Essays on mechanisms of technological catch-up and industrial upgrading in economic development

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Candidate Statement

I, Yixiao Zhou, hereby declare that, except where acknowledged, this thesis is my own original work and has not been submitted for a higher degree at any other university or institution.

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Abstract

This thesis examines the channels and mechanisms of technological catch-up and industrial upgrading in the context of economic development. Technological progress is critical for a country's sustainable growth and for the successful transition of a country from imitation to innovation. Therefore, to clarify the main channels and mechanisms driving the accumulation of knowledge and technologies in an economy contributes to an understanding of the sources of economic growth.

The specific aspects of technological catch-up and industrial upgrading covered in the thesis include inter-sectoral industrial upgrading, the intensification of R&D activities, a country's tapping into foreign sources of knowledge, and a country's changing position in the global value chain. In studying these channels and mechanisms, in-depth theoretical discussion and quantitative methods are applied. In terms of theoretical discussion, the thesis covers many issues relating to the factors contributing to technological progress and draws our attention to the key aspects of such progress. In terms of quantitative methods, advanced econometric methods such as Generalized Method of Moments (GMM), the estimator from Kyriazidou (1997), the Heckman two-step estimator, the Tobit and Probit estimators and various instrumental variable estimators are employed to address different econometric issues and data structures in model estimations.

The thesis finds evidence of the critical role of institutional quality in promoting the productive use of scarce tertiary human capital, in stimulating the Research and Development (R&D) investment of firms, and in attracting R&D investment in host countries by multinational enterprises. The thesis also reveals the importance of human capital as an essential input to the process of technological catch-up and industrial upgrading. A case study of Chinese manufacturing firms clarifies the determinants of firm-level R&D investment, which helps us understand and predict the prospects for innovation in the Chinese economy. By linking firm-level production and customs datasets, the thesis probes into the important question of how trade participation affects innovation in the context of the Chinese economy, which is an especially interesting case due to the huge contribution from trade to China's growth miracle to date. The findings draw attention to processing trade and suggest that under some circumstances deep and long-term engagement in processing trade may adversely influence the R&D investment and innovation prospect of firms. This point reflects the difficulty of

technological catch-up and industrial upgrading in a world where global production sharing continues to deepen.

Based on the results of empirical and quantitative analyses, several policy suggestions are proposed. These include (1) enhancing institutional quality to accompany other growth-promoting policies, (2) encouraging individual and household-level investment in human capital, (3) nurturing domestic R&D stock and research talents at relatively early stages of development and (4) looking beyond the direct targets of industrial and trade policies to take into account the implications for technological catch-up and industrial upgrading when making such policies.

The thesis also points out some directions for future research to extract from the dynamics of the world economy those channels and mechanisms of technological catch-up and industrial upgrading yet unclarified by this thesis.

Table of Contents

List of Tables

List of Figures

Chapter 1: Introduction

1.1 The key issues and main contributions

When countries have either more resources or better ideas for transforming inputs into goods and services, economic growth occurs. Since there are limits to increases in available resources, technological progress is the fundamental force underlying long-run growth in real income per person (Aghion and Howitt, 2007). As a result, differences in innovative activities and the consequent technological gaps between countries are significant factors in explaining cross-country variation in productivity and per capita income levels. According to several studies, roughly half of the cross-country differences in per capita income can be explained by differences in total factor productivity (TFP), a widely-used indicator of an economy's technological level (Parisi et al., 2006; Fagerberg, Mowery et al., 2005; Fagerberg, Srholec et al., 2009; Guinet et al., 2009; Jones and Romer, 2010).

When modelling economic growth, the neoclassical growth model assumes that technological progress is exogenous and occurs at no cost, and that all countries are faced with a common world technology frontier and receive new knowledge at a common pace (Solow, 1956; Cass, 1965). Yet these assumptions are clearly problematic in reality: countries vary significantly in their access to the global stock of knowledge and therefore in their pace of technological progress. This variance is a consequence of the vastly different extents to which domestic and international conditions are favourable to technological catch-up and innovation across countries. Hence, in terms of growth convergence, the real world situation is far from the predictions by a neoclassical growth model where countries that begin from the same level of per capita GDP will experience catch-up growth at the same speed due to the transitional dynamics of physical capital accumulation. In fact, between 1960 and 2000, variation in the rates of growth of per capita GDP increased with distance from the world frontier (Jones and Romer, 2010). That is, there was a much greater variation in the growth rates of countries with low levels of per capita income than in the growth rates of countries close to the world frontier. Using the "Historical Cross-country Technology Adoption Dataset", Comin and Hobjin (2010) argue that the remarkable development records of Japan in the second half of the nineteenth century and the first half of the twentieth century, and the development records of the "East Asian Tigers" in the second half of the twentieth century, all coincided with these countries' catch-up in the range of technologies used by industrialized countries. All these development "miracles" involved a substantial reduction in technology adoption lags compared with other countries beginning from similar income levels.

Beyond the neoclassical growth model, endogenous growth models aim broadly to endogenously explain knowledge production and technological change. The development of the endogenous growth literature reflects a reorientation of focus from capital accumulation towards the process of technological progress itself. It is this reorientation that sets the stage of this thesis, which explores various mechanisms that affect the pace of technological progress and its variation across countries. In this thesis, technological progress is understood through several dimensions, including industrial upgrading, the intensification of R&D activities, a country's tapping into foreign source of knowledge, and a country's changing position in the global value chain. Taken together, a deeper understanding of the factors and mechanisms that determine these various tangible aspects of technological progress is intended to contribute to a deeper understanding of why some countries grow more rapidly than others, which is one of the fundamental questions posed by economists and one for which clear-cut answers have yet to be found.

While the thesis is not limited to the issue of technological progress in developing countries, one major context is the technological progress of countries that are aiming to pursue technological catch-up towards countries on the world frontier. China is an important case to be studied in this context. Since initiating market reforms in 1978, China has undergone a significant economic transformation (Lin, 2011a). As China continues to converge towards countries on the world frontier, the concern has arisen that China may enter a "middle-income trap" (Eichengreen et al., 2013; Aiyar et al., 2013), in which a middle-income country loses its comparative advantage in labour intensive goods and yet fails to build up sufficient technological capability in technology intensive goods. At its current stage of development, the need for the Chinese economy to become more knowledge intensive and innovative in order to sustain the momentum for growth and to avoid entering the "middle-income trap" has become increasingly urgent in the eyes of the Chinese leadership and many of the economists who advise them. The transition from imitation to innovation does not necessarily mean that China will be as innovative or knowledge intensive as countries on the world technology frontier, such as the United States, Germany and Japan in the short run. The essence of this transition is to latch onto a track that will lead to continuous technological progress, industrial upgrading and the production of products with higher value-added over time. To consider the factors that influence the innovation prospects for China is particularly important both for China and for other developing countries that are approaching middle-income status in the future.

Before discussing the factors and mechanisms that influence technological progress, it is helpful to explain the specific aspects of technological progress that will be covered in the thesis and how these impact on economic growth. The first aspect is performance in industrial upgrading, which is defined as an increase in the value-added proportion of technology-intensive industries in the total manufacturing value-added of a national economy. In the literature, two channels through which industrial upgrading influences the long-term growth prospects of an economy have been identified. The first is a "level effect": since technologically-sophisticated sectors enjoy higher labour productivity, the level of national productivity will increase as these more productive sectors expand in terms of shares of output, capital and labour in an economy (Nelson and Pack, 1999). The second is a "growth effect": more sophisticated manufactured products have productivity frontiers that are further away and therefore present greater room for technological catch-up towards the frontier (Rodrik, 2006). Therefore, structural transformation that lifts a country from less-connected sectors towards more-connected sectors will enlarge the space for technological catch-up and hence the growth potential of the economy. Products such as metal, machinery and chemicals are located in a densely connected core of the product space while some other products such as fishing, animal, tropical and cereal agriculture occupy a less connected periphery.[1] Since countries tend to move to goods close to those in which they currently specialize, countries will be able to upgrade their production structures more quickly if their current production structures are already located in, or can be changed to, the densely connected parts of the product space (Hidalgo et al., 2007).

The second aspect to be examined is the R&D intensification of an economy, defined by a rising ratio of R&D investment to a country's (or an industry's, or firm's) total output. Although Total Factor Productivity (TFP) captures the technological level of a country, it has certain limitations and a focus on R&D investment can inform us of the technological capability of a country from another angle. As pointed out by Iradian

[1] According to Hidalgo et al (2007), connectedness between products exists because countries specializing in one product may or may not also specialize in the other. Empirically, this relatedness/connectedness is calculated at a certain time point from trade data, and governs how countries change their specialization patterns over time: countries move preferentially to related or 'nearby' goods.

