.00120** (0.000608)	-0.00110* (0.000601)	-0.000102 (0.000128)	-0.00120** (0.000608)	-0.00110* (0.000601)	-0.000102 (0.000128)
Training Intensity (β)	24.79*** (7.279)	24.48*** (7.343)	0.304 (1.751)	24.37*** (7.327)	24.08*** (7.414)	0.288 (1.727)
Capital Intensity (K/L)	39.81** (20.04)	55.59*** (19.00)	-15.78*** (5.870)	36.79* (19.65)	52.66*** (18.74)	-15.87*** (5.805)
Skill Intensity	-0.0183 (0.0190)	-0.0173 (0.0187)	-0.000971 (0.00411)	-0.0518 (0.0417)	-0.0446 (0.0423)	-0.00721 (0.0101)
Constant	0.0178*** (0.00548)	0.0144*** (0.00555)	0.00341** (0.00140)	0.0176*** (0.00553)	0.0142** (0.00558)	0.00340** (0.00139)
R-squared	0.015	0.014	0.014	0.015	0.014	0.014

Specification is the same as column (3) in Tables 5.4 – 5.6.
The regression is at the level of (4-digit industry × year) level. 2-digit industry dummies are included.
Robust standard errors in parentheses.
*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

powers. Compared with domestic firms, the HMT-owned production displays patterns closer to the multinational operations, which may indicate that it is in character more similar to multinational subsidiaries. For both types of production, it is the within-firm margin that dominates as the main source of change in overall VR.

5.5 Concluding Remarks

The theory of global value chain presented in previous chapters has a key and critical prediction as to how the Southern host country's share of industrial value added behaves over time: its dynamics essentially follows a convergence pattern similar to the evolution path of the offshoring threshold. The VR of a multinational industry in a Southern host country will grow at a decreasing speed, as predicted. Using subsidiary-level data on Chinese multinational operations, the prediction is empirically investigated in this chapter.

The empirical results show evidence supporting the theoretical predictions. The multinational

Table 5.9: ΔVR and its Two Margins, Local Production and HMT-Owned Operations

	(1)	(2)	(3)	(4)	(5)	(6)
	Domestically-Funded Production			HMT-Owned Production		
Dependent Variables	ΔVR	Within-Firm Margin	Cross-Firm Margin	ΔVR	Within-Firm Margin	Cross-Firm Margin
Initial VR	-0.0279**	-0.0205	-0.00739*	-0.0873***	-0.0849***	-0.00240
	(0.0141)	(0.0151)	(0.00438)	(0.0129)	(0.0121)	(0.00408)
Year Trend	0.0000995	-0.000159	0.000258***	0.000926	0.000743	0.000183
(τ)	(0.000211)	(0.000203)	(0.0000596)	(0.000661)	(0.000658)	(0.000137)
Training	-13.54**	-12.41*	-1.135	3.119	3.938	-0.819
Intensity (β)	(5.898)	(6.349)	(0.773)	(6.773)	(6.401)	(1.852)
Capital	-10.89	-10.14	-0.749	-33.25	-39.21	5.960
Intensity (K/L)	(10.65)	(8.999)	(4.355)	(32.22)	(32.88)	(5.808)
Skill	0.0178**	0.0198**	-0.00200	0.0596***	0.0615***	-0.00186
Intensity	(0.00813)	(0.00773)	(0.00256)	(0.0216)	(0.0219)	(0.00537)
Constant	0.0125***	0.0103***	0.00225	0.0149***	0.0150***	-0.0000722
	(0.00341)	(0.00370)	(0.00142)	(0.00537)	(0.00527)	(0.00121)
Observations	3,777	3,777	3,777	2,521	2,521	2,521
R-squared	0.021	0.021	0.019	0.021	0.022	0.008

Specification is the same as column (3) in Tables 5.4 – 5.6.
The regression is at the level of (4-digit industry × year) level. 2-digit industry dummies are included.
Robust standard errors in parentheses.
*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

subsidiaries in China experience VR growth during the time period covered in the dataset, at a declining pace. The employee training intensity of an industry has a significant positive effect on VR growth. The results are robust to different choices of initial years and control variables' measures. A similar convergence pattern is not found when I perform regression using the same specification on domestic and HMT-owned operations. Certainly, it is ideal that the empirical investigation is performed at the task level, i.e., the observations are tasks conducted within subsidiaries. While task-level data are difficult to obtain and not widely available, in this chapter firm-level data are examined to the best exertion.

Chapter 6

An Extenstion: Multinational Production, Innovation, and the Dynamics of Task Allocation

In the basic model presented in Chapter 3, the technologically advanced country serves as the learning boundary, which does not change over time. Recently, there is a rising phenomenon catching people's attention – "reshoring," which refers to the trend that previously offshored activities are now moved back to their originating home countries. One important driving force behind this occurrence is that the technologically developed home countries improve their production efficiency over time, which gradually makes it more economic to conduct even the low-end activities back there. Therefore, this chapter considers the task-allocation dynamics in global production with technology innovation in the North incorporated.

In this theoretical extension of the basic model, while the South learns by carrying out tasks beyond its capability, the North keeps innovating. The technologies in the developed country keep being improved – the technology frontier and learning boundary of the world keeps being pushed forward. The task allocation pattern at any point of time depends on countries' relative cost of conducting each activity. The dynamics of global production are thus critically determined by the two countries' relative speed of technology improvement – one through learning and the other through innovation. Under this framework, both offshoring expansion and reshoring may occur.

This chapter mainly discusses the task-allocation dynamics under different circumstances of technology improvement interaction between countries. It is organized as follows. In Section 6.1, I introduce the environment and set-up of the model. Section 6.2 studies the instantaneous equilibrium of multinational production. The dynamics of task allocation are discussed in Section 6.3 and 6.4, for an initially efficient and inefficient South, respectively. Section 6.5 concludes.

6.1 Set-up of the Model

The environment is the same as in the basic model introduced in Chapter 3. There are two countries: North (N) and South (S), with one industry producing a final product Y and supplying it to both countries' consumers, with no trade cost. Consumer preferences are the same in the two countries. Labor is the only factor of production, which is inelastically supplied and immobile across countries. The labor endowment of country i is denoted by L_i, and it is constant over time. Time is continuous and indexed by t. The environment is perfectly competitive.

6.1.1 Production

As in the basic model, the production of Y requires the completion of a continuum of tasks, indexed by $z \in [0,1]$. The value of z indicates the technological sophistication of a task. The production function of Y at any time t is expressed as:

$$\ln Y(t) = \int_0^1 \ln x(z,t)dz, \tag{6.1}$$

where $x(z,t)$ is the amount of task z completed at time t. Each task can be carried out in either country with constant returns to scale.

Initially at $t = 0$, the North can perform any task with the best technology available at that time. The unit labor requirement for conducting a task z in the North at $t = 0$ is given by

$$a_N(z,0) = \bar{a}e^{-z}, \tag{6.2}$$

where $\bar{a} > 0$ is a parameter. The South, in contrast, has the best technology in use initially only for some low-sophistication tasks. Specifically, let $T(0)$ denote the efficiency frontier of technology in the South at $t = 0$, with $0 < T(0) < 1$. For the simple tasks with $z \leq T(0)$, the South's production technologies are as good as the North's. For the complicated ones with $z > T(0)$, the

Southern technologies are less efficient, and the more sophisticated a task is, the further the South lags behind. Specifically, the unit labor requirement for conducting a task z at $t = 0$ in the South is given by

$$a_S(z,0) = \begin{cases} a_N(z,0) = \bar{a}e^{-z} & \text{if } z \leq T(0)\,, \\ \bar{a}e^{z-2T(0)} & \text{if } z > T(0)\,. \end{cases} \tag{6.3}$$

6.1.2 Innovation

The North keeps improving its production technologies through innovation. The resulting effect is the continuous productivity enhancement in the country for all tasks. It is assumed that the unit labor requirement for conducting task z at time t in the North is expressed as

$$a_N(z,t) = \bar{a}e^{-z-\alpha t}, \tag{6.4}$$

with parameter $\alpha > 0$. The innovation speed is implied as $\frac{\partial a_N(\cdot,t)/\partial t}{a_N(\cdot,t)} = -\alpha$, which is the pace of reduction in the unit labor requirement over time, constant across all tasks.

6.1.3 Learning-by-Doing

Tasks may be conducted in either country. Because of the cost-minimization incentive, certain activities are offshored to the South, starting from the simplest ones for which the South has the best technologies initially. Through conducting the offshored activities, the South may improve its own technologies through the learning-by-doing effect. Particularly, the country accumulates experience and enhances production efficiency by conducting the "beyond" tasks on which it lags behind the North. Furthermore, it is assumed that the learning effect is bounded with spillovers across tasks, with the Northern unit labor requirement schedule serving as the learning boundary. Specifically, the South experiences gradual reduction in its unit labor requirement:

$$\frac{\partial a_S(\cdot,t)/\partial t}{a_S(\cdot,t)} = -\int_0^1 2\beta \left\{1 \middle| \frac{a_S(z,t)}{a_N(z,t+\epsilon)} > 1\right\} L_S(z,t)\, dz\,, \tag{6.5}$$

where $\left\{1 \middle| \frac{a_S(z,t)}{a_N(z,t+\epsilon)} > 1\right\}$ is an indicator function whose value equals 1 if there is still room for the South to improve its technology for task z at time t, and it equals 0 otherwise ($\epsilon > 0$ is infinitely small); $L_S(z,t)$ denotes the amount of labor used for carrying out task z in the South at time t; and $\beta > 0$ is a parameter implying the learning ability of the South. The basic idea is that while the North keeps improving technologies for every task, the world's production efficiency frontier continues moving forward, which may lead the South to keep trying catching up with the North.

At the same time, the learning effect has a boundary. It is assumed that the North always has the best technologies, and the South is not able to achieve better than the North at any time. Hence, the Northern efficiency function always serves as the boundary of Southern learning.

Examining the learning function (6.5), it is found that with the constant Northern technology improvement, the Southern learning effect is essentially given by

$$\frac{\partial a_S(\cdot,t)/\partial t}{a_S(\cdot,t)} = -\int_0^1 2\beta \times 1 \times L_S(z,t)\,dz = -2\beta L_S, \tag{6.5$'$}$$

when $a_S(z,t) \geq a_N(z,t)$, and if the South does conduct some tasks at time t. Intuitively, while the North keeps innovating on all technologies, the South only learns from the North. As a result, there always exists room for the South to learn the most up-to-date technologies. The learning effect reveals the possibility that a host country may improve its own technologies constantly by conducting offshored tasks, and all resources devoted contribute to technology improvement.

With Northern innovation and Southern learning, the pattern of how the productivity schedules may evolve over time depends on the interaction between the two. There are three possible cases with regard to the relationship between innovation and learning:

- Case I. Northern Innovation Pace = Southern Learning Pace ($\alpha = 2\beta L_S$)
- Case II. Northern Innovation Pace > Southern Learning Pace ($\alpha > 2\beta L_S$)
- Case III. Northern Innovation Pace < Southern Learning Pace ($\alpha < 2\beta L_S$)

The dynamics of task allocation vary upon different circumstances. I will examine each case in detail in later discussions.

All tasks, wherever allocated, are conducted using the local unit labor requirement schedules. In this model with perfectly competitive environment, tasks are undertaken with constant returns to scale. Therefore, firms do not have a substantial role here from the theoretical perspective.