(2007), TFP is a measure of a range of factors such as managerial capabilities and organizational competence, R&D, inter-sectoral transfers of resources, increasing returns to scale, embodied technological progress, and diffusion of technology. More broadly, TFP is a measure of our ignorance and covers many components, some wanted such as the effects of technical and organizational innovation, and others unwanted such as measurement error, omitted variables, aggregation bias, and model misspecification (Hulten, 2000). In contrast to the fact that many factors other than technological progress could impact on TFP, R&D investment directly reflects the resources invested in innovation activities and is a major indicator of the technological level and the innovativeness of production activities in an economy. The intensification of R&D is critical for a country's transition from a technology imitator to a technology innovator, a key mechanism underpinning continuous technological catch-up. Since both domestic and international resources can contribute to the R&D intensification of an economy, the thesis will explore the determinants of R&D investment of domestic firms (Chapter 3) and also the factors in a host country that attract overseas R&D investment by multinational enterprises (Chapter 5).

The third aspect to be studied is the positions of countries in the global value chain (Chapter 6) and how these positions affect the pace of countries' technological catch-up (Chapter 4). One of the recent major trends in global manufacturing is "trade in tasks" or the "global value chain" or "production fragmentation" (Baldwin and Robert-Nicoud, 2010). These terms all refer to the fragmentation of production of final output into geographically dispersed task-based production, which is enabled by the reduction in logistics costs and tariff and non-tariff barriers to trade. Not only are the manufactured final goods traded, intermediate goods embodied in production tasks are increasingly traded as well. Against such a background, technological catch-up can begin from specialization in certain production tasks instead of mastering knowledge for the entire bundle of tasks that constitute the final output. Since the technological complexity of the goods that a country has comparative advantage in determines the position of that country in the global value chain, to identify where a country is in the global value chain is important for identifying the technological capability of a country.

Having explained the specific aspects of technological progress that will be covered in the thesis, I now use Figure 1-1 to provide a synopsis of the factors and mechanisms that influence the process of technological progress. Since technological progress happens when countries tap into the world knowledge stock and then absorb and build upon that knowledge, the relevant factors can be broadly categorized into international factors and domestic factors. International factors reflect the channels of inflows of knowledge and technology, while domestic factors determine the absorptive capacity for new technologies and the ability to build upon the existing knowledge stock.

In terms of the domestic factors, there are three key elements. The first is the human capital endowment of a country. Human capital is not only a critical input in the production process but also a key input in the process of adopting and creating new technologies. A larger human capital stock is associated with improved on-the-job efficiency of labour, higher rates of technology adoption and higher rates of innovation (Rogers, 2008). It is true that the state of technological knowledge at any time is mostly embodied in machinery and codified in blueprints, machine manuals and textbooks. Thus a developing economy can adopt more advanced technologies and promote the growth of technologically sophisticated industries by accumulating physical capital in the form of equipment and machinery. However, knowing how to employ the embodied technologies to their full productivity and to assimilate and build new knowledge upon the current technologies requires human capital input. Hence, whether an economy can absorb imported equipment and realize the associated physical capital accumulation needed for technological progress depends critically on whether the human capital endowment permits the investment in these technologies to be profitable.

The second element is the institutional quality of the economy. Better overall institutional quality may foster the strength of entrepreneurship in the face of profit opportunities. Baumol (1990) and others in the subsequent literature, such as Sobel (2008), argue that in economies with institutions that provide secure property rights, a fair and balanced judicial system, contract enforcement, and effective limits on government's ability to transfer wealth through taxation and regulation, creative individuals are more likely to engage in productive market entrepreneurship—activities that create wealth (eg, investment in the adoption of new technologies). In economies without strong institutions, these same individuals are instead more likely to engage in attempts to manipulate the political or legal process to capture transfer of existing wealth through unproductive political and legal entrepreneurship—activities that reduce wealth (eg, rent-seeking, lobbying and lawsuits). Therefore, attaining better institutional quality, by promoting the response of productive entrepreneurs when more sophisticated technologies become profitable, can help channel resources towards productive sectors more effectively and thus facilitate technological progress.

Labour market arrangements, as one dimension of institutions, can also impede or support technological progress depending on whether the incentive structures provided to workers suit the need of new technologies or not. For example, industrial upgrading as one aspect of technological progress is essentially about lowering the relative importance of the mode of mass production based on imported technologies, physical capital input and semi-skilled labour input, and switching towards industries that rely more on diversified quality production and on high-skill workers. Hence, in order to realize the changes in labour composition required by new technologies and industrial upgrading, a country may need to move further in the direction of a more decentralized and flexible labour market that accepts wider and more variable wage differentials to give incentives to high-skill workers (Eichengreen and Iversen, 1999).

Freedom of exchange across borders may help skilled labour contribute more to technological progress by allowing them easier and wider access to the world stock of knowledge. The absorbed knowledge and information will allow tertiary human capital to be employed more productively and thus make it contribute more to the process of technological progress. This point links to the importance to technological progress both of human capital as discussed above and of trade as shown below. Institutional quality could also impact on a firm's innovation activities and hence on the technological progress of an economy. The specific channels at the firm level will be discussed in detail in Chapter 3 which examines how institutional quality impacts on firm-level R&D investment in China.

The third element of the domestic factors is the domestic R&D activities of an economy. R&D activities have two functions, namely to contribute to innovation and imitation (Cohen and Levinthal, 1989, 1990; Griffith et al., 2004). R&D activities are efforts made to digest and build upon existing technologies and therefore will significantly influence the capability of an economy to make use of the international knowledge stock. Therefore, R&D intensification of an economy is not only an indicator of technological progress but also a facilitating factor for further technological progress itself.

Turning now to international factors, there are four elements. The first is trade, both imports and exports. Opening up to international trade is often argued to be beneficial to economic growth through channels such as specialization, which reflects differences in factor endowments, and increased scale and varieties, which come with horizontal product differentiation. In fact, the link between trade participation and technological progress is also a fundamentally important channel though which trade impacts on growth performance. Trade and innovation are closely related. Imported consumer goods bring new ideas of products into the domestic economy and domestic firms can imitate and learn from these products. Imported intermediate goods and capital goods are embodied with advanced technologies (Coe et al., 1997; Coe et al., 2009). Domestic firms can produce new and more sophisticated products through the use of imported machinery and can also produce outputs with enhanced productivity (Amiti and Konings, 2007; Kasahara and Rodrigue, 2008; Goldberg et al., 2010; Kugler and Verhoogen, 2009; Halpern et al., 2011; Wang, 2012). Another mechanism that potentially counteracts the enhancing effect of imports on innovation is discussed in a strand of literature that explores the relationship between technological imports and firm-level intramural R&D (Katrak 1991, 1994, 1997). The central question in this literature is whether a firm's technological imports and its intramural R&D are substitutes or complements. If technological imports are substitutes for intramural R&D, then we may find that imports exert a negative impact on innovation.

In terms of exports, there could be “learning-by-exporting” effects. That is, exporting firms are better informed about the development of international markets and new technologies and may need to upgrade their operations to meet the criteria of consumers in more advanced countries (Rhee et al., 1984; Westphal et al., 1984; Grossman and Helpman, 1991; Silva et al., 2010). These mechanisms could increase the productivity and returns to R&D investment and hence promote the R&D investment by a firm. Another mechanism through which exporting to international markets may stimulate a firm's innovation activities is the pressure to retain its competitive edge. Baum et al. (2012) find that geographical sales diversification across different regions of the world induces UK firms to increase their R&D expenditures due to the need to maintain a competitive advantage when faced with more vigorous competition and differing consumer preferences in foreign markets. Therefore, the more geographically diversified a firm's sales structure, the higher the demand for firm-level R&D to enable the firm to survive international competition.

In the literature, several specific issues regarding trade and technological progress have been investigated. These issues include the impact of trade liberalization on firm-level productivity (Yu, 2009; Yu, 2011; Yu et al., 2013), the implication of participating in global value chains for industrial upgrading and the path dependence of the composition of exports and how industrial policies could lead a country onto a continuous track of technological catch-up and industrial upgrading (Steinfeld, 2004; Rodrik, 2006; Hidalgo et al., 2007). One observation on the Chinese economy, however, motivates me to propose a new channel through which trade affects R&D investment and hence technological progress. This channel -processing trade- has not yet received much attention in the literature and to my knowledge firm-level evidence on this topic is scarce.

The observation that processing trade is very important for China compared to most other countries inspires me to analyze one novel hypothesis linking trade with innovation: the form of trade that a firm is engaged in matters for the depth and potential of technological learning that this firm can gain from trade specialization.

Processing trade is the process via which a domestic firm obtains raw materials or intermediate inputs from abroad, and, after local processing, exports final goods that contain value-added produced by the firm.[2] Processing exports have accounted for over 50% of China's total exports since 1992 (Yu, 2011). Furthermore, evidence provided by Woo (2012) suggests that China plays a primary role as a final product assembler engaged in processing trade. In 2007, China's exports of finished goods account for 59% of its total manufactures exports and imports of finished goods account for 33% of its total imports. In contrast, China's imports of parts and components account for 66% of its total manufactures imports and exports of parts and components account for only 35% of its total exports.

Several studies have drawn attention to the implication of processing trade for China's technological catch-up (Lemoine and Unal-Kesenci, 2004; Steinfeld, 2004). These authors place China's rapid export growth in the context of global production fragmentation and find assembly trade to have contributed considerably to the expansion of China's foreign trade. However, these authors argue that taking part in the labour-intensive stages of production does not automatically lead to technological catch-up or upward movement along the value chain. When faced with relatively low protection of property rights and limited external financing, firms may get stuck in the stage of production that makes use of low-cost labour and compete with each other on a

[2] The Chinese government encourages processing trade by making all the imported goods for processing trade duty free. Among Chinese firms, two important types of processing trade are "processing assembly" with 100% duty free imports and "processing with inputs" with 100% rebate on the cost of imports when the products are ultimately exported (Yu 2011).

cost-cutting basis. When the cost pressure becomes too high, firms choose to diversify into other markets but still organize their production activities based on the advantage of low-cost labour, rather than developing proprietary skills and moving up the value chain (Steinfeld, 2004). In fact, Yu (2011) finds that firms that are engaged in processing trade have lower TFP compared with firms that are engaged in ordinary trade in China.

One mechanism behind the weak TFP performance of firms engaged in processing trade could be that the "learning by importing" effects from imported intermediate goods vary across different end purposes. Among all types of imports, three are most likely to provide in-depth technological learning: ordinary trade, equipment investment by foreign-invested enterprises, and imported equipment by export processing zones. Ordinary imports happen when a firm needs to import equipment, machinery or critical intermediate goods for the production of a product otherwise impossible using domestic inputs only. When these ordinary imports enter the production process of a firm, they may trigger learning about more advanced production technologies embodied in the imports, which will enhance the firm's technological capability and potential of doing R&D. Also, the application of imported equipment or machinery in foreign-invested enterprises or in export processing zones may meet unexpected difficulties due to the fact that the imported equipment is designed for a foreign economy with different endowments and business environment. In this case, R&D investment may be required to help solve technical problems in adapting the imported equipment to local conditions. Also, through the adoption of imported equipment, firms can take advantage of R&D abroad to relax technological constraints and improve the efficiency of production. Therefore, these three types of imports are likely to enable firms to expand their production technology possibility sets and enhance their technological capabilities.

In contrast, since processing trade mainly takes advantage of the relatively low labour costs in developing countries and is often associated with low value added, firms involved in processing trade may be less likely to develop innovative capacity for survival in a competitive market. Intermediate goods and capital goods imported for processing trade are less likely to be used for the purpose of relaxing the technology constraints in production and changing the production technologies of a firm and are therefore likely to be linked to technological learning in a shallow manner.

The second element among the international factors is foreign direct investment (FDI), both inward and outward. Domestic firms could benefit from spillovers from inward

FDI (Buckley et al., 2006). Spillovers can happen when domestic firms observe and learn from the production technologies or management systems of foreign affiliates (Cheung and Lin, 2004); when former employees of foreign affiliates are hired by domestic firms (Balsvik, 2011); when domestic firms become upstream firms of foreign affiliates and foreign affiliates convey knowledge about production to these domestic firms in order to improve the quality of the intermediate inputs they can source; and when domestic firms become downstream firms of foreign affiliates and the resulting higher quality of intermediate inputs relaxes the technological constraints of domestic firms (Reganati and Sica 2010).

Outward FDI can help source countries to obtain technologies from advanced countries and hence may impact positively on technological progress as well. For instance, multinational enterprises increasingly locate their R&D activities in countries other than their home countries. An important motivation for the globalization of R&D by multinational enterprises is to seek technologies and knowledge developed in other parts of the world. Since knowledge transfer tends to be localized and the degree of technology diffusion tapers down as geographical distances increase, outward FDI is an important way of gaining access to knowledge pools outside the multinational enterprises' home countries (Amighini et al., 2010).

The third element of the international factors is the cross-border movement of talents. While some economies are faced with the "brain drain" problem, meaning the loss of talents to other countries, there is also the possibility of "brain circulation", which induces the returning home of talented people who have expanded their horizons overseas. These returning talents can bring back information about new technologies and developments in the world market and therefore contribute to the technological catch-up of their home countries (Kale et al., 2008; Daugeliene and Marcinkevičiene, 2009). Another way for firms to obtain technological information is to send their engineers or scientists to visit overseas firms or to study abroad. Firms can also hire foreign experts to help with the introduction and set-up of new production technologies or operation systems (Mitchell, 1997).

The last element of the international factors is the international flow of intangible assets such as patents, technological licenses and academic literature. Firms can purchase patents or technological licenses in markets for these intangible assets and use the knowledge and technology contained therein in production (Troy and Werle, 2008).

R&D personnel in a firm can also utilize academic literature to gain understanding about recent developments in production technologies and international markets.

1.2 Thesis structure and preview

As explained in Section 1.1, the dynamics of technological catch-up in a country are determined both by the inflows of knowledge from other countries and by the efforts to build up domestic capability or absorptive capacity. Hence, the structure of the thesis reflects both the domestic and international dimensions of the issues surrounding the process of technological catch-up.

Since the factors and mechanisms that determine a country's technological progress are numerous, the thesis does not cover all of them but focuses on several of the most significant ones, as identified in Figure 1-1. There are five core chapters in the thesis. Chapters 2 and 3 are focused on the effects of domestic capability building on technological catch-up while Chapters 4, 5 and 6 explore the international dimensions of, respectively, trade participation, globalization of R&D activities and global value chains. Each chapter is self-contained with this introductory chapter aiming to set up the context of the thesis, provide a brief summary of what lies ahead, and identify the major contributions of the thesis. What follows is a preview.

Chapter 2 uses country-level data to examine inter-sectoral industrial upgrading, measured as the increasing value-added share of high-tech industries among all industries of a country. This chapter investigates how institutional quality and human capital, two key aspects of domestic capability, impact on the speed of industrial upgrading. While there is previous literature that emphasizes the importance of institutional quality and human capital for technological catch-up, this literature tends to examine these factors separately and does not pay enough attention to the synergies between them. Unlike previous literature, Chapter 2 takes a different view and proposes the hypothesis that human capital and institutional quality are not independent but instead are complementary to each other in promoting industrial upgrading. The empirical findings in Chapter 2 support this hypothesis. Better institutional quality facilitates the effectiveness of tertiary human capital in enhancing industrial upgrading. In addition, when measuring human capital, Chapter 2 recognizes both the importance of its quantity and the quality, which fleshes out the concept of human capital in the context of industrial upgrading. In terms of the econometric estimation, since the lagged dependent variable is included to allow for the adjustment of industrial structure towards the equilibrium, the error term, which includes country-industry fixed effects, may co-vary with the lagged dependent variable. Under such a dynamic structure, both the Ordinary Least Squares (OLS) estimator and the fixed effects estimator are biased and I therefore choose to use the Arellano-Bond (1991) difference General Method of Moments (GMM) to estimate the model.

Chapter 3 focuses on the relationship between institutional quality and R&D activities of firms in various provincial regions in China. Institutional quality is a key part of domestic capability and is argued to be fundamentally important for the R&D investment decisions of firms. The spectacular growth of China in recent decades has been driven mainly by the reallocation of labour and capital across manufacturing firms (Song et al., 2011) and by the expansion/growth of export-oriented, labour-intensive manufacturing activities (Wu, 2010). The success of such an economy could rely much less on institutional quality compared with an economy that relies on R&D investment from firms as a major source of technological progress and productivity growth. This is because R&D investment is a long-term investment process, the returns of which take time to realize. Also, compared with physical capital investment and technology imitation or technology imports, R&D investment is intrinsically more risky and costly. If the protection of property rights and especially the protection of intellectual property rights are weak, firms may be reluctant to invest in R&D due to the high risk of losing the fruit of their costly R&D efforts. While the institutional environment within which a firm operates lies outside the scope of the individual firm, the institutional environment determines the firm's incentives and opportunities for technological learning. Therefore, if China is to continue to converge towards the world technology frontier and become increasingly knowledge intensive, it may not be possible to be an outlier in terms of its institutional quality in the long run. Besides the above mechanism, another channel through which institutional quality improvement may induce technology upgrading and firm-level innovation is that entrepreneurs take actions to upgrade their production technologies in order to maintain their competitive edge in the market when it is anticipated that there will be future institutional reforms such as the reduction of market entry barriers or easier access to finance.

While there exist studies that regard China as a whole, and look at how its institutional quality is related to its economic growth in a cross-country context, this study explores this issue inside China. The identification strategy is to examine how regional variations in institutional quality within China affect the R&D efforts of firms located in various provincial regions. It is found that institutional quality at the provincial level positively affects the entry decision of firms into R&D activities. But once firms start to invest in R&D, the subsequent expansion of firm-level R&D intensity depends on other factors. Therefore, sorting out domestic institutional quality is just the first step towards the goal of building a knowledge-intensive economy, becoming a global R&D player and contributing to the world pool of knowledge and technology. A better understanding of the other factors that influence the R&D intensity of firms after they begin to have R&D investment is important for ensuring continuous growth of firms' innovative capabilities.