6.2 Instantaneous Equilibrium of Multinational Production

6.2.1 Instantaneous Equilibrium

Let $w_i(t)$ denote the wage rate in coutry i at time t. The unit cost functions for conducting a task z in the two countries are, respectively,

$$C_S(w_S(t), z) = w_S(t) a_S(z, t) \,, \tag{6.6}$$

$$C_N(w_N(t), z) = w_N(t) a_N(z, t) \,. \tag{6.7}$$

A certain range of tasks are offshored to the South, starting from the simplest ones, since the South has the most advanced technologies for them initially. The cost conditions (6.6) and (6.7) combine to form a no-arbitrage condition of offshoring, determining the pattern of task allocation between countries. There exists a threshold task $\bar{z}(t)$ at time t such that $C_S(w_S(t), z) = C_N(w_N(t), z)$ in equilibrium, i.e.,

$$w_S(t)\, a_S(\bar{z}(t), t) = w_N(t)\, a_N(\bar{z}(t), t) \,, \tag{6.8}$$

where $\bar{z}(t) > 0$ is the most sophisticated task that is performed in the South. The tasks beyond $\bar{z}(t)$ are conducted in the North.

The labor-market clearing conditions in the two countries at time t are:

$$South: \int_0^{\bar{z}(t)} x_S(z, t) a_S(z, t) dz = L_S \,, \tag{6.9}$$

$$North: \int_{\bar{z}(t)}^1 x_N(z, t) a_N(z, t) dz = L_N \,, \tag{6.10}$$

where $x_i(z, t)$ denotes the amount of task z conducted in country i at time t.

Similar as in Chapter 3, let $E(t)$ denote the world expenditure on the final consumer product Y at time t, defined as the sum of factor payments in the two economies:

$$E(t) = w_S(t) L_S + w_N(t) L_N \,. \tag{6.11}$$

Then the demand for a task z conducted in country i at time t is

$$x_i(z,t) = \frac{E(t)}{C_i(w_i(t), z)}\,, \quad i \in \{N, S\}\,. \tag{6.12}$$

With the unit cost functions (6.6) and (6.7), together with (6.12), the labor-market clearing conditions are simplified to

$$South: \int_0^{\bar{z}(t)} \frac{E(t)}{w_S(t)} dz = L_S\,, \tag{6.9$'$}$$

$$North: \int_{\bar{z}(t)}^1 \frac{E(t)}{w_N(t)} dz = L_N\,. \tag{6.10$'$}$$

Therefore, the instantaneous equilibrium at any time t is characterized by the offshoring threshold determination condition (6.8), the labor-market clearing conditions (6.9$'$) and (6.10$'$), and the world expenditure expression (6.11). I normalize world expenditure at unity by Walras' Law: $E(t) = 1$, and hereby wage rates are thus measured as shares of world factor income.

6.2.2 The Wage-Equalization Threshold

There exists a threshold task z^*, such that if all tasks with $z \in [0, z^*]$ are offshored to the South, and all tasks with $z \in (z^*, 1]$ are conducted in the North, the two countries' wage rates are equalized. From conditions (6.9$'$) and (6.10$'$), this wage-equalization threshold task z^* is

$$z^* = \frac{L_S}{L_S + L_N}\,. \tag{6.13}$$

This wage-equalization threshold task z^* is critical for analyzing the equilibrium dynamics. On one hand, it determines whether the host country receives "beyond" tasks to conduct when offshoring begins. If it is lower than the initial Southern technology stock ($z^* < T(0)$), the North will not offshore more than z^* (thus no more than $T(0)$) tasks to the South. However, if $z^* > T(0)$, the North may offshore more than $T(0)$ tasks, and thus the South conducts activities that it is not good at, at the initial time. On the other hand, the position of z^* significantly influences how task allocation evolves over time. My discussion thus will proceed with two possible cases:

- Case I. The South is relatively efficient initially: $z^* \leq T(0)$;
- Case II. The South is relatively inefficient initially: $z^* > T(0)$.

6.3 The Evolution Dynamics: An Initially Efficient South

This is the case where the South is relatively capable in terms of production efficiency: $z^* \leq T(0)$. In this situation, all low-sophistication tasks below z^* will be offshored to the South initially. All tasks thus are conducted using the best available technologies. The initial equilibrium is characterized by the following:

$$w_S(0)\,\bar{a}e^{-\bar{z}(0)} = w_N(0)\,\bar{a}e^{-\bar{z}(0)}\,, \tag{6.14}$$

$$\int_0^{\bar{z}(0)} \frac{1}{w_S(0)} dz = L_S\,, \tag{6.15}$$

$$\int_{\bar{z}(0)}^1 \frac{1}{w_N(0)} dz = L_N\,. \tag{6.16}$$

Given the conditions, the task threshold of offshoring $\bar{z}(0)$ and wage rates are given by, respectively,

$$\bar{z}(0) = z^* = \frac{L_S}{L_S + L_N}\,, \tag{6.17}$$

$$w_S(0) = w_N(0) = w^* = \frac{1}{L_S + L_N}\,. \tag{6.18}$$

6.3.1 Evolution Dynamics: Equal Paces of Technological Progress

When the technological progresses in the two countries are at the same pace ($\alpha = 2\beta L_S$), the efficiency gap between the two countries' technologies will not be changing over time. With the learning function (6.5′), at any time t, the Southern unit labor requirement schedule is given by

$$a_S(z,t) = \begin{cases} a_N(z,t) = \bar{a}e^{-z-\alpha t} & \text{if } z \leq T(0)\,, \\ \bar{a}e^{z-2T(0)-\alpha t} & \text{if } z > T(0)\,. \end{cases} \tag{6.19}$$

This indicates that the relative efficiency of conducting tasks is:

$$\frac{a_S(z,t)}{a_N(z,t)} = \begin{cases} 1 & \text{if } z \leq T(0)\,, \\ e^{2z-2T(0)} & \text{if } z > T(0)\,, \end{cases} \tag{6.20}$$

which keeps the same over time.

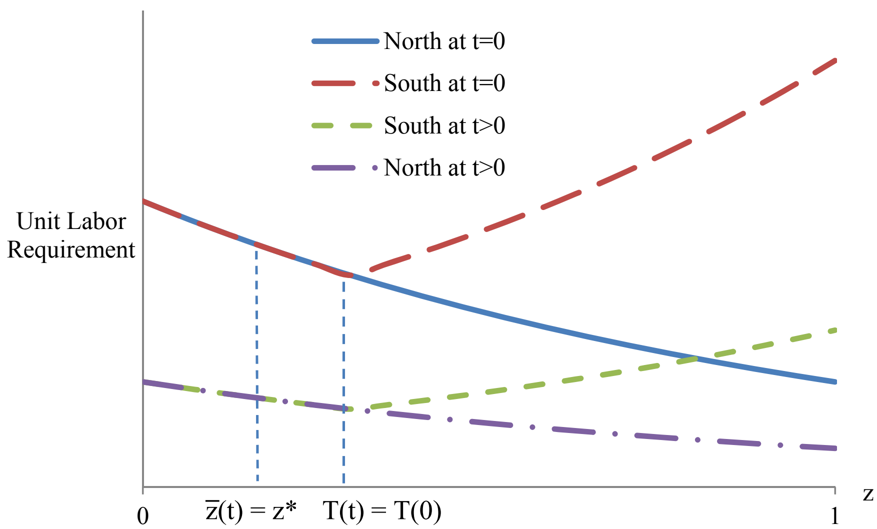
Given the fact the relative efficiency schedule does not change, the task allocation pattern also stays the same as initially. When both countries are improving their technologies at the same pace, the countries' comparative advantages in terms of task-conduct do not change, which leads to an overall static equilibrium in this case:

$$\bar{z}(t) = z^* = \frac{L_S}{L_S + L_N}\,, \tag{6.21}$$

$$w_S(t) = w_N(t) = w^* = \frac{1}{L_S + L_N}\,. \tag{6.22}$$

Figure 6.1 shows this situation graphically.

Figure 6.1: Dynamics of Task Offshoring: an Initially Efficient South, Equal Paces of Technological Progress ($z^* \leq T(0)$, $\alpha = 2\beta L_S$)



6.3.2 Evolution Dynamics: Fast Northern Innovation

This is the situation where the initially technologically developed country pushes the world's technology frontier faster than the Southern learning pace: $\alpha > 2\beta L_S$. Therefore, the Southern learning under this circumstance will not be bounded – the South will not be able to catch up with the North. Specifically, the unit labor requirement schedule of the South is:

$$a_S(z,t) = \begin{cases} \bar{a}e^{-z-2\beta L_S t} & \text{if } z \leq T(0)\,, \\ \bar{a}e^{z-2T(0)-2\beta L_S t} & \text{if } z > T(0)\,. \end{cases} \tag{6.23}$$

The technological difference between the countries becomes increasingly significant over time:

$$\frac{a_S(z,t)}{a_N(z,t)} = \begin{cases} e^{(\alpha-2\beta L_S)t} & \text{if } z \leq T(0)\,, \\ e^{2z-2T(0)+(\alpha-2\beta L_S)t} & \text{if } z > T(0)\,. \end{cases} \tag{6.24}$$

Reshoring Behavior With the productivity schedules, the conditions for instantaneous equilibrium (6.8), (6.9′) and (6.10′) after the initial time period boil down to

$$e^{(\alpha-2\beta L_S)t} = \frac{1-\bar{z}(t)}{\bar{z}(t)} \times \frac{L_S}{L_N}\,, \tag{6.25}$$

$$w_S(t) = \frac{\bar{z}(t)}{L_S}\,, \tag{6.26}$$

$$w_N(t) = \frac{1-\bar{z}(t)}{L_N}\,. \tag{6.27}$$

Comparing the two task-threshold determination functions at $t = 0$ vs. $t > 0$ ((6.17) vs. (6.25)), it is easy to find that with fast Northern innovation, at any $t > 0$, it is the case that less than z^* tasks are offshored: $\bar{z}(t) < \bar{z}(0) = z^*$. Here a potential assumption is that task allocation is sticky: the progress of offshoring keeps the set of tasks offshored as close as that in the previous time period. This is consistent with the common observations in real business, where sharp and significant shifts of the offshoring pattern seldom occur.