There are three major issues in the econometric estimation in Chapter 3: potential endogeneity of institutional quality to the actual intensity of innovation activities, firm-level fixed effects and a sample selection problem that arises from the fact that there are many zero-value observations of R&D investment in the sample. The endogeneity issue is not only important for the soundness of estimation but also for a proper understanding of the intertwining process of innovation and institutional quality improvement. The positive association between higher institutional quality and enhanced R&D investment of firms is compatible with two mechanisms. One is that relatively high institutional quality is a facilitating force behind the R&D intensification of an economy; the other is that relatively high institutional quality is a consequence of, or a response to, the R&D intensification of an economy. These two mechanisms imply different policies for long-term growth. Therefore, an effort to tackle the endogeneity between institutional quality and firm R&D performance is necessary. Ideally, we should tackle the three problems at the same time. However, there is not an existing estimator that could achieve this ambition. Therefore, I resort to the estimator in Kyriazidou (1997), which can address firm-level fixed effects and the sample selection problem at the same time. This estimator provides the baseline result of Chapter 3 as discussed above. In order to take into account the potential endogeneity of institutional quality, I perform instrumental Tobit and instrumental Probit models on cross-sectional data of a year extracted from the original three-year panel. The results of these regressions are largely consistent with the baseline result.

Chapters 4, 5 and 6 are focused on the inflow of knowledge from other countries, or the international dimension of technological progress. Chapter 4 explores how international trade influences the innovative activities of firms in a country through an analysis of the case of China, a country that has enjoyed huge benefits from specialization in industries of national comparative advantage and that has achieved an outstanding growth performance for over three decades. This chapter conducts an analysis of the effects of trade participation on firm-level R&D activities by using a merged dataset of Chinese firm-level production data and Chinese transaction-level customs data.

In order to see how trade participation influences the prospects for innovation, variables that reflect various aspects of trade are constructed and used as independent variables in the regression analyses of firm-level R&D intensity, the dependent variable. It is found that several trade-related channels are significantly associated with firm-level R&D activities. Geographical diversification of export markets, the share of imports from high-income countries in total imports, the average unit value of imports and share in total imports of ordinary trade, goods imported as equity investment in joint-ventures and imported equipment by export processing zone are all positively and significantly related to firm-level R&D intensity.

Among others, the finding that the share in total imports of ordinary trade, goods imported as equity investment in joint-ventures and imported equipment by export processing zones are positively and significantly related to firm-level R&D intensity prompts us to think about the implications of the current pattern, which is characterized by a large share of processing trade, for China's long-term growth performance. Processing trade has become increasingly important in the past three decades. Under such a structure of trade, will there be dynamic benefits to growth from trade through stimulating indigenous innovation? The firm-level evidence in this study suggests that imports for various purposes (ie, for processing trade, ordinary trade, equity investment by foreign-invested enterprises and imported equipment by export processing zones) do not all promote indigenous innovation to the same extent as each other. If the organization of production is constantly based on processing trade and the advantage of relatively low-cost labour, then firms may be locked into a production mode with low technological learning potential. In this case, the difficulty of engaging in R&D activities will be increased and the incentive to move up the value-chain will be even weaker. This further retards the upgrading of production organization and hence forms a vicious cycle characterized by low R&D, low technological learning and a low position in the global value chain.

What is needed to help domestic firms, industries and the market break out of this trap of technological catch-up? The answer lies in the factors that affect the incentives of firms to invest in R&D in order to produce new and high-quality products. As discussed above, low protection of property rights or low institutional quality can reduce the incentive to invest in R&D since this type of investment is particularly sensitive to institutional quality as a consequence of the long gestation process and the fact that knowledge is a non-rival good. This point links back to Chapter 3 where it is found that institutional quality affects the entry decision of firms into R&D activities.

Chapter 5 focuses on the globalization of R&D activities by multinational enterprises (MNE), a topic that is nowadays highly relevant to both developed and developing countries. While countries' own R&D efforts are vital for their technological advancement, the diffusion of knowledge generated in other parts of the world can also play an important role in bridging the technological gap with countries on the world technology frontier (Coe et al., 1997; Coe et al., 2009). Hence, the attraction of overseas R&D investment by MNEs is part of the force behind the intensification of R&D of a host country and is therefore critical for that country's technological progress.

MNEs are constantly looking for the most favourable conditions for the internationalisation of their activities along the production chain. Gradually, activities that were previously locally integrated and locally concentrated have increasingly been relocated to other countries, and these activities include R&D and innovation. The location of R&D activities continues to spread beyond the borders of MNEs' home countries. How can other countries tap into this outflow of knowledge? Understanding how MNEs decide where to locate their overseas R&D investment is vital for answering this question. The study in Chapter 5 narrows its focus onto drivers of overseas R&D investment by MNEs from a single country, the United States. The study covers seven two-digit level North American Industry Classification System (NAICS) manufacturing industries in 22 developed countries and one developing country over the period 1999-2008. The empirical findings suggest that the technology-seeking motive, access to an abundant pool of researchers and the market-seeking motive determine the R&D intensity of U.S.-based MNEs. The investment position of MNEs, institutional quality of the host country and distance between the United States and the host country are not found to exert significant impacts on the R&D intensity of MNEs. The findings point to the need for policies that strengthen the domestic R&D or knowledge stock, enhance the human capital endowment and support a domestic market that is open to the world. In terms of estimation, the system GMM estimator (Blundell and Bond 1998) is adopted since the lagged dependent variable is included on the right hand side of the estimation equation.

Chapter 6 characterizes the international division of labour and global production sharing in a theoretical framework. It tracks the positions of 40 countries that take up around 80% of global GDP in the global value chain. The position of a country in the global value chain is reflected by the production structure of the country. Production structure, in turn, is defined by the income shares of various inputs: the share of capital income and the shares of incomes of three types of labour (high skill, medium skill and low skill). The theoretical model in Acemoglu and Autor (2011) is adapted and extended to illustrate how a country's changing position in the global value chain will influence its inputs' income shares. The major innovation of my extension is to change the production function of each task service from being a linear combination of various types of labour and capital inputs to being a linear combination of Leontief production functions. This extension from the original model in Acemoglu and Autor (2011) enables a simultaneous examination of the patterns of shares of compensation to three types of labour and capital when countries' positions in the global value chain change. It is theoretically shown that the changing positions of countries in the global value chain can be an underlying force behind the changing income distributions of countries. Hence, empirical observations made of a country's income distribution can inform us about that country's position in the global value chain and its technological performance.

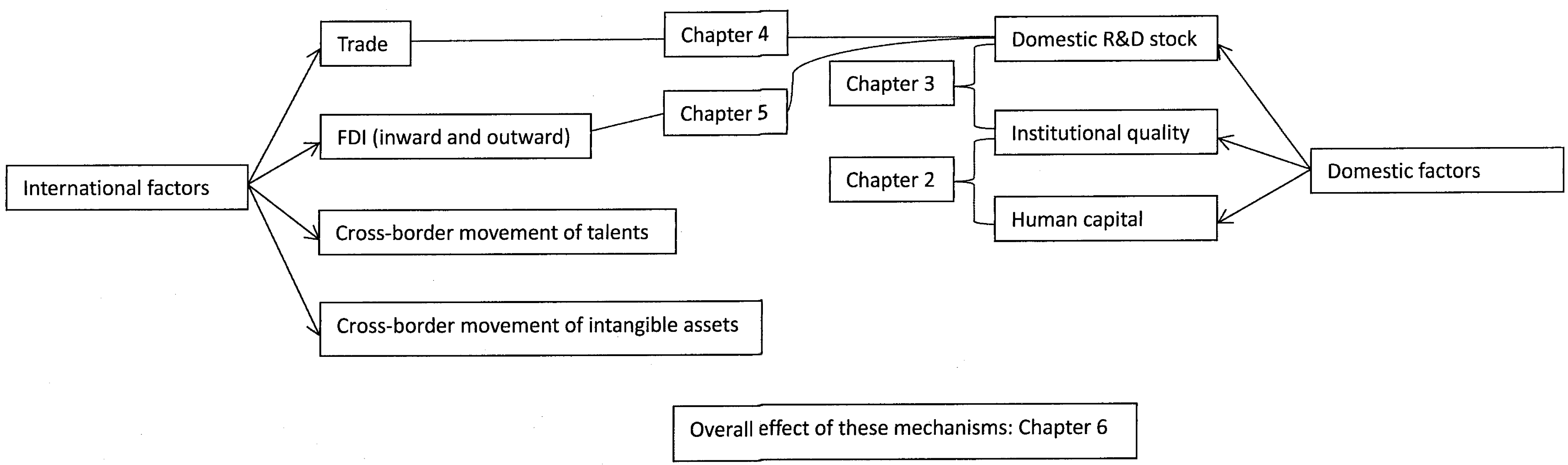
Data used in this chapter are from the World Input-Output Database covering the period from 1980 to 2008. Four groups of countries are identified according to their distinctive trends in income distribution shares. Countries in the first group are developed countries and may have experienced increasing specialization towards the part of global value chain that is of high technology content. They may also have grown into major suppliers of high-tech intermediate inputs to other countries. Countries in the second group are developed countries and may have experienced significant production offshore of high-tech intermediate goods. These countries may be moving more and more towards complex production activities such as product design and R&D activities that mainly rely on human capital, and moving away from the physical production of products. Countries in the third group are developing countries that have been experiencing industrialization. Despite their significant industrialization and catch-up, these countries are still technology followers. The compensation for high-skilled labour in these economies grows slowly or stagnates and this is consistent with a production structure that requires less input from high-skill labour and therefore is less technology intensive.

For countries in the fourth group, their patterns of income distributions cannot be clearly identified and therefore these countries are categorized into one group. We can see that countries specialize in tasks of various degrees of complexity and technology intensity within the same industry. Hence, the proper definition of technological catch-up and the framework used for analysis is a topic that requires further thinking. Chapter 6 serves as a departing point for future research.

Finally, Chapter 7 provides a summary of key findings and discusses policy implications for the technological progress and economic growth of countries. Areas for future research on the channels of technological catch-up are suggested. Overall, the thesis provides a significant amount of new empirical evidence on the factors and mechanisms of technological progress, explored at various analytical levels. For example, in Chapters 2, 5 and 6, cross-country industry-level data are employed; in Chapters 3 and 4, firm-level data are used. Furthermore, a variety of econometric methods have been used to tackle issues of estimation encountered in examining various channels of technological catch-up. For instance, in Chapters 2 and 5, the GMM estimator is adopted to accommodate the dynamic structure due to the inclusion of the lagged dependent variable as a regressor. In Chapter 3, in order to take the sample selection problem, the fixed effects problem and the endogeneity problem into consideration, the estimator proposed in Kyriazidou (1997) is implemented with a Mata program written by me, and instrumental Tobit, instrumental Probit and Heckman two-step estimators are also used in the model estimations.

Although the thesis does not exhaust the factors and mechanisms that determine technological progress, it provides important clues on several major fronts both domestically and internationally. The complexity of the channels of technological progress is reflected in the interaction between these factors. For example, while institutional quality and human capital both affect the speed of technological catch-up, they could impact each other as well. On the one hand, people living in an economic environment with higher institutional quality are more willing to invest in education and training; on the other hand, when people in an economy become better educated, they will become more demanding of institutional quality. Furthermore, to fully grasp the process of technological progress requires understanding the mechanisms and channels working at various levels from the country to the individual firm. Despite the complexity of the issue, the following message is worth conveying: technological catch-up and innovation are critical for economic growth and development. Countries will continue to converge towards the technology frontier when the necessary accommodating institutional changes and other conditions have successfully evolved so that technological absorption and innovative activities can take place.

Figure 1-1 Channels of technological catch-up: a synopsis



Chapter 2: Human capital, institutional quality and industrial upgrading

2.1 Introduction

Historical experience has shown that countries that have enjoyed successful economic development have tended to quickly diversify into more sophisticated and technically-demanding sectors (Imbs and Wacziarg, 2003; Rodrik, 2006). Technological catch-up and taking industrial leadership in certain industries often accompany economic catch-up. For example, in the steel industry, industrial leadership shifted from the United States to Japan and then to Korea and increasingly to China; in the semi-conductor industry, industrial leadership changed from the United States to Japan and then to Korea.

As discussed in Chapter 1, industrial upgrading can have a significant positive impact on economic growth. For example, Nelson and Pack (1999) argue that shifts in the size of firms and sectors of specialization were a fundamental component of the Asian growth miracle. In the literature, several types of industrial upgrading activities have been identified, including process upgrading, product upgrading, functional upgrading and inter-sectoral upgrading (Humphrey and Schmitz, 2002). This chapter tackles the question of industrial upgrading through an analysis of structural change across sectors, that is, inter-sectoral upgrading. The increasing proportion of technology-intensive industries in the total manufacturing value-added of the national economy is interpreted as an indicator of industrial upgrading.

What determines a country's industrial upgrading performance? Whether the current structure of the economy is located in a densely-connected area of the product space is one of the determinants (Hidalgo et al., 2007). Industrial policies may also steer the direction of structural change by shaping the incentives faced by economic agents (Shapiro, 2007). A changing endowment structure in the economy determines the evolution of the production structure as well. Lin and Wang (2012) argue that industrial structures are endogenous to the endowment structure. In other words, a country with more abundant physical capital and human capital will generate a more sophisticated industrial structure. According to this view, in order to achieve the goal of upgrading the industrial structure, the government's development strategy should aim to upgrade the endowment structure first.

When looking at the endowments of an economy more carefully, one will find that human capital plays a more fundamental role compared with physical capital in promoting the growth of technologically-sophisticated industries. This chapter, therefore, takes the view that human capital is the fundamental endowment in enabling industrial upgrading while other factors, such as physical capital, respond to the changes in human capital and in turn exert an influence on the production structure.

While the above discussion implies that human capital is a fundamental determinant of industrial upgrading performance in general, there exists another strand of literature that attempts to explain the different abilities of economies to adopt new technologies and to upgrade their production structures based on differences in the quality of their institutions (Parente and Prescott, 2002; Nelson, 2008). Then there come efforts to synthesize these two strands of literature. One example is Rogers (2008), who argues that, schooling-related variables such as years of schooling and enrolment rates are often used as proxies for human capital. However, schooling is not equivalent to productive skills or human capital used in the economy since schooling does not automatically find its way into productive use (ie activities that increase value added in the domestic economy). Instead, institutional quality is an important conditioning factor that determines the effectiveness and productiveness of increased human capital for economic growth.

In this chapter, I adopt the view in Rogers (2008) and test this view in the context of industrial upgrading, an effort not yet made in the previous literature. The central hypothesis of this chapter is that the rate at which a country experiences inter-sectoral industrial upgrading when its tertiary human capital stock is increased depends on the institutional quality of the country. Sound institutions facilitate workers to be employed productively by providing a well-functioning and informative labour market that responds actively to the changing labour supply and demand conditions in declining and growing sectors. Entry and exit barriers to business need to be reduced in order for human capital and other resources to be guided towards the most productive use and this can also promote industrial upgrading. High institutional quality allows talent to be employed more productively and hence allows human capital to have a larger marginal impact on industrial upgrading. The empirical results found in this chapter will provide important background for policymaking for industrial upgrading. One point that is worth noting is that institutional quality can possibly be endogenous to the level of human capital (Tebaldi and Elmslie, 2008). However, this is beyond the scope of this chapter and will require further work to be clarified.

This chapter also contributes to the strand of literature that tries to understand the fundamental determinants of growth performance. In the efforts to find out the underlying causes of growth, institutions and human capital are regarded as two potential candidates of the fundamental determinants. Support for the former has been provided by works such as Acemoglu et al. (2001, 2002, 2005a, 2005b) and Zhang et al. (2010).

As for human capital, recent models of endogenous growth emphasize that growth is brought about by the creation and adoption of new ideas, the generation of which relies on R&D activities for countries on the world technology frontier and on technology imitation and adoption for countries inside the frontier. Both R&D activities and technology adoption, in turn, require human capital as a critical input. Despite this seemingly forceful argument, empirical research that looks for the importance of human capital in economic growth using growth regressions often finds its effect to be weak and non-robust. Faced with weak empirical evidence, researchers have made efforts to explain this and to find ways to reconcile the inconsistency between empirical findings and theories (Benhabib and Spiegel, 1994; Hanushek and Kimko, 2000; Hanushek and Woessmann, 2012; Altinok et al., 2013). For instance, Hanushek and Kimko (2000) argue that weak empirical evidence is due to the inadequate measure of human capital when attentions is paid only to the quantity of schooling and not the quality of schooling. This study has made efforts to take this concern into account. In the main specification of this chapter, I examine whether the quantity of schooling matters for industrial upgrading. In the robustness check, I will examine whether the quality of schooling has an impact on industrial upgrading as well.

Benhabib and Spiegel (1994) suggest that the reason why researchers fail to establish the importance of human capital is a misunderstanding of the channels through which human capital influences growth. They maintain that human capital is not just an input into production activities similar to capital and land. Rather, the major roles of human capital are to absorb and to invent new technologies. Therefore, it is not the incremental increase but the absolute stock of human capital that matters for growth performance, implying that previous researchers have looked in the wrong place for evidence.

This chapter proposes another reason why human capital may not significantly affect growth: institutional quality. People's capability and knowledge need to go through a process of transformation to become productive inputs that add value to output, and hence promote industrial upgrading. The transformation rate depends on the quality of economic institutions where people are situated. Therefore, if one hopes to identify the role of human capital in growth properly, one needs to take institutional quality into account in the analysis.

The structure of the chapter is as follows. Section 2.2 draws upon a two-sector model from Nelson and Pack (1999) to help explain the factors that determine the speed of industrial upgrading. Section 2.3 discusses the empirical strategies and the data issues. In Section 2.4, the regression results are presented. Section 2.5 draws the conclusions and implications from the empirical findings.