Therefore, with the widening of the technological gap between countries, fewer than $\bar{z}(0)$ tasks are allocated to the South. Productivity growth arising from innovation alleviates the reliance of multinational production on the South for production. Over time, with both Southern learning and Northern innovation, global production evolves. Particularly, while the South lags increasingly further behind, the Southern coverage of tasks shrinks, including fewer sophisticated tasks. This can been seen by examining (6.25):[1]

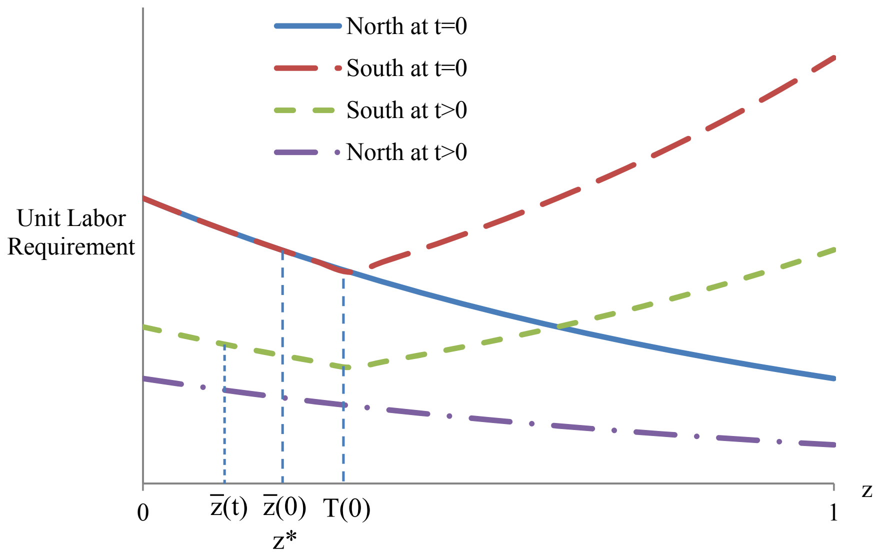
$$\frac{d\bar{z}(t)}{dt} < 0\,, \tag{6.28}$$

The task offshoring threshold gradually lowers over time. After initial offshoring, with fast Northern innovation, tasks that were originally offshored are moved back to the North, starting

[1] From (6.25), $\bar{z}(t) = \frac{L_S}{L_S + L_N e^{(\alpha-2\beta L_S)t}}$, which monotonically decreases in t with $\alpha > 2\beta L_S$.

from those relatively sophisticated ones. The "reshoring" trend thus occurs. This can be seen graphically in Figure 6.2.

Figure 6.2: Dynamics of Task Offshoring: an Initially Efficient South, Fast Northern Innovation ($z^* \leq T(0)$, $\alpha > 2\beta L_S$)



How fast the reshoring behavior will proceed depends on the two countries' difference in their domestic paces of technology progress. From (6.25), it is found that a constant threshold, $\frac{1}{2}$, serves as the threshold of sign-change of $\frac{d^2\bar{z}(t)}{dt^2}$. When more than half of the tasks are offshored to the South, the reshoring speed is increasingly fast; when less than half of the tasks are offshored, the reshoring speed decreases. In functional form, it can be expressed as:[2]

$$\frac{d^2\bar{z}(t)}{dt^2}\begin{cases} < 0 & \text{when } \bar{z}(t) > \frac{1}{2}\,, \\ = 0 & \text{when } \bar{z}(t) = \frac{1}{2}\,, \\ > 0 & \text{when } \bar{z}(t) < \frac{1}{2}\,. \end{cases} \tag{6.29}$$

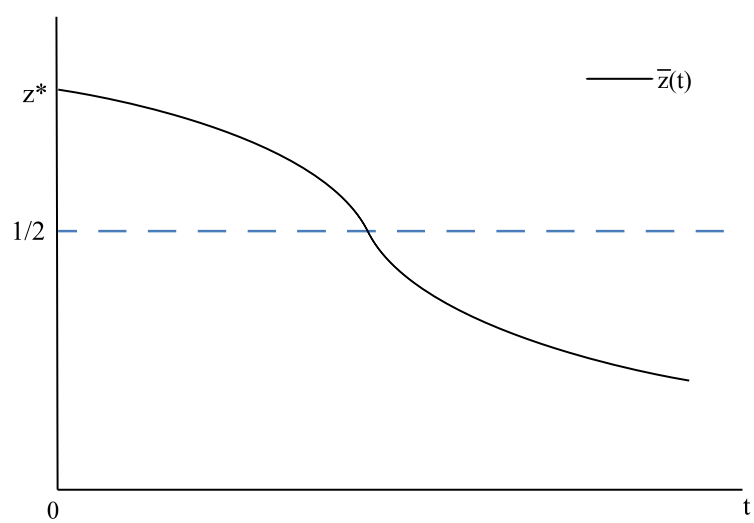
Over time, the offshoring threshold converges to: $\lim_{t\to+\infty}\bar{z}(t) = 0$. Certainly, the threshold $\bar{z}(t)$ will not really touch 0, and the progress mainly indicates that the range of tasks that are offshored will be shrinking over time, with the South increasingly only focusing on the simplest

[2] See Appendix C.1 for the derivation.

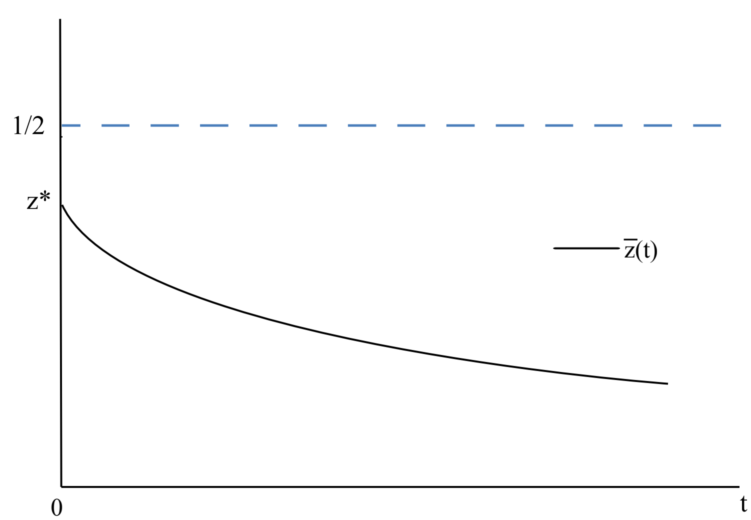
activities. Figure 6.3 illustrates two possible evolution paths of the reshoring behavior. In Panel A, the initial threshold $\bar{z}(0) = z^*$ is above $\frac{1}{2}$. Given the definition of z^*, (6.13), this situation essentially indicates a large South: $L_S > L_N$. Therefore, this evolution pattern is likely to occur when the South is both large and initially efficient. In Panel B, offshoring starts with $\bar{z}(0) < \frac{1}{2}$, which is likely to be case when the South is relatively small: $L_S < L_N$. This story illustrates

Figure 6.3: Evolution of Offshoring Threshold: An Initially Efficient South, Fast Northern Innovation ($z^* \leq T(0)$, $\alpha > 2\beta L_S$)

(a) Panel A: A Relatively Large South: $\frac{1}{2} < z^* \leq T(0)$



(b) Panel A: A Relatively Small South: $z^* < \frac{1}{2}$



that with technology progressing faster in the home country, the learning effect in the South is not adequate to enable the host country to receive more tasks to conduct. It is the relative technology advantage/disadvantage that determines the offshoring pattern.

6.3.3 Evolution Dynamics: Fast Southern Learning

With fast Southern learning ($2\beta L_S > \alpha$), the technological gap between the two economies closes over time – the host country catches up with the home country gradually. It is assumed that during this process, the Northern schedule serves as the learning boundary. The Southern technologies do not get better than the corresponding Northern ones at any point of time. After the initial time period, considering the productivity schedules (6.3) and (6.4), and learning function (6.5′), together with the condition $\alpha < 2\beta L_S$, the unit labor requirement in the South is given by

$$a_S(z,t) = \begin{cases} a_N(z,t) = \bar{a}e^{-z-\alpha t} & \text{if } z \le T(t) = T(0) + (\beta L_S - \frac{\alpha}{2})t\,, \\ \bar{a}e^{z-2T(0)-2\beta L_S t} & \text{if } z > T(t) = T(0) + (\beta L_S - \frac{\alpha}{2})t\,. \end{cases} \tag{6.30}$$

It thus is the case that the Southern stock of technology ($T(t)$) moves towards more sophisticated tasks over time, i.e., the South is getting the most advanced technologies for increasingly more difficult tasks. The technological gap between countries gradually diminishes:

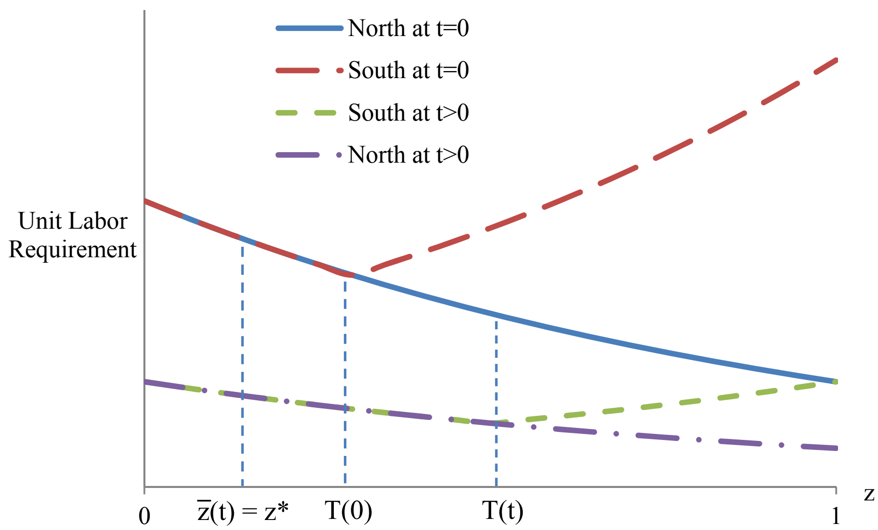
$$\frac{a_S(z,t)}{a_N(z,t)} = \begin{cases} 1 & \text{if } z \le T(t) = T(0) + (\beta L_S - \frac{\alpha}{2})t\,, \\ e^{2z-2T(0)+(\alpha-2\beta L_S)t} & \text{if } z > T(t) = T(0) + (\beta L_S - \frac{\alpha}{2})t\,. \end{cases} \tag{6.31}$$

It is obvious that countries' efficiency gap of conducting all tasks will be closing over time, with faster Southern learning, $2\beta L_S > \alpha$.

While the technology stock in the South, $T(t)$, shifts to the right, it thus is the case that $z^* \le T(0) < T(t)$ when $t > 0$. Therefore, following the same logic as when discussing the initial equilibrium at the beginning of this section, it is easy to tell that under this situation, $\bar{z}(t) = \bar{z}(0) = z^*$. No more than z^* tasks will be offshored as it will not be cost-minimizing, even if the South has increasingly better technologies. The reason is that although the South learns faster than the

North innovates, the country's comparative advantage on the offshored tasks does not change over time. The effect of learning is reflected in the relative potential efficiency improvement on those high-end tasks which are not offshored. Therefore, the actual offshoring pattern stays static. While the South is catching up with the North, it will always receive the most it can. Figure 6.4 displays the situation graphically.

Figure 6.4: Dynamics of Task Offshoring: an Initially Efficient South, Fast Southern Learning ($z^* \leq T(0)$, $\alpha < 2\beta L_S$)



The three cases discussed in this section are likely to occur when the host country is small but technologically efficient. The limitation of resource endowment in the South is a critical factor leading to the situation that no more than initial offshoring will happen, in all three cases. With Northern innovation, the South needs to try to catch up with the world technology improvement in order to keep its comparative advantages in task production.

6.4 The Evolution Dynamics: An Initially Inefficient South

For many developing host countries participating in multinational production, their advantages are not in technology but in factor supply – they have enough labor resources for production but not enough advanced technologies. This is the case that $z^* > T(0)$. Under this situation, following the same logic as discussed in the corresponding section of Chapter 3, the initial offshoring threshold $\bar{z}(0)$ lies between the Southern technology stock indicator $T(0)$ and the wage-equalization point z^*: $\bar{z}(0) \in (T(0), z^*)$.