2.2 An illustrative model

To examine the impact of increased human capital stock on industrial upgrading, consider a simple two-sector model from Nelson and Pack (1999).[3] In this model, there is a modern sector and a traditional craft sector denoted by m and c respectively. Each sector has a Leontif fixed proportion constant returns to scale production technology with physical capital and labour as inputs (Eq. 2.1 and Eq. 2.2). Output per unit of capital is the same in the two technologies but output per unit of labour is higher in the modern sector than in the craft sector. Hence, capital per unit of labour is also higher in the modern sector as well.

$$Y_c = \min\{bK_c, a_cL_c\} \tag{2.1}$$

$$Y_m = \min\{bK_m, a_mL_m\} \tag{2.2}$$

where K_C and L_C are respectively capital input and labour input in the craft sector; K_m and L_m are respectively capital input and labour input in the modern sector; a_c is output per unit of labour in the craft sector and a_m is output per unit of labour in the modern sector and $a_c < a_m$. As mentioned, output per unit of capital is the same in the

[3] The model presented in Eq. 2.1 to Eq. 2.6 is taken directly from Nelson and Pack (1999). The interpretation of this model in the context of industrial upgarding is my own.

two technologies and hence b denotes the output per unit of capital in both craft and modern technologies. The modern sector requires skilled labour L_m while the craft sector employs unskilled labour L_c. Total labour in the economy is L and $L = L_c + L_m$.

Denote total output as Q then total output per capita is:

$$\frac{Q}{L} = \frac{Q_m+Q_c}{L} = \frac{a_m*L_m+a_c*L_c}{L} = \frac{a_m*L_m}{L} + \frac{a_c*(L-L_m)}{L} = a_c + (a_m - a_c) * \frac{L_m}{L} \quad (2.3)$$

As $\frac{L_m}{L}$ grows over the development process, so does $\frac{Q}{L}$. The shift in the proportions of labour in the two sectors drives growth. The faster the shift is, the faster the economy grows given the level of labour productivity in each sector. Then the next step is to identify what factors determine the speed of structural change. Two main factors are the profitability of investing in the modern sector and the institutional quality of the economy. If the profit gain of moving into the modern sector is large, then the incentive to invest in the modern sector will be large, which speeds up industrial upgrading. Also, if the economy has institutions that facilitate the allocation of resources towards their most productive use, this will also speed up the pace of structural change.

The profit gain ΔC from industrial upgrading, namely from shifting out of craft technology towards modern technology, for each unit of output is:

$$\Delta C = w * (\frac{1}{a_c} - g * \frac{1}{a_m}) \quad (2.4)$$

where w is the unskilled wage rate and g is the education premium paid to skilled workers required by the modern sector.

The speed of industrial upgrading is then determined by the following equation:

$$\frac{d}{dt}[\, ln(K_m/K_c)] = e * \Delta C = e * w * (\frac{1}{a_c} - g * \frac{1}{a_m}) \quad (2.5)$$

where e is the institutional quality of the economy.

Hence, the growth of the share of modern sector in the economy is:

$$\frac{d}{dt}[\,ln(Q_m/Q)] = \frac{d}{dt}[\,ln(K_m/K)] = e * w * \left(\frac{1}{a_c} - g * \frac{1}{a_m}\right) * (1 - Q_m/Q) \qquad (2.6)$$ [4]

If w and g are constants, the time path of Q_m/Q will trace out a logistic function.

The original emphasis in the model of Nelson and Pack (1999) is that the ultimate cause of per capita output growth is industrial upgrading driven by the profitability of the modern sector relative to the craft sector; thus the accumulation of physical capital is the result rather than the cause of economic growth. Therefore, the "accumulation" theories (Krugman 1994, Young 1992, 1994, 1995) that argue that there is little technological progress in the Asian growth miracle are combatted by this mechanism of reverse causality. This chapter, however, reinterprets the theoretical model proposed in Nelson and Pack (1999) and draws attention to a perspective on this model not considered before. This novel perspective is to focus on the mechanisms of industrial upgrading themselves.

These mechanisms, namely, the interaction between increased human capital, institutional quality and industrial upgrading, captured in the Nelson and Pack (1999) model, can be understood as follows: If w increases as development proceeds, but not g, the rate of expansion of the modern sector relative to the craft sector will be accelerated since an increased w enhances the labour-saving cost advantage of modern technology. The change of the stock of skilled labour will influence the skill premium in an economy, with an increase of skilled labour stock driving down g. A decline in g due to an increasing abundance of educated labour will enhance the cost advantage of modern technology and promote industrial upgrading.[5] While the levels of w and g influence industrial upgrading by determining the profitability of the employment of modern technology, the rate at which the modern sector replaces the craft sector is also determined by institutional quality as a facilitating force behind the development.

Now consider the dynamics of industrial upgrading when the stock of tertiary human capital increases in two economies that have exactly the same initial conditions but

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[4] Since $K_m + K_c = K$, we have $\frac{d}{dt}\left[ln\left(\frac{K_m}{K}\right)\right] = \frac{d}{dt}\left[ln\left(\frac{K_m}{K_m+K_C}\right)\right] = -\frac{d}{dt}[ln\left(1+\frac{K_C}{K_m}\right)]$. Then Taylor expansion of the expression $ln(1+\frac{K_C}{K_m})$ gives $ln\left(1+\frac{K_C}{K_m}\right) \approx \frac{K_C}{K_m} - \frac{1}{2}\left(\frac{K_C}{K_m}\right)^2$. Therefore $\frac{d}{dt}\left[ln\left(\frac{K_m}{K}\right)\right] \approx \left(1-\frac{K_m}{K}\right) * \frac{d}{dt}(\frac{K_C}{K_m})$. According to Eq. 2.5, $\frac{d}{dt}(\frac{K_C}{K_m})$ is equal to $e * w * (\frac{1}{a_c} - g * \frac{1}{a_m})$. We then obtain Eq. 2.6.

[5] In the theoretical model of Nelson and Park (1999), there is no feedback from technological progress on the growth of skilled labour stock. The model is focused on the impact of exogenous growth of skilled labour growth on industrial upgrading. Individuals' human capital investment decisions are not modelled.

different institutional quality. When both economies experience an increase in their skilled labour force and thus a decrease in g, investment in the modern technology becomes profitable, which will induce the relative growth of the modern sector. The speed with which the modern sector outstrips the craft sector depends on e, which is the institutional quality of the economy. The economy with a larger e will experience faster adjustment of the production structure from the craft to the modern sector. From this theoretical model we thus derive the empirical measures employed in this study as explained in the next section.

2.3 Various performances in industrial upgrading

Before we proceed to the econometric specifications, it is interesting to have a look at several countries' performances in industrial upgrading (Figure 2-1). The horizontal axis of the figure is the year and the period 1980 to 2008 is covered. The vertical axis of the figure is the aggregate nominal share of all high-tech industries (Industry 6, 11, 12, 13, 14) in the total manufacturing value-added of the economy.[6] Here, I report the patterns of industrial upgrading for these countries because data of these countries are complete in the sense that value added for all high-tech industries are reported in most of the years covered in this study.

We can see that industrial upgrading is an ongoing process in countries at various stages of development. Although Japan is one of the countries on the world technology frontier, it is still experiencing a strong upward trend of industrial upgrading. In contrast, while the United States is also a country on the world technology frontier, the value-added share of high-tech industries in the United States has been fluctuating within a narrow band. The Republic of Korea has gone through dramatic industrial upgrading with very limited setbacks along the way. Indonesia has had an uneven process of industrial upgrading, with both periods of contraction and expansion of the share of high-tech industries. Now look at China and India, two emerging economies. It seems that China has undertaken more industrial upgrading when compared with India. However, caution is needed here and this is one limitation of this study. India is well known for its extraordinary performance in service industries and India's industrial upgrading may be better reflected in the shift towards service industries. Since this study is focused on manufacturing industries, it does not capture industrial upgrading towards service

[6] The data used and the way to classify industries into high-tech industries, medium-tech industries and low-tech industries will be discussed in Section 2.5.

industries. Greece and Spain have not been able to sustain a strong performance of industrial upgrading. The various patterns of industrial upgrading observed in these countries prompt us to examine the role of human capital and institutional quality in determining countries' industrial upgrading performance.

2.4 Model specification:

I first examine the relationship between the increase of tertiary human capital and industrial structure[7]. To allow for the slow adjustment in industrial structure, I set the time unit to be five years. The initial estimation equation is as follows:

$$lnShare_{ij,t} - lnShare_{ij,t-1} = a_1 + (a_2 - 1) * lnShare_{ij,t-1} + a_3 * Ter_{j,t-1} + a_4 * Ter_{j,t-1} * Midtech_i + a_5 * TER_{j,t-1} * Hightech_i + a_6 * year_t + u_{ij} + \varepsilon_{ij,t} \qquad (2.7)$$

Equivalently, Eq. 7 can be written as follows:

$$lnShare_{ij,t} = a_1 + a_2 * lnShare_{ij,t-1} + a_3 * Ter_{j,t-1} + a_4 * Ter_{j,t-1} * Midtech_i + a_5 * TER_{j,t-1} * Hightech_i + a_6 * year_t + u_{ij} + \varepsilon_{ij,t} \qquad (2.8)$$

where i is the industry index, j is the country index, t is the time index, $lnShare_{ij,t}$ and $lnShare_{ij,t-1}$ are the natural logarithms of nominal value-added share of industry i in the total manufacturing value-added of country j in the last year of each 5-year window and in the beginning year of each 5-year window respectively, $Ter_{j,t-1}$ is the tertiary human capital stock in country j at the beginning year of each 5-year window, and, $Midtech_i$ and $Hightech_i$ are dummy variables indicating whether the industry is high tech or a medium tech respectively. The error term consists of a country-industry fixed effect and an observation specific error:

According to Eq. 8, the effect of increased tertiary human capital on the dependent variable $lnShare_{ij,t}$ is:

$$\frac{\partial lnShare_{ij,t}}{\partial TER_{j,t-1}} = a_3 + a_4 * Midtech_i + a_5 * Hightech_i \qquad (2.9)$$

Hence, ceteris paribus, a one unit increase of tertiary human capital will cause the share of a low-tech industry to grow by a_3 on average; the share of a mid-tech

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[7] In this chapter, the definition of tertiary human capital follows that in Barro and Lee (2010).

industry to grow by $a_3 + a_4$ on average; and the share of a high-tech industry to grow by $a_3 + a_5$ on average. If an increase of skilled labour is to promote industrial upgrading, then a_3 is expected to be negative while a_4 and a_5 are expected to be positive.

Next, to capture the possible contingency of the relationship between increased tertiary human capital and industrial upgrading on institutional quality, I add three interaction terms $INS_{j,t-1} * TER_{j,t-1}$, $INS_{j,t-1} * TER_{j,t-1} * Hightech_i$, $INS_{j,t-1} * Hightech_i$ and one level variable $INS_{j,t-1}$ to Eq. 2.8 as additional explanatory variables. The variable $INS_{j,t-1}$ is the institutional quality of the economy at the beginning year of each five-year window. Therefore, the following equation is estimated:

$$lnShare_{ij,t} = b_1 + b_2 * lnShare_{ij,t-1} + (b_3 * Ter_{j,t-1} + b_4 * Ter_{j,t-1} * Midtech_i + b_5 * TER_{j,t-1} * Hightech_i) + (b_6 * INS_{j,t-1} + b_7 * INS_{j,t-1} * Hightech_i) + (b_8 * INS_{j,t-1} * TER_{j,t-1} + b_9 * INS_{j,t-1} * TER_{j,t-1} * Hightech_i) + b_{10} * year_t + e_{ij,t} \quad (2.10)$$

According to Equation 2.10, the effect of increased tertiary human capital on the dependent variable $lnShare_{ij,t}$ is:

$$\frac{\partial lnShare_{ij,t}}{\partial TER_{j,t-1}} = b_3 + b_4 * Midtech_i + b_5 * Hightech_i + b_8 * INS_{j,t-1} + b_9 * INS_{j,t-1} * Hightech_i \quad (2.11)$$

Hence, ceteris paribus, a one unit increase of tertiary human capital will cause the share of a low-tech industry to grow by $(b_3 + b_8 INS_{j,t-1})$ on average; the share of a mid-tech industry to grow by $(b_3 + b_4 + b_8 INS_{j,t-1})$ on average; and the share of a high-tech industry to grow by $(b_3 + b_5 + b_8 INS_{j,t-1} + b_9 * INS_{j,t-1})$ on average.

In this model specification, $INS_{j,t-1} * TER_{j,t-1}$ as a whole captures the complementary relationship between institutional quality and tertiary human capital. If institutional quality is an important mediating factor that determines the effectiveness of increased skilled labour for promoting industrial upgrading, then b_9 is expected to be positive. That is, poor institutional quality will reduce the impact that an increase of tertiary human capital stock will have on industrial upgrading. To ensure that the interaction terms $(INS_{j,t-1} * TER_{j,t-1}, INS_{j,t-1} * TER_{j,t-1} * Hightech_i)$ do not proxy for the independent effects from institutional quality or human capital on industrial upgrading, both sets of variables $(INS_{j,t-1}, INS_{j,t-1} * Hightech_i)$ and $(Ter_{j,t-1}, Ter_{j,t-1} * Midtech_i, TER_{j,t-1} * Hightech_i)$ are included in the regression independently.

If the coefficients for the interaction terms $INS_{j,t-1} * TER_{j,t-1}$ and $INS_{j,t-1} * TER_{j,t-1} * Hightech_i$ are significant, it implies that the marginal effect of tertiary human capital on industrial upgrading depends on the level of institutional quality. It is worth mentioning here that the addition of an interaction term may lead to multicollinearity as the interaction term tends to be strongly correlated with the original variables used to construct them (Darlington, 1990). In order to alleviate this problem, the triple interaction term $(INS_{j,t-1} * TER_{j,t-1} * Hightech_i)$ is orthogonalized using the following two-step procedure: First, the triple interaction term $(INS_{j,t-1} * TER_{j,t-1} * Hightech_i)$ is regressed on the variables $INS_{j,t-1}$, $Ter_{j,t-1}, Hightech_i$, $INS_{j,t-1} * Hightech_i$, $INS_{j,t-1} * TER_{j,t-1}$ and $TER_{j,t-1} * Hightech_i$. Second, the residuals from the regression in the first step are used to represent the triple interaction term (see Burill 2007).[8] It is worth noticing that the coefficient for the triple interaction term obtained with this method cannot be interpreted directly since the orthogonalized value rather than the original value is used in the regression. But the sign and the significance of the coefficient are still informative about whether higher institutional quality enhances the positive marginal impact of increased tertiary human capital on industrial upgrading.

The lagged dependent variable is included to allow for the possible "path-dependence" or slow adjustment towards the equilibrium. The inclusion of the lagged dependent variable on the right hand side of Eq. 2.8 creates a dynamic structure. Under this structure, the error term, which includes the country-industry fixed effects, may co-vary

[8] It should be noted that the specification in Eq. 2.11 can only help detect the role of institutional quality in promoting industrial upgrading on a high-tech and non-high-tech basis since I group low-tech and mid-tech industries into the non-high-tech industries. While it would be ideal if the influence of institutional quality could be examined for a classification of high-, medium- and low-tech industries, this approach would cause a multicollinearity problem that could not be solved by the orthogonalisation method adopted above.

with the lagged dependent variable. Hence, the OLS estimator will be inconsistent. A fixed effects estimator is also biased since the within transformation will make the transformed error and lagged dependent variable correlated. I therefore use the Arellano-Bond (1991) difference GMM method to estimate the model. Arellano and Bond (1991) proposed that the lagged levels of the regressors can be used as instruments. This is valid under the following assumptions: (1) the error term is not serially correlated, and (2) the lags of the explanatory variables are weakly exogenous. These two conditions will be checked when the estimation is conducted in Section 2.6.

2.5 Data

The entire sample is a panel of 71 countries covering the period 1980-2005. Appendix 2.A lists the countries in the sample. The choice of countries and time period is primarily dictated by the availability of data.

The data used to reflect the industrial structures of the economies are from the INDSTAT2 2011 ISIC Rev. 3 Database. The data of INDSTAT2 2011 ISIC Rev. 3 are arranged at the 2-digit level of the International Standard Industrial Classification of All Economic Activities (ISIC) Revision 3 pertaining to the manufacturing sector, which comprises 23 industries. In order to employ the OECD classification of manufacturing industries based on technology intensity (Hatzichronoglou 1997, OECD 2011) to reflect the industrial structure of economies, the 23 industries are aggregated into 15 sectors (Table 2-1). According to the OECD technology intensity classification, among the 15 sectors, industrial sectors 1, 2, 3, 4 and 15 are low-tech industries. Industrial sectors 5, 7, 8, 9 and 10 are mid-tech industries, and industrial sectors 6, 11, 12, 13, 14 are high-tech industries. The nominal value-added shares of these 15 industrial sectors in the total manufacturing value-added of the national economy by country and year are calculated to reflect the industrial structures of the economies.

The Barro-Lee Data Set (Barro and Lee, 2010) is used to construct measures of tertiary human capital. It provides information about the distribution of the population over age 25 across seven schooling attainment levels— no formal education, incomplete primary, complete primary, lower secondary, upper secondary, incomplete tertiary, and complete tertiary. I use two ways to measure tertiary human capital: (1) the fraction of the population over the age of 25 having complete tertiary (*TER*) education, and (2) the average year of tertiary (*YTER*) schooling for the population aged 25 years and above.

The data from the Economic Freedom of the World database (Gwartney et al. 2011) are used to proxy for the insitutional quality of an economy overall. The database reports a chain-linked summary index together with chain-linked sub-indices for the five areas that compose the summary index. The chain-linked summary index permits better comparisons over time. These five areas are: (1) size of government, (2) legal structure and property rights, (3) access to sound money, (4) freedom to trade internationally, and (5) regulation of credit, labour and business.

As explained in Section 2.1, we need to take into account the quality of schooling in order to perform a complete analysis about the influence of human capital on industrial upgrading. The difficulty of taking into account the quality of schooling in this study lies in data limitation. To my knowledge, measures of cross-country schooling quality are provided by two studies. The first is Altinok et al. (2013). This study provides a database that allows a comparative evaluation of the relative performances of schooling systems in 103 countries and areas in primary education and 111 countries and areas in secondary education between 1965 and 2010.[9] The second is Hanushek and Woessman (2012). This study develops a common metric that allows tracking student achievement across countries, over time, and along the within-country distribution over the period between 1960 and 2000. While panel structures exist in both datasets, data lengths for individual countries are too short to be used in a meaningful panel data analysis. Therefore, I adopt the average measures in both datasets. An average measure is the arithmetic mean of any available data for an individual country between 1965 and 2010 in the case of Altinok et al. (2013) and between 1960 and 2000 in the case of Hunushek and Woessman (2012).