Given conditions (6.2), (6.3), (6.8), (6.9′) and (6.10′), the initial equilibrium ($t = 0$) is characterized by

$$e^{2\bar{z}(0)-2T(0)} = \frac{1-\bar{z}(0)}{\bar{z}(0)} \times \frac{L_S}{L_N}\,, \tag{6.32}$$

$$w_S(0) = \frac{\bar{z}(0)}{L_S}\,, \tag{6.33}$$

$$w_N(0) = \frac{1-\bar{z}(0)}{L_N}\,. \tag{6.34}$$

The initial equilibrium is essentially the same as the corresponding one discussed in Chapter 3.

6.4.1 Evolution Dynamics: Equal Paces of Technological Progress

With the Southern learning pace equal to the Northern innovation speed, the two countries' relative technology difference will not change over time. As discussed in Section 6.3.1, with the condition $\alpha = 2\beta L_S$,

$$a_S(z,t) = \begin{cases} a_N(z,t) = \bar{a}e^{-z-\alpha t} & \text{if } z \le T(0)\,, \\ \bar{a}e^{z-2T(0)-\alpha t} & \text{if } z > T(0)\,. \end{cases} \tag{6.35}$$

The two countries' relative efficiency of conducting tasks thus is:

$$\frac{a_S(z,t)}{a_N(z,t)} = \begin{cases} 1 & \text{if } z \le T(0)\,, \\ e^{2z-2T(0)} & \text{if } z > T(0)\,, \end{cases} \tag{6.36}$$

which keeps the same over time.

The relative efficiency schedule determines how tasks are allocated between countries. With equal speeds of technology progress, the Southern technology stock indicator will not shift – $T(0)$ is always the most sophisticated task that the South can perform as efficiently as the North. Thus, with $z^* > T(0)$, the offshoring threshold at any time period is always in between: $T(0) < \bar{z}(t) < z^*$. Particularly, by examining the equilibrium conditions, together with the productivity schedules, it is found that at any time, the equilibrium is characterized by essentially the same conditions as the initial case:

$$e^{2\bar{z}(t)-2T(0)} = \frac{1-\bar{z}(t)}{\bar{z}(t)} \times \frac{L_S}{L_N}\,, \tag{6.37}$$

$$w_S(t) = \frac{\bar{z}(t)}{L_S}\,, \tag{6.38}$$

$$w_N(t) = \frac{1-\bar{z}(t)}{L_N}\,. \tag{6.39}$$

Therefore, the task offshoring thus the multinational production organization keeps the same as the initial situation, i.e., a static equilibrium over time:

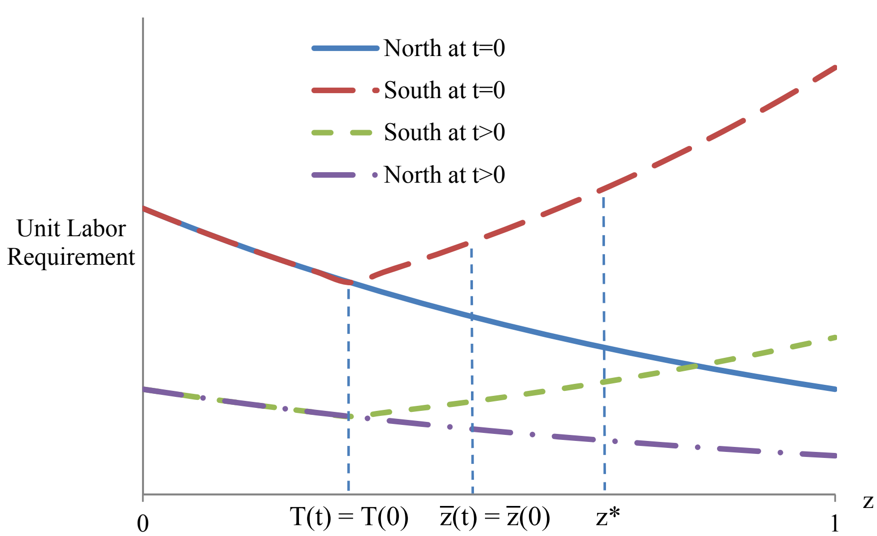
$$\bar{z}(t) = \bar{z}(0) \in (T(0), z^*)\ , \forall t\,, \tag{6.40}$$

$$w_S(t) = w_S(0)\,, \forall t\,, \tag{6.41}$$

$$w_N(t) = w_N(0)\,, \forall t\,. \tag{6.42}$$

This situation is graphically illustrated in Figure 6.5.

Figure 6.5: Dynamics of Task Offshoring: an Initially Inefficient South, Equal Paces of Technological Progress ($z^* > T(0)$, $\alpha = 2\beta L_S$)



6.4.2 Evolution Dynamics: Fast Northern Innovation

As discussed earlier in the chapter, when the North is able to push the world technology frontier faster than the South can catch up ($\alpha > 2\beta L_S$), the efficiency gap between countries widens over time. The developing country will be increasingly lagging behind, although it is also improving. At $t > 0$, the unit labor requirement schedule of the South is:

$$a_S(z,t) = \begin{cases} \bar{a}e^{-z-2\beta L_S t} & \text{if } z \leq T(0)\,, \\ \bar{a}e^{z-2T(0)-2\beta L_S t} & \text{if } z > T(0)\,. \end{cases} \tag{6.43}$$

The technological gap between the countries widens over time:

$$\frac{a_S(z,t)}{a_N(z,t)} = \begin{cases} e^{(\alpha-2\beta L_S)t} & \text{if } z \leq T(0)\,, \\ e^{2z-2T(0)+(\alpha-2\beta L_S)t} & \text{if } z > T(0)\,. \end{cases} \tag{6.44}$$

After the countries start establishing the multinational production chain at $t = 0$, within a certain time period, the offshoring threshold $\bar{z}(t)$ is still within the interval $(T(0), z^*)$. During this time period, the equilibrium is characterized by

$$e^{2\bar{z}(t)-2T(0)+(\alpha-2\beta L_S)t} = \frac{1-\bar{z}(t)}{\bar{z}(t)} \times \frac{L_S}{L_N}\,, \tag{6.45}$$

$$w_S(t) = \frac{\bar{z}(t)}{L_S}\,, \tag{6.46}$$

$$w_N(t) = \frac{1-\bar{z}(t)}{L_N}\,. \tag{6.47}$$

Comparing the task threshold determination conditions at $t > 0$ vs. at $t = 0$ ((6.45) vs. (6.32)), together with the condition that $\alpha > 2\beta L_S$, it is easy to tell that the offshoring threshold in the following time period, $\bar{z}(t)$, shifts towards less-sophisticated tasks: $\bar{z}(t) < \bar{z}(0)$. Therefore, with the increasingly wide technological gap between countries, multinationals tend to move previously offshored tasks back to the home country. Although during the process, the wage rate in the South is always lower than in the North ($w_S(t) < w_N(t)$)[3] , reshoring behavior still occurs. The developing country's labor cost advantage is not adequate to attract more offshoring. In contrast, although it

[3] This can be told by comparing (6.46) and (6.47), together with the condition that $\bar{z}(t) < z^* = \frac{L_S}{L_S+L_N}$.

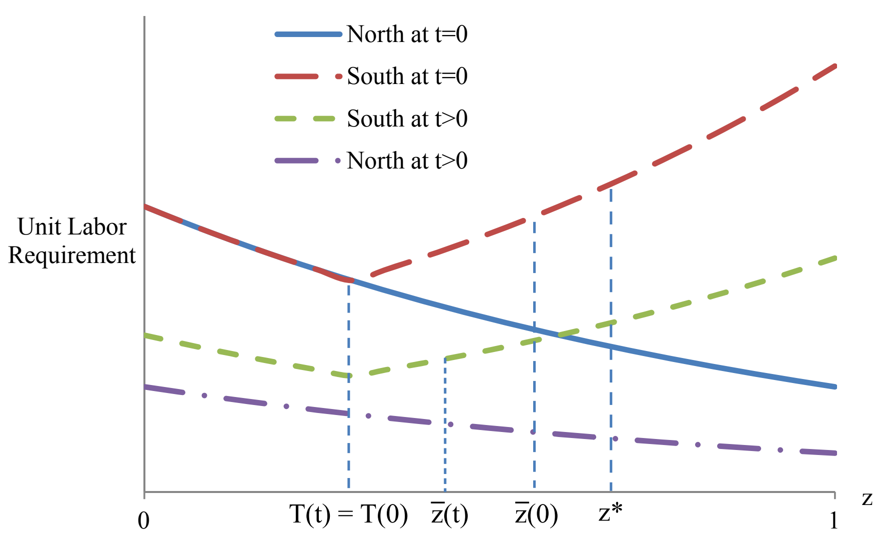
costs higher in the developed country to hire workers, the technology advantage there attracts more activities to return. Anecdotal evidence has shown that multinational firms invest in reshoring in recent years, even though host countries' unit labor costs are lower than home countries'. Such stories and observations are consistent with the analysis presented here – with better technologies and continuous improvement, the developed countries may enjoy more manufacturing activities being relocated back.

After a certain time period, the offshoring threshold $\bar{z}(t)$ moves down to $T(0)$. After that, as the efficiency gap between the countries continues widening, the reshoring behavior will continue. That is, the South starts only conducting the tasks that it is relatively good at. The first condition characterizing the equilibrium – the threshold determination condition – thus changes to:

$$e^{(\alpha - 2\beta L_S)t} = \frac{1 - \bar{z}(t)}{\bar{z}(t)} \times \frac{L_S}{L_N}. \tag{6.48}$$

As time passes, with high innovation pace in the North, the scope of tasks that are conducted in the South shrinks. During the whole process, reshoring persists. The situation can be graphically shown in Figure 6.6.

Figure 6.6: Dynamics of Task Offshoring: an Initially Inefficient South, Fast Northern Innovation ($z^* > T(0)$, $\alpha > 2\beta L_S$)



Reshoring Behavior Examining the reshoring behavior in the two stages respectively, it is found that before the offshoring threshold goes below $T(0)$, the following pattern applies:[4]

$$\left.\frac{d\bar{z}(t)}{dt}\right|_{T(0)\leq\bar{z}(t)<z^*} = -\frac{(\alpha-2\beta L_S)\times\bar{z}(t)\,(1-\bar{z}(t))}{1+2\bar{z}(t)\,(1-\bar{z}(t))} < 0\,, \tag{6.49}$$

$$\left.\frac{d^2\bar{z}(t)}{dt^2}\right|_{T(0)\leq\bar{z}(t)<z^*} \begin{cases} <0 & \text{when } \bar{z}(t) > \frac{1}{2}\,, \\ =0 & \text{when } \bar{z}(t) = \frac{1}{2}\,, \\ >0 & \text{when } \bar{z}(t) < \frac{1}{2}\,. \end{cases} \tag{6.50}$$

After the offshoring threshold goes below $T(0)$, the situation will follow a similar pattern as discussed in Section 6.3.2, where the offshoring threshold is below the initial technology stock in the South, $T(0)$, with the Northern innovation speed faster than that in the South. Technically, this can be seen by comparing the equilibrium conditions (6.48) and (6.25). Therefore, following the same logic, in this stage, the reshoring behavior is characterized by

$$\left.\frac{d\bar{z}(t)}{dt}\right|_{\bar{z}(t)\leq T(0)<z^*} < 0\,, \tag{6.51}$$

$$\left.\frac{d^2\bar{z}(t)}{dt^2}\right|_{\bar{z}(t)\leq T(0)<z^*} \begin{cases} <0 & \text{when } \bar{z}(t) > \frac{1}{2}\,, \\ =0 & \text{when } \bar{z}(t) = \frac{1}{2}\,, \\ >0 & \text{when } \bar{z}(t) < \frac{1}{2}\,. \end{cases} \tag{6.52}$$

At $\bar{z}(t) = T(0)$, $\frac{d\bar{z}(t)}{dt}$ is not continuous.[5] When time goes infinite, the technology gap also goes infinite, which leads to $\lim_{t\to+\infty}\bar{z}(t) = 0$.

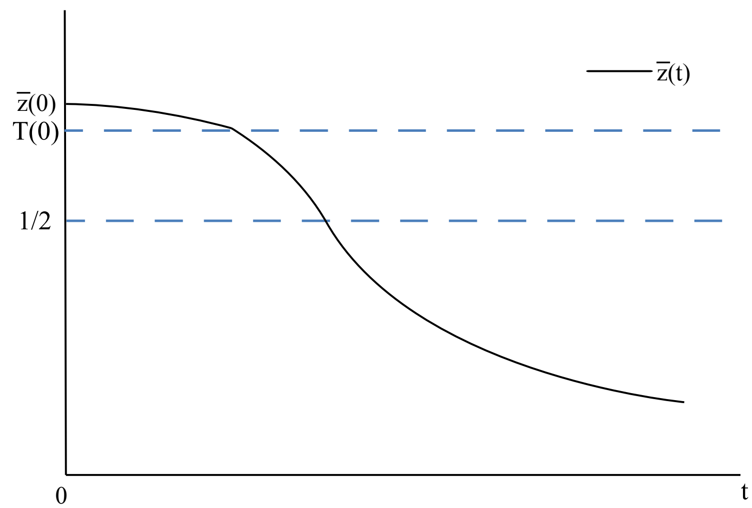
Figure 6.7 displays a couple possible evolution paths of the reshoring behavior for a relatively large South: $L_S > L_N$ thus $z^* > \frac{1}{2}$. Panel A shows the case where the South has a relatively large technology stock at the beginning: $\frac{1}{2} < T(0) < z^*$. In Panel B, the initial stock of technology in the South is relatively small: $T(0) < \frac{1}{2} < \bar{z}(0) < z^*$. In Figure 6.8, the South is relatively small in terms of labor endowment: $L_S < L_N$. Therefore, the wage equalization point $z^* < \frac{1}{2}$.

[4] The expression for $\frac{d\bar{z}(t)}{dt}$ is from examining (6.45). See Appendix C.2.1 for the derivation of $\frac{d^2\bar{z}(t)}{dt^2}$.

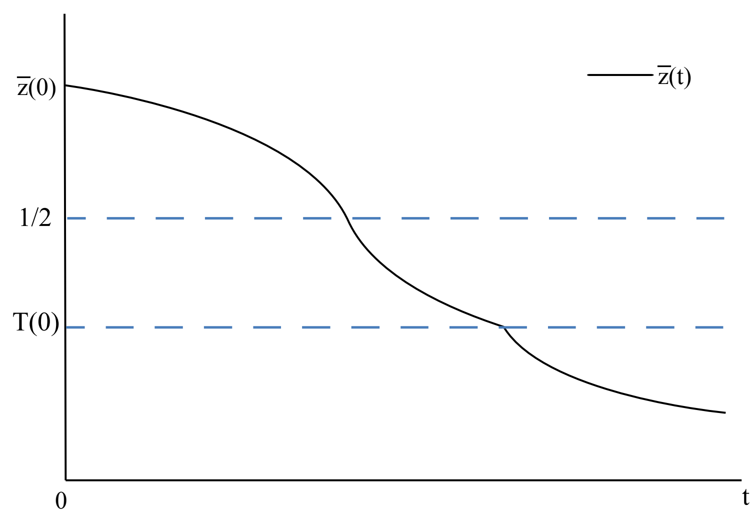
[5] From (6.49), $\frac{d\bar{z}(t)}{dt}|^-_{\bar{z}(t)=T(0)} = -\frac{(\alpha-2\beta L_S)\times T(0)(1-T(0))}{1+2T(0)(1-T(0))}$; From (6.48), $\frac{d\bar{z}(t)}{dt}|^+_{\bar{z}(t)=T(0)} = -(\alpha-2\beta L_S)T(0)(1-T(0))$. Therefore, $\frac{d\bar{z}(t)}{dt}|^-_{\bar{z}(t)=T(0)} > \frac{d\bar{z}(t)}{dt}|^+_{\bar{z}(t)=T(0)}$.

Figure 6.7: Evolution of Offshoring Threshold: A Large and Initially Inefficient South, Fast Northern Innovation ($L_S > L_N$, $z^* > T(0)$, $\alpha > 2\beta L_S$)

(a) Panel A: A High Stock of Technology in the South: $\frac{1}{2} < T(0) < z^*$

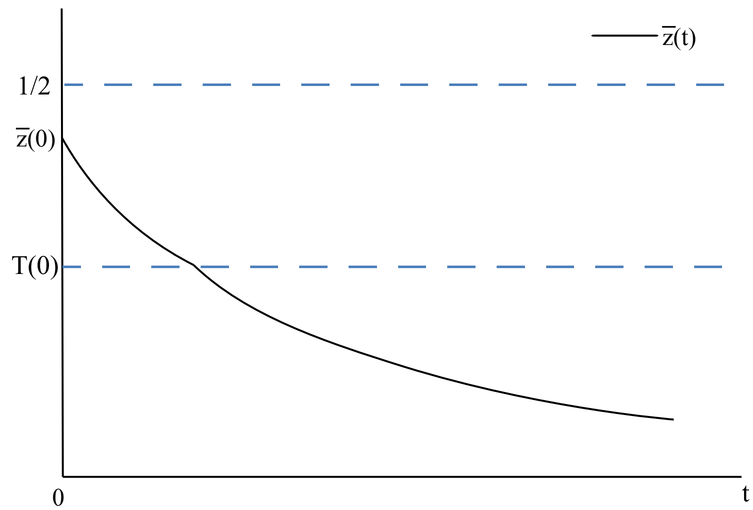


(b) Panel B: A Low Stock of Technology in the South: $T(0) < \frac{1}{2} < \bar{z}(0) < z^*$



When the developed country keeps technology improvement faster than the South can catch up with, reshoring behavior leads to fewer tasks being offshored. Tasks are moved back to the home country, even though the factor price is higher there during the whole process. This demonstrates the possibility that technology advantages can make up for the factor cost disadvantages.

Figure 6.8: Evolution of Offshoring Threshold: A Small and Initially Inefficient South, Fast Northern Innovation ($L_S < L_N$, $T(0) < z^* < \frac{1}{2}$, $\alpha > 2\beta L_S$)



6.4.3 Evolution Dynamics: Fast Southern Learning

With fast learning pace in the South ($2\beta L_S > \alpha$), the country catches up with the North over time – the technology stock of the South, $T(t)$, improves gradually. It is found that with learning function (6.5′), the South's productivity schedule under this circumstance is:

$$a_S(z,t) = \begin{cases} a_N(z,t) = \bar{a}e^{-z-\alpha t} & \text{if } z \leq T(t) = T(0) + (\beta L_S - \frac{\alpha}{2})t\,, \\ \bar{a}e^{z-2T(0)-2\beta L_S t} & \text{if } z > T(t) = T(0) + (\beta L_S - \frac{\alpha}{2})t\,. \end{cases} \tag{6.53}$$

With both countries' progresses, the efficiency gap between their technologies diminishes, which can be told by comparing the two schedules:

$$\frac{a_S(z,t)}{a_N(z,t)} = \begin{cases} 1 & \text{if } z \leq T(t) = T(0) + (\beta L_S - \frac{\alpha}{2})t\,, \\ e^{2z-2T(0)+(\alpha-2\beta L_S)t} & \text{if } z > T(t) = T(0) + (\beta L_S - \frac{\alpha}{2})t\,. \end{cases} \tag{6.54}$$

As discussed earlier, the initial offshoring threshold locates between the Southern technology stock $T(0)$ and the wage-equalization point z^*. After the multinational production chain is formed, within a certain period of time, the offshoring threshold $\bar{z}(t)$ is still within the range $(T(t), z^*)$. The reason and logic is the same as discussed in early chapters. During this time period, the equilibrium is characterized by

$$e^{2\bar{z}(t)-2T(0)+(\alpha-2\beta L_S)t} = \frac{1-\bar{z}(t)}{\bar{z}(t)} \times \frac{L_S}{L_N}, \tag{6.55}$$

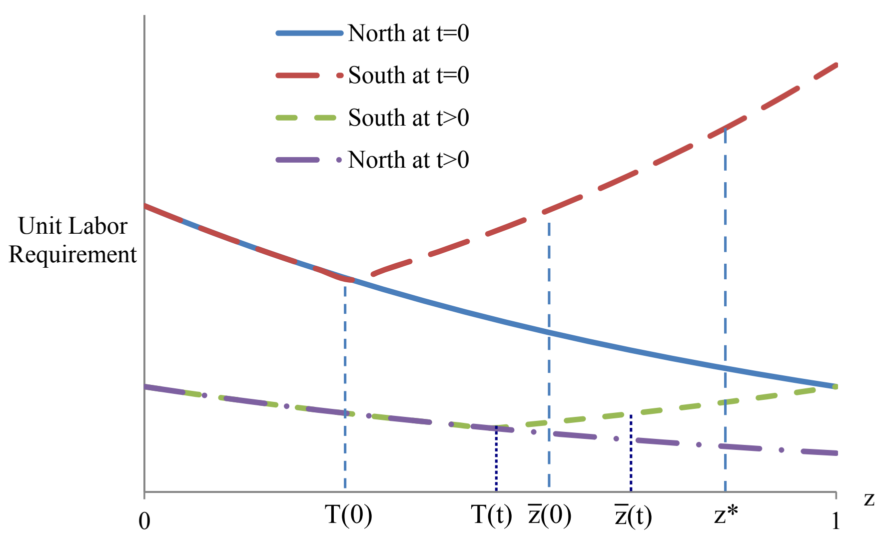
$$w_S(t) = \frac{\bar{z}(t)}{L_S}, \tag{6.56}$$

$$w_N(t) = \frac{1-\bar{z}(t)}{L_N}. \tag{6.57}$$

From the conditions above, it is easy to tell that the scope of tasks conducted in the South in later time periods is greater than the initial task scope: $\bar{z}(t) > \bar{z}(0)$ at $t > 0$.[6] Namely, compared with the initial pattern of task allocation, the South receives more tasks to conduct in later time.

The story is that as the South catches up with the North with fast learning, it can carry out tasks more efficiently, even in terms of the relative productivity with respect to the North. Therefore, more tasks are offshored to take advantage of the cost reduction. Hence, the scope of task expands in developing countries, as displayed in Figure 6.9.

Figure 6.9: Dynamics of Task Offshoring: an Initially Inefficient South, Fast Southern Learning ($z^* > T(0)$, $\alpha < 2\beta L_S$)



Expansion of Task Scope in the South Examining condition (6.55), it is the case that[7]

[6] With $\alpha < 2\beta L_S$, comparing the equilibrium conditions (6.32) and (6.55), it can be told.

$$\left.\frac{d\bar{z}(t)}{dt}\right|_{T(t)<\bar{z}(t)<z^*} = -\frac{(\alpha - 2\beta L_S) \times \bar{z}(t)\,(1-\bar{z}(t))}{1+2\bar{z}(t)\,(1-\bar{z}(t))} > 0\,, \tag{6.58}$$

$$\left.\frac{d^2\bar{z}(t)}{dt^2}\right|_{T(t)<\bar{z}(t)<z^*} \begin{cases} < 0 & \text{when } \bar{z}(t) > \frac{1}{2}\,, \\ = 0 & \text{when } \bar{z}(t) = \frac{1}{2}\,, \\ > 0 & \text{when } \bar{z}(t) < \frac{1}{2}\,. \end{cases} \tag{6.59}$$

As long as the Southern technology stock $T(t)$ is below z^*, it is always the case that $\bar{z}(t) \in (T(t), z^*)$, and the evolution pattern described above applies. With the learning effect, the technology stock $T(t)$ keeps moving toward the complex activities and will reach z^* at some time t^*. Once this is the situation($T(t^*) = z^*$), the South has the best up-to-date technologies available for all the tasks that are conducted in the country. The offshoring threshold will also be at z^* then: $\bar{z}(t^*) = T(t^*) = z^*$. After t^*, the Southern technology stock moves even further – the South is catching up with the North on even more complicated activities. With $T(t) > z^*$, following the same logic as in Section 6.3.3, the offshoring threshold will not move further beyond z^*. Therefore, in this case, z^* serves as the long-run steady state of task allocation.

Given different relative positions of $T(0)$ and z^*, how the task allocation may evolve varies. Figure 6.10 shows two possible evolution paths of the offshoring threshold $\bar{z}(t)$. In Panel A, the size of the South is relatively large: $\bar{z}(0) < \frac{1}{2} < z^*$. In contrast, Panel B shows the evolution progress with a small South: $z^* < \frac{1}{2}$. In both situations, the task scope of the South expands until all tasks below z^* are offshored. In the long run, even though the South may actually catch up with the North on all activities ($T(t) = 1$ at some time t), no more than z^* will be offshored.

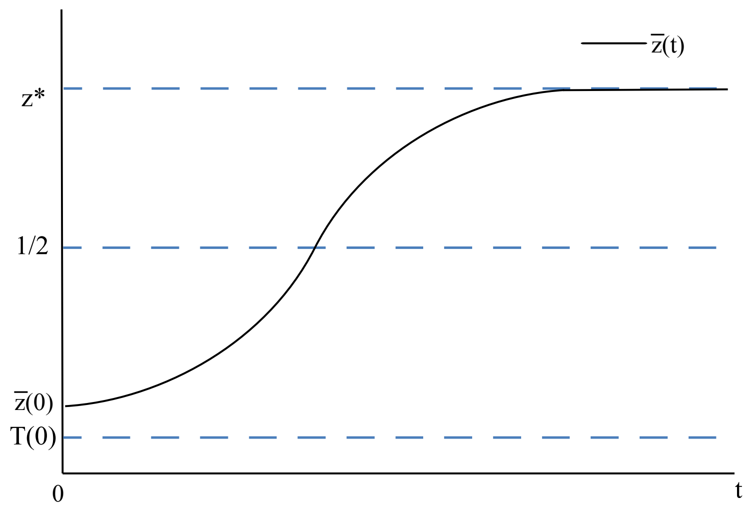
6.5 Concluding Remarks

This chapter is an extension of the basic model introduced in Chapter 3, incorporating an important factor that influences how the multinational production chain may evolve over time – innovation. Technology innovations occurring in developed countries constantly push the world's

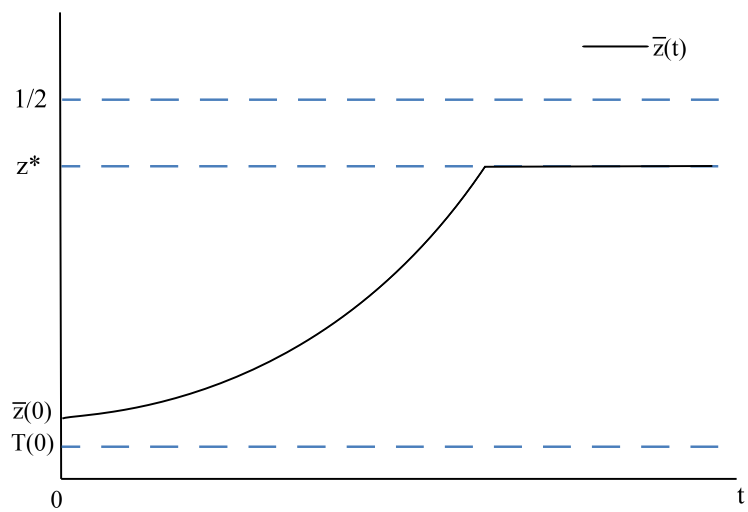
[7] See Appendix C.2.2 for the derivation of $\left.\frac{d^2\bar{z}(t)}{dt^2}\right|_{T(t)<\bar{z}(t)<z^*}$.

Figure 6.10: Evolution of Offshoring Threshold: A Initially Inefficient South, Fast Southern Learning ($z^* > T(0)$, $\alpha < 2\beta L_S$)

(a) Panel A: A Relatively Large South: $\bar{z}(0) < \frac{1}{2} < z^*$



(b) Panel B: A Relatively Small South: $z^* < \frac{1}{2}$



efficiency frontier to newer limits. This creates room for constant learning in the South, and it also raises the possibility that the efficiency gap between the two countries widens over time. When the learning effect in the South is not adequate to lead the country to catch up with the North, reshoring will occur, where the previously offshored activities return to the originating home country, even though the factor price in the South is lower relative to that in the North during the reshoring process. Certainly, the ongoing reshoring trend may be out of various incentives of firms. The production-efficiency advantage of developed countries is one critical factor that contributes to the development of this trend.

The technologically less advanced country here is still able to climb up the global value chain, as it does in models in previous chapters. This is achieved by fast learning within the country. When the South learns faster than the North can innovate, it catches up with the latter gradually, which then enables more sophisticated activities to be offshored. Essentially, the change of relative efficiency of the two countries is the key driving offshoring evolution over time.

Several limitation are involved in developing the task-based framework of global production. These can be addressed in future research. First, consider a framework with more players (e.g., three countries). The interaction among countries' characteristics may bring richer descriptions with regard to how countries may evolve along the global value chain respectively. The position and task scope of countries may display quite different evolution paths – a country may conduct fewer but all the more sophisticated tasks. Then the phrase, "moving up the global value chain," will have different meanings and dynamics to be considered.

Another limitation here relates to firm identification. In the basic framework, firms do not play a critical role. In the monopolistic competition model, symmetric firms have been assumed, with plants in the same country performing the same set of tasks. This provides convenience for the theoretical analyses here, but it may sacrifice flexibility in discussing firm dynamics. A possible avenue for future research is thus to consider firms as collections of tasks that are not necessarily symmetric, with each conducting a certain range of tasks along the spectrum and/or with heterogeneous productivities. This will provide opportunities to study the firm dynamics and thus may offer further empirical investigation possibilities.

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Appendix A

Derivations for Chapter 3

A.1 Transition Dynamics of Task Offshoring

A.1.1 Evolution of Technology Stock with Learning-by-Doing

(1) Derivation of Equation (3.29)

First, note that $L_S(z,t) = 0$ for all $z > \bar{z}(t)$ at any time t. For tasks $z \leq \bar{z}(t)$, from (3.7) and (3.13),

$$L_S(z,t) = \frac{1}{w_S(t)}\,. \tag{A.1}$$

With (3.27), the technology stock accumulation function (3.6) turns to

$$\begin{aligned}\frac{dT(t)}{dt} &= \int_{T(t)}^{\bar{z}(t)} \beta L_S(z,t)dz = \int_{T(t)}^{\bar{z}(t)} \beta \times \frac{1}{w_S(t)} dz = \int_{T(t)}^{\bar{z}(t)} \beta \frac{L_S}{\bar{z}(t)} dz \\ &= \beta L_S \times \frac{\bar{z}(t) - T(t)}{\bar{z}(t)}\,.\end{aligned} \tag{A.2}$$

(2) Derivation of (3.32): $\frac{d^2T(t)}{dt^2} < 0$

By examining (3.29), it is found that

$$\frac{d^2T(t)}{dt^2} = -\beta L_S \times \frac{1}{\bar{z}(t)^2} \times \left(\bar{z}(t)\frac{dT(t)}{dt} - T(t)\frac{d\bar{z}(t)}{dt}\right)\,. \tag{A.3}$$

During the evolution process, it is the case that $\bar{z}(t) > T(t) > 0$ and $\frac{dT(t)}{dt} > \frac{d\bar{z}(t)}{dt} > 0$. Therefore, it is easy to tell that $\frac{d^2T(t)}{dt^2} < 0$ along the way.

A.1.2 Evolution of Offshoring Threshold with Learning-by-Doing

From (3.26), (3.29) and (3.30), it can be calculated that

$$\frac{d^2\bar{z}(t)}{dt^2} = \left\{ -\frac{\beta L_S}{\bar{z}(t)} \times \frac{1}{1+2\bar{z}(t)\left(1-\bar{z}(t)\right)} - \beta L_S \times 2\left(\bar{z}(t) - T(t)\right) \times \frac{2\left[1-\bar{z}(t)\right]^2+1}{\left[1+2\bar{z}(t)\left(1-\bar{z}(t)\right)\right]^2} \right\} \times \frac{d\bar{z}(t)}{dt} \tag{A.4}$$

Given the condition that $0 < T(t) < \bar{z}(t) < 1$ and $\frac{d\bar{z}(t)}{dt} > 0$, it is the case that $\frac{d^2\bar{z}(t)}{dt^2} < 0$ before the steady state is reached.

A.2 Dynamics of National Welfare and Gains from Offshoring

A.2.1 Evolution of Output with Learning-by-Doing

(1) Output Amount at t

Given the production function (3.1), the unit labor requirement functions (3.2) and (3.5), as well as (3.7), (3.8), (3.13), and the equilibrium conditions (3.26) – (3.28), it is the case that

$$\begin{aligned} \ln Y(t) &= \int_0^1 \ln x(z,t)dz \\ &= \int_0^{T(t)} \ln \frac{1}{w_S(t) \times \bar{a}e^{-z}} dz + \int_{T(t)}^{\bar{z}(t)} \ln \frac{1}{w_S(t) \times \bar{a}e^{z-2T(t)}} dz + \int_{\bar{z}(t)}^1 \ln \frac{1}{w_N(t) \times \bar{a}e^{-z}} dz \\ &= \bar{z}(t)^2 - T(t)^2 + \ln \frac{L_N}{\bar{a}(1-\bar{z}(t))} + \frac{1}{2} \end{aligned} \tag{A.5}$$

This indicates that the total world output at time t can be expressed as

$$Y(t) = \frac{L_N}{\bar{a}(1-\bar{z}(t))} \times e^{\bar{z}(t)^2 - T(t)^2} \times e^{\frac{1}{2}} \tag{A.6}$$

(2) Derivation of Equation (3.34)

Given the output expression (3.33),

$$\frac{dY(t)}{dt} = Y(t) \times \left[2\bar{z}(t)\frac{d\bar{z}(t)}{dt} - 2T(t)\frac{dT(t)}{dt} + \frac{1}{1-\bar{z}(t)}\frac{d\bar{z}(t)}{dt} \right]. \tag{A.7}$$

Given (3.30), (A.7) can be simplified to

$$\frac{dY(t)}{dt} = Y(t) \times 2[\bar{z}(t) - T(t)]\frac{dT(t)}{dt} . \tag{A.8}$$

During the evolution process before arriving at the steady state, $\bar{z}(t) > T(t)$, and $\frac{dT(t)}{dt} > 0$, and thus it is the case that $\frac{dY(t)}{dt} > 0$.

(3) Derivation of Equation (3.35)

Given (3.33) and (3.34),

$$\begin{aligned}\frac{d^2Y(t)}{dt^2} =& \frac{dY(t)}{dt} \times 2\left[\bar{z}(t) - T(t)\right]\frac{dT(t)}{dt} + Y(t) \times 2\left[\frac{d\bar{z}(t)}{dt} - \frac{dT(t)}{dt}\right] \times \frac{dT(t)}{dt} \\ & + Y(t) \times 2\left[\bar{z}(t) - T(t)\right] \times \frac{d^2T(t)}{dt^2} \\ =& Y(t) \times 4\left[\bar{z}(t) - T(t)\right]^2 \times \left(\frac{dT(t)}{dt}\right)^2 + Y(t) \times 2\left[\frac{d\bar{z}(t)}{dt} - \frac{dT(t)}{dt}\right] \times \frac{dT(t)}{dt} \\ & + Y(t) \times 2\left[\bar{z}(t) - T(t)\right] \times \frac{d^2T(t)}{dt^2}\end{aligned} \tag{A.9}$$

With (3.29), (3.30) and (A.3), it is simplified to

$$\frac{d^2Y(t)}{dt^2} = 4Y(t) \times \left(\frac{dT(t)}{dt}\right)^2 \times A\left(\bar{z}(t), T(t)\right) , \tag{A.10}$$

where $A\left(\bar{z}(t), T(t)\right) = \left[\bar{z}(t) - T(t)\right]^2 - \frac{1+[1-\bar{z}(t)][\bar{z}(t)-T(t)]}{1+2\bar{z}(t)[1-\bar{z}(t)]}$. With the condition that $0 < T(t) < \bar{z}(t) < 1$, $A\left(\bar{z}(t), T(t)\right) \in (-1, 0)$. Therefore, $\frac{d^2Y(t)}{dt^2} < 0$ before multinational production arrives at the steady state.

A.2.2 Evolution of Southern Welfare with Learning-by-Doing

Differentiating (3.39), together with (3.30), (3.34), (A.3) and (A.10), it is obtained that

$$\begin{aligned}\frac{d^2\omega_S(t)}{dt^2} =& 4Y(t)\bar{z}(t) \times \left(\frac{dT(t)}{dt}\right)^2 \times \Theta\left(\bar{z}(t),\, T(t)\right) \\ & - Y(t) \times \frac{2\beta L_S}{1 + 2\bar{z}(t)(1 - \bar{z}(t))} \times \frac{1 + 2(1 - \bar{z}(t))(\bar{z}(t) - T(t))}{1 + 2\bar{z}(t)(1 - \bar{z}(t))} \times \frac{dT(t)}{dt} ,\end{aligned} \tag{A.11}$$

where $\Theta\left(\bar{z}(t),\, T(t)\right) = (\bar{z}(t) - T(t))^2 + \frac{(1-\bar{z}(t))(\bar{z}(t)-T(t))-1}{1+2\bar{z}(t)(1-\bar{z}(t))} + \frac{(1-2\bar{z}(t))(1-\bar{z}(t))}{[1+2\bar{z}(t)(1-\bar{z}(t))]^3}$. With $0 < T(t) < \bar{z}(t) < 1$, $\Theta\left(\bar{z}(t),\, T(t)\right) \in (-1, 0)$. Therefore, it is the case that $\frac{d^2\omega_S(t)}{dt^2} < 0$ during the offshoring evolution process before the steady state is reached.

A.2.3 Evolution of Northern Welfare with Learning-by-Doing

Differentiating (3.38),

$$\frac{d\omega_N(t)}{dt} = -Y(t)\frac{d\bar{z}(t)}{dt} + (1-\bar{z}(t))\frac{dY(t)}{dt} \,. \tag{A.12}$$

With (3.26), (3.30) and (3.34), it can be simplified to

$$\frac{d\omega_N(t)}{dt} = 2Y(t) \times (1-\bar{z}(t)) \times \frac{dT(t)}{dt} \times \Lambda(\bar{z}(t))\,, \tag{A.13}$$

where $\Lambda(\bar{z}(t)) = -\frac{\bar{z}(t)}{1+2\bar{z}(t)(1-\bar{z}(t))} + \frac{1}{2}\ln\left[\frac{L_S}{L_N} \times \frac{1-\bar{z}(t)}{\bar{z}(t)}\right]$. The sign of $\frac{d\omega_N(t)}{dt}$ is determined by $\Lambda(\bar{z}(t))$. Therefore, the cut-off value $\tilde{z}_N$ for sign change of Northern welfare is determined by the condition:

$$\frac{z}{1+2z(1-z)} = \frac{1}{2}\ln\left[\frac{L_S}{L_N} \times \frac{1-z}{z}\right] \,. \tag{A.14}$$

For the above equation, the left-hand side is a monotonically increasing function of z, while the right-hand side is a monotonically decreasing one, and thus the solution is unique. At $\tilde{z}_N$, $\frac{d\omega_N(t)}{dt} = 0$. Before multinational production reaches the steady state, when $\bar{z}(t) < \tilde{z}_N$, $\frac{d\omega_N(t)}{dt} > 0$; when $\bar{z}(t) > \tilde{z}_N$, $\frac{d\omega_N(t)}{dt} < 0$. When $\bar{z}(t)$ is very close to the steady state, the right-hand side of (A.14) is close to zero, while the left-hand side is positive – $\Lambda(\bar{z}(t)) < 0$ under this circumstance. Therefore, at the latest stages when offshoring is close to the steady state, the North always experiences a decline in its welfare.

Appendix B

Derivations for Chapter 4

B.1 Transition Dynamics of Task Offshoring

B.1.1 Evolution of Technology Stock with Learning-by-Doing

(1) Derivation of Equation (4.26)

By equation (4.13) and (4.19),

$$L_S(z,t) = \frac{\rho}{w_S(t)} \,. \tag{B.1}$$

Recall that $L_S(z,t) = 0$ for all $z > \bar{z}(t)$ at any time t and that all Southern plants are symmetric. Together with (4.23′) and (4.25′), the technology accumulation function (4.12) turns to

$$\begin{aligned}\frac{dT(t)}{dt} &= \int_{T(t)}^{\bar{z}(t)} \frac{\beta L_S(z,t)}{J(t)} dz = \int_{T(t)}^{\bar{z}(t)} \frac{\beta}{J(t)} \frac{\rho}{w_S(t)} dz = \int_{T(t)}^{\bar{z}(t)} \frac{\beta}{J(t)} \frac{L_S}{\bar{z}(t)} dz \\ &= \frac{\beta L_S}{J(t)} \frac{\bar{z}(t) - T(t)}{\bar{z}(t)} = \beta\sigma f\left(1 - \rho\bar{z}(t)\right) \frac{L_S}{L_N} \frac{\bar{z}(t) - T(t)}{\bar{z}(t)} \,.\end{aligned} \tag{B.2}$$

(2) Derivation of (4.29): $\frac{d^2T(t)}{dt^2} < 0$

By examining (4.26), it is obtained that

$$\frac{d^2T(t)}{dt^2} = -\frac{\beta L_S}{J(t)} \times \frac{1}{\bar{z}(t)^2} \times \left(\bar{z}(t)\frac{dT(t)}{dt} - T(t)\frac{d\bar{z}(t)}{dt}\right) - \beta\sigma\rho f \times \frac{L_S}{L_N} \times \frac{\bar{z}(t) - T(t)}{\bar{z}(t)} \times \frac{d\bar{z}(t)}{dt} \,. \tag{B.3}$$

It is easy to tell that $\frac{d^2T(t)}{dt^2} < 0$ before it reaches the steady state.

B.1.2 Evolution of Offshoring Threshold with Learning-by-Doing

From examining (4.26) and (4.27), $\frac{d^2\bar{z}(t)}{dt^2}$ can be derived as:

$$\frac{d^2\bar{z}(t)}{dt^2} = \left\{ -\frac{\beta L_S}{J(t)\bar{z}(t)} \times \frac{1}{1+2\bar{z}(t)(1-\rho\bar{z}(t))} - \frac{\beta L_S}{J(t)} \times 2(\bar{z}(t)-T(t)) \times \frac{2[1-\rho\bar{z}(t)]^2+\rho}{[1+2\bar{z}(t)(1-\rho\bar{z}(t))]^2} \right\} \times \frac{d\bar{z}(t)}{dt} - \beta\sigma\rho f \times \frac{L_S}{L_N} \times \frac{\bar{z}(t)-T(t)}{\bar{z}(t)} \times \frac{2\bar{z}(t)(1-\rho\bar{z}(t))}{1+2\bar{z}(t)(1-\rho\bar{z}(t))} \times \frac{d\bar{z}(t)}{dt} . \tag{B.4}$$

It is not hard to tell from the result that $\frac{d^2\bar{z}(t)}{dt^2} < 0$ before the steady state is reached.

B.2 Evolution of Number of Variety with Learning-by-Doing

B.2.1 Derivation of (4.30): $\frac{dJ(t)}{dt} > 0$

By condition (4.25′),

$$\frac{dJ(t)}{dt} = \frac{\rho L_N}{\sigma f} \times \frac{1}{[1-\rho\bar{z}(t)]^2} \times \frac{d\bar{z}(t)}{dt} , \tag{B.5}$$

which is positive before $\bar{z}(t)$ arrives at its steady state.

B.2.2 Derivation of (4.30): $\frac{d^2J(t)}{dt^2} < 0$

Further examination of the condition (B.5), together with (4.26), (4.27) and the conditions derived in Appendices B.1.1 and B.1.2, shows that

$$\frac{d^2J(t)}{dt^2} = \frac{\beta\rho L_S}{1-\rho\bar{z}(t)} \times \frac{d\bar{z}(t)}{dt} \times \frac{1}{\bar{z}(t)[1+2\bar{z}(t)(1-\rho\bar{z}(t))]^2} \times \{2\bar{z}(t)(1-\rho\bar{z}(t))[2(\bar{z}(t)-T(t))(2\rho\bar{z}(t)-1)-1]-1\} , \tag{B.6}$$

which is negative when $\bar{z}(t)$ moves to its steady state.

B.3 Evolution of Per-Brand Output with Learning-by-Doing

B.3.1 Derivation of Per-Brand Output − (4.33)

Given the production function (4.7) and the symmetry of firms, together with conditions (4.8), (4.11), (4.13), (4.14), (4.19), and equilibrium conditions (4.22′), (4.23′), (4.24′), and (4.25′), it is the case that

$$\begin{aligned}\ln Y(t) =& \int_0^1 \ln x(z,j,t)dz \\ =& \int_0^{T(t)} \ln\left(\frac{1}{J(t)}\frac{\rho}{w_S(t)\bar{a}e^{-z}}\right)dz + \int_{T(t)}^{\bar{z}(t)} \ln\left(\frac{1}{J(t)}\frac{\rho}{w_S(t)\bar{a}e^{z-2T(t)}}\right)dz+ \\ & \int_{\bar{z}(t)}^1 \ln\left(\frac{1}{J(t)}\frac{\rho}{w_N(t)\bar{a}e^{-z}}\right)dz \\ =& \bar{z}(t)^2 - T(t)^2 + \frac{1}{2} + \ln\left(\frac{\rho\sigma f}{\bar{a}}\right).\end{aligned} \tag{B.7}$$

This implies that the per-brand output $Y(t)$ is

$$Y(t) = \frac{\rho\sigma f}{\bar{a}} e^{\frac{1}{2}} \times e^{\bar{z}(t)^2 - T(t)^2}. \tag{B.8}$$

B.3.2 Time Dynamics of Per-Brand Output

Given the per-brand output expressed by (4.33),

$$\frac{dY(t)}{dt} = Y(t) \times 2\left[\bar{z}(t)\frac{d\bar{z}(t)}{dt} - T(t)\frac{dT(t)}{dt}\right]. \tag{B.9}$$

There is no deterministic relationship between $\bar{z}(t)\frac{\bar{z}(t)}{dt}$ and $T(t)\frac{dT(t)}{dt}$, thus the path of $Y(t)$ may be non-monotonic. With (4.22′) and (4.27), it is found that there exists a stationary point $\tilde{z}_y$, which is determined by the following equation:

$$\frac{z}{1+2z(1-\rho z)} = \frac{1}{2}\ln\left[\frac{L_S}{L_N}\frac{1-\rho z}{\rho z}\right], \tag{B.10}$$

that at $\tilde{z}_y$, $\frac{dY(t)}{dt} = 0$. The solution is unique, as the left-hand side of the equation above monotonically increases in z, while the right-hand side of the equation monotonically decreases in z. By examining the values of the left-hand-side and the right-hand-side of the equation above at z^*, it is found that it must be the case: $\tilde{z}_y < z^*$. Similarly, the values examined at $z = 0$ indicate that $\tilde{z}_y > 0$.

B.4 Dynamics of National Welfares

B.4.1 Derivation of $\frac{dU_S(t)}{dt}$

Given (4.36), together with condition (4.27),

$$\begin{aligned}\frac{dU_S(t)}{dt} =&\rho \times \left(\frac{L_N}{\sigma f}\right)^{\frac{1}{\rho}} \times \frac{\rho\sigma f}{\bar{a}} \times e^{\frac{1}{2}} \times (1-\rho\bar{z}(t))^{-\frac{1}{\rho}} \times e^{\bar{z}(t)^2-T(t)^2} \times \frac{d\bar{z}(t)}{dt}\times \\ &\left\{\frac{(1-\rho\bar{z}(t))+(\bar{z}(t)-T(t))\times[1+2\bar{z}(t)(1-\rho\bar{z}(t))]}{1-\rho\bar{z}(t)}\right\},\end{aligned} \tag{B.11}$$

which is non-negative, and is positive before $\bar{z}(t)$ reaches the steady state.

B.4.2 Dynamics of Northern Welfare $U_N(t)$

Given (4.37), together with condition (4.27),

$$\begin{aligned}\frac{dU_N(t)}{dt} =& \left(\frac{L_N}{\sigma f}\right)^{\frac{1}{\rho}} \times \frac{\rho\sigma f}{\bar{a}} \times e^{\frac{1}{2}} \times (1-\rho\bar{z}(t))^{-\frac{1}{\rho}} \times e^{\bar{z}(t)^2-T(t)^2} \times \frac{d\bar{z}(t)}{dt}\times \\ &\left\{1-\rho+2\bar{z}(t)(1-\rho\bar{z}(t))-\frac{T(t)}{\bar{z}(t)}-2T(t)(1-\rho\bar{z}(t))\right\}.\end{aligned} \tag{B.12}$$

With condition (4.22′) and (4.27), it is found that there exists a stationary point $\tilde{z}_{UN}$, which is determined by

$$\frac{\rho z}{1+2z(1-\rho z)} = \frac{1}{2}\ln\left(\frac{L_S}{L_N}\frac{1-\rho z}{\rho z}\right). \tag{B.13}$$

At $\tilde{z}_{UN}$, $\frac{dU_N(t)}{dt}=0$. The left-hand side of the equation above monotonically increases in z, while the right-hand side monotonically decreases in z, and therefore the solution is unique. Moreover, by comparing the values of the two sides of the equation at different points of z, it is found that

$$\tilde{z}_{UN} > \tilde{z}_y\,, \tag{B.14}$$

and

$$\tilde{z}_{UN} \in (0, z^*)\,. \tag{B.15}$$

B.5 Extreme-End Evolution

B.5.1 Derivation of (4.40)

Given the production function (4.7) and the symmetry of firms, together with conditions (4.8), (4.11), (4.13), (4.14), (4.19), (4.23′), (4.24′), (4.25′), and the condition that $\bar{z}(t) = 1$, it is the case that

$$\begin{aligned} \ln Y(t)' &= \int_0^1 \ln x(z, j, t) dz \\ &= \int_0^{T(t)} \ln \left(\frac{1}{J(t)} \frac{\rho}{w_S(t)\bar{a}e^{-z}} \right) dz + \int_{T(t)}^1 \ln \left(\frac{1}{J(t)} \frac{\rho}{w_S(t)\bar{a}e^{z-2T(t)}} \right) dz \\ &= \ln \frac{L_S f}{L_N \bar{a}} - T(t)^2 + 2T(t) - \frac{1}{2} \, . \end{aligned} \tag{B.16}$$

This implies that the per-brand output $Y(t)'$ is

$$Y(t)' = \frac{L_S f}{L_N \bar{a}} \times e^{-(T(t)-1)^2 + \frac{1}{2}} \, . \tag{B.17}$$

B.5.2 Derivation of $\frac{dY(t)'}{dt}$

Given (4.40),

$$\frac{dY(t)'}{dt} = \frac{L_S f}{L_N \bar{a}} \times e^{-(T(t)-1)^2 + \frac{1}{2}} \times [2(1 - T(t))] \times \frac{dT(t)}{dt} \, , \tag{B.18}$$

which is positive when $T(t) < 1$ and $\frac{dT(t)}{dt} > 0$.

B.6 Northern Gains from Offshoring under Complete Offshoring

From (4.59),

$$\frac{U_N^{*\prime}}{U_N^A} = \frac{L_S}{L_N} \times \frac{1}{\rho} \times (1 - \rho)^{2 - \frac{1}{\rho}} \, . \tag{B.19}$$

The function $\frac{1}{\rho} \times (1 - \rho)^{2 - \frac{1}{\rho}}$ is monotonically decreasing in ρ on the interval $(0, 1)$. Thus, with $\rho < \frac{L_S}{L_S + L_N}$ in the extreme offshoring case,

$$\frac{U_N^{*\prime}}{U_N^A} > \frac{U_N^{*\prime}}{U_N^A}\bigg|(\rho = \frac{L_S}{L_S + L_N}) = \left(\frac{L_S + L_N}{L_N} \right)^{\frac{L_N}{L_S}} > 1. \tag{B.20}$$

Therefore, the North's national welfare is higher with offshoring in the long run than under autarky.

Appendix C

Derivations for Chapter 6

C.1 The Evolution Dynamics: An Initially Efficient South, Fast Northern Innovation

From (6.25), $\bar{z}(t) = \frac{L_S}{L_S + L_N e^{(\alpha - 2\beta L_S)t}}$. Together with the condition (6.25), it is found:

$$\frac{d^2\bar{z}(t)}{dt^2} = L_S^2 \times L_N \times e^{(\alpha - 2\beta L_S)t} \times (\alpha - 2\beta L_S)^2 \times \frac{1}{\left[L_S + L_N e^{(\alpha - 2\beta L_S)t}\right]^3} \times \left[\frac{1 - \bar{z}(t)}{\bar{z}(t)} - 1\right]. \quad \text{(C.1)}$$

With $\alpha > 2\beta L_S$, the sign of $\frac{d^2\bar{z}(t)}{dt^2}$ depends on the last term in the function above. Therefore, it is the case that

$$\frac{d^2\bar{z}(t)}{dt^2} = \begin{cases} < 0 & \text{when } \bar{z}(t) > \frac{1}{2}, \\ = 0 & \text{when } \bar{z}(t) = \frac{1}{2}, \\ > 0 & \text{when } \bar{z}(t) < \frac{1}{2}. \end{cases} \quad \text{(C.2)}$$

C.2 The Evolution Dynamics: An Initially Inefficient South

C.2.1 Evolution Dynamics: Fast Northern Innovation

Examining (6.49), with condition (6.45), it is found:

$$\left.\frac{d^2\bar{z}(t)}{dt^2}\right|_{T(0) \leq \bar{z}(t) < z^*} = -(\alpha - 2\beta L_S) \times \frac{1}{[1 + 2\bar{z}(t)(1 - \bar{z}(t))]^2} \times (1 - 2\bar{z}(t)) \times \frac{d\bar{z}(t)}{dt}. \quad \text{(C.3)}$$

With $\alpha > 2\beta L_S$ and $\frac{d\bar{z}(t)}{dt} < 0$, the sign of $\frac{d^2\bar{z}(t)}{dt^2}$ depends on the term $1 - 2\bar{z}(t)$ in the function above. Therefore, it is the case that

$$\left.\frac{d^2\bar{z}(t)}{dt^2}\right|_{T(0)\leq\bar{z}(t)<z^*} = \begin{cases} < 0 & \text{when } \bar{z}(t) > \frac{1}{2}\,, \\ = 0 & \text{when } \bar{z}(t) = \frac{1}{2}\,, \\ > 0 & \text{when } \bar{z}(t) < \frac{1}{2}\,. \end{cases} \tag{C.4}$$

C.2.2 Evolution Dynamics: Fast Southern Learning

Examining (6.58), with condition (6.55), it is found:

$$\left.\frac{d^2\bar{z}(t)}{dt^2}\right|_{T(t)<\bar{z}(t)<z^*} = -(\alpha - 2\beta L_S) \times \frac{1}{[1 + 2\bar{z}(t)(1-\bar{z}(t))]^2} \times (1 - 2\bar{z}(t)) \times \frac{d\bar{z}(t)}{dt}\,. \tag{C.5}$$

With $\alpha < 2\beta L_S$ and $\frac{d\bar{z}(t)}{dt} > 0$, the sign of $\frac{d^2\bar{z}(t)}{dt^2}$ depends on the term $1 - 2\bar{z}(t)$ in the function above. Therefore, it is the case that

$$\left.\frac{d^2\bar{z}(t)}{dt^2}\right|_{T(t)<\bar{z}(t)<z^*} = \begin{cases} < 0 & \text{when } \bar{z}(t) > \frac{1}{2}\,, \\ = 0 & \text{when } \bar{z}(t) = \frac{1}{2}\,, \\ > 0 & \text{when } \bar{z}(t) < \frac{1}{2}\,. \end{cases} \tag{C.6}$$