Table 2-2 presents the descriptive statistics of the institutional quality variables for the 71 countries that enter the entire sample. Table 2-3 shows the correlation matrix of the overall indicator and the five sub-indicators. It can be seen that the chain summary index is highly correlated with all the sub-indicators except with the size of the government.

[9] In Altinok et al. (2013), measures for primary education alone, for secondary education alone and for primary and secondary education together are reported. In this study, I use the measure for the primary and secondary education together as the schooling quality variable in the regression analyses reported in Table 2-7. While this does not directly reflect the schooling quality of tertiary education, I assume that the schooling quality of various levels of education within a country is correlated.

Figure 2-2 displays the share of high-tech industries in total manufacturing value added and the percentage of the population with tertiary education averaged over the entire period (1980–2005) for each country. The fitted line shows a weak positive relationship between the two ($R^2 = 0.082$). Meanwhile, Figure 2-3 illustrates a stronger correlation between the share of high-tech industries in total manufacturing value-added and the summary index of institutional quality averaged over the entire period ($R^2 = 0.242$).[10] However, correlation does not imply causation, which is the type of relation that we are interested in for this study. Indeed, if institutional quality plays an important role in influencing the effectiveness of increased tertiary human capital and thus in promoting industrial upgrading, it is expected that countries with the same increase in tertiary human capital but with different levels of institutional quality will have different industrial upgrading performances.

2.6 Empirical results

This section presents the empirical findings using the model specification discussed in the Section 2.4. The regression results are presented in Tables 2-4, 2-5, and 2-6. Results using the second measure of tertiary human capital are largely consistent with the results using the first set of human capital measures and are presented in the Appendix 2.B due to space limitations.

Table 2-4 reports the results of the preliminary analysis of the effects of increased tertiary human capital on the shares of low-, medium- and high-tech industries based on Eq. 2.8. Table 2-5 presents the coefficient estimates obtained from the specification based on Eq. 2.10, which uses the interaction terms constructed as products of $INS_{j,t-1}$, $TER_{j,t-1}$ and $Hightech_i$. Table 2-6 reports the estimation results of the specification based on Eq. 10 using the different components of $INS_{j,t-1}$, which will reflect the different effects of various aspects of institutional quality.

The results in Table 2-4 indicate that, ceteris paribus, when a country experiences an increase in tertiary human capital, the share of low-tech industries decreases while that of medium-tech industries decreases to a lesser extent and that of high-tech industries increases. This is consistent with the empirical literature that

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[10] Since the human capital and institutional quality measures employed in the data of this study are on a five-year base, I calculate the averaged share of high-tech industries, the averaged percentage of population with tertiary education and the averaged summary index of institutional quality by using the arithmetic mean of their values in 1980, 1985, 1990, 1995, 2000 and 2005.

aims to test the Heckscher-Ohlin and Rybczynski theorems (Harrigan, 1997; Schott, 2003; Romalis, 2004; Che, 2012)[11]. These studies found that changes in the prices or endowments of physical capital or human capital result in changes in industrial structure or trade structure.

The main interest of this chapter, however, is to examine whether the impact from increased tertiary human capital on industrial upgrading is contingent on the institutional quality of an economy. As can be seen from Table 2-5, when the interaction terms involving institutional quality are added to the initial regression, the triple interaction term turns out to be positively signed and statistically significant at the 1% level. This result implies that the effect of tertiary human capital on the relative growth of the share of high-tech industries increases monotonically with institutional quality. This complementary relationship between tertiary human capital and institutional quality is established when the independent effects from institutional quality or tertiary human capital are controlled for. In fact, the coefficient for the interaction term $INS_{j,t-1} * Hightech_i$ is positive and significant at the 10% level, which suggests a direct influence of institutional quality on the relative growth of high-tech industries. Hence, the benefit from institutional quality on industrial upgrading is both direct and indirect via tertiary human capital.

Using the summary institutional quality index may not be all that useful for policy formulation. Since the summary index consists of approximately 40 variables that can be grouped into five major components, the role of each of the five components can be examined respectively. These are government size (GOVT), legal structure (LEGAL), access to sound money (MONEY), freedom to trade with foreigners (TRADE) and market regulations (REG). The findings on the interplay between tertiary human capital, industrial upgrading and various aspects of institutional quality should be more useful for policymakers in devising specific policies to facilitate the impact from better-educated workers. Table 2.6 presents the results of applying the model in Eq. 2.10 to each of the five components. The results indicate that the GOVT, MONEY, TRADE and REG components are all found to be important conditioning factors for the effectiveness of tertiary human

[11] These theorems state, respectively, that differences in countries' exports are determined by differences in their factor endowments, and that a rise in the endowment of a factor will lead to more than proportional output increase in sectors that use the factor intensively, given constant goods prices.

capital, since the coefficients for the triple interaction terms are all positive and significant at the 10% level. However, the LEGAL component is not found to be significant in influencing the effectiveness of increased tertiary human capital. The coefficients for both the interaction term $INS_{j,t-1} * Hightech_i$ and the triple interaction term $INS_{j,t-1}, * Ter_{j,t-1} * Hightech_i$ are not significant, which implies that there is no evidence to support the direct or indirect role of the LEGAL component on industrial upgrading.

This result on the LEGAL component is in contrast with those on the other four components. It may result from the inclusion of intellectual property rights (IPR) protection as a component of the LEGAL measure. Whether the strengthening of IPR protection is beneficial to growth or not is still an open question and this chapter confirms the complex relationship between IPR protection and technological catch-up. Without identifying and isolating the concrete channels through which IPR protection promotes technological improvement, one may not be able to reach a definite conclusion due to the interplay of various channels.

The validity of the estimation result is checked as follows. By using internal instruments (lagged variables), the dynamic panel estimation applied in the analysis allows for the likely weak endogeneity of main regressors. We therefore use the Hansen test of over-identification to test for the validity of these instruments. The null hypothesis is that the instruments as a group are exogenous. The results are reported for each regression and none of them rejects the null hypothesis that the moment conditions are valid at a 10% confidence level. This result indicates that the estimations are not subject to a substantial endogeneity bias. Furthermore, the Arellano-Bond test for autocorrelation in first differences, which has a null hypothesis of no autocorrelation, is performed on all the regressions. The test results, as reported in each regression, cannot reject the non-presence of second order autocorrelation in all the regression at conventional confidence levels. These two specification tests point out the validity of internal instruments and the assumption of zero autocorrelation of error term, thus testifying to the validity of the estimation results.

We have seen that both tertiary human capital stock and institutional quality have a direct impact on industrial upgrading and they are also complementary to each other in promoting industrial upgrading. It is worth notiing that the tertiary human capital stock is measured by the proportion of the population above 25 years old having complete tertiary education and by the average years of tertiary education. These measures are proxies for the tertiary human capital stock and may suffer the problem of not reflecting the true tertiary human capital stock.

The two measures of tertiary human capital stock used above both only reflect the quantity side. If we assume that tertiary education received at any place in the world is of the same quality or that people with tertiary education from different places in the word have the same capability, then the two measures used above are proper proxies for the true tertiary human capital stock in various countries. If not, then the true tertiary human capital stock will not be properly captured by measures of the quantity alone. In fact, many empirical studies ignore the problem of different schooling quality (Hanushek and Woessmann, 2012).

I separate out the industry-country individuals that are observed in 1980 and 2005 from the panel data used above. The average growth rate of the share of a country-industry individual between 1980 and 2005 is then calculated as the difference of the natural logarithm values of the shares in 1980 and 2005. I then obtain the average value of the proportion of population having tertiary education and the average value of the overall institutional quality for countries in this sample over the period between 1980 and 2005. When there are missing values of these two variables, the average of the available data is used. Table 2-7 presents five regressions. The first regression looks at the impact of the proportion of the population having tertiary education on industrial upgrading; the second regression examines the impact of the average years of tertiary education on industrial upgrading; the third regression looks at the impact of overall institutional quality on industrial upgrading; the fourth regression examines the impact of schooling quality provided in Altinok et al. (2013); the fifth regression shows the impact of the labour force's cognitive level provided in Hunushek and Woessman (2012) on industrial upgrading.

The coefficients of the interaction terms between the high-tech dummy and the five key variables are all positive and significant at the 1% level.[12] This finding

[12] The five variables are: proportion of population having tertiary education, the average year of tertiary education, overall institutional quality, schooling quality provided in Altinok, Diebolt and Demeulemeester (2013) and the labour force's cognitive level provided in Hunushek and Woessman (2009).

suggests that a larger quantity of tertiary education, higher quality of tertiary education and higher quality of institutional quality are all associated with a larger share of high-tech industries in the economies. The coefficients of the interaction terms between the medium-tech dummy and the five variables, however, are not significant at the conventional level, which suggest that these five variables matter more for the expansion of high-tech industries than for medium-tech industries.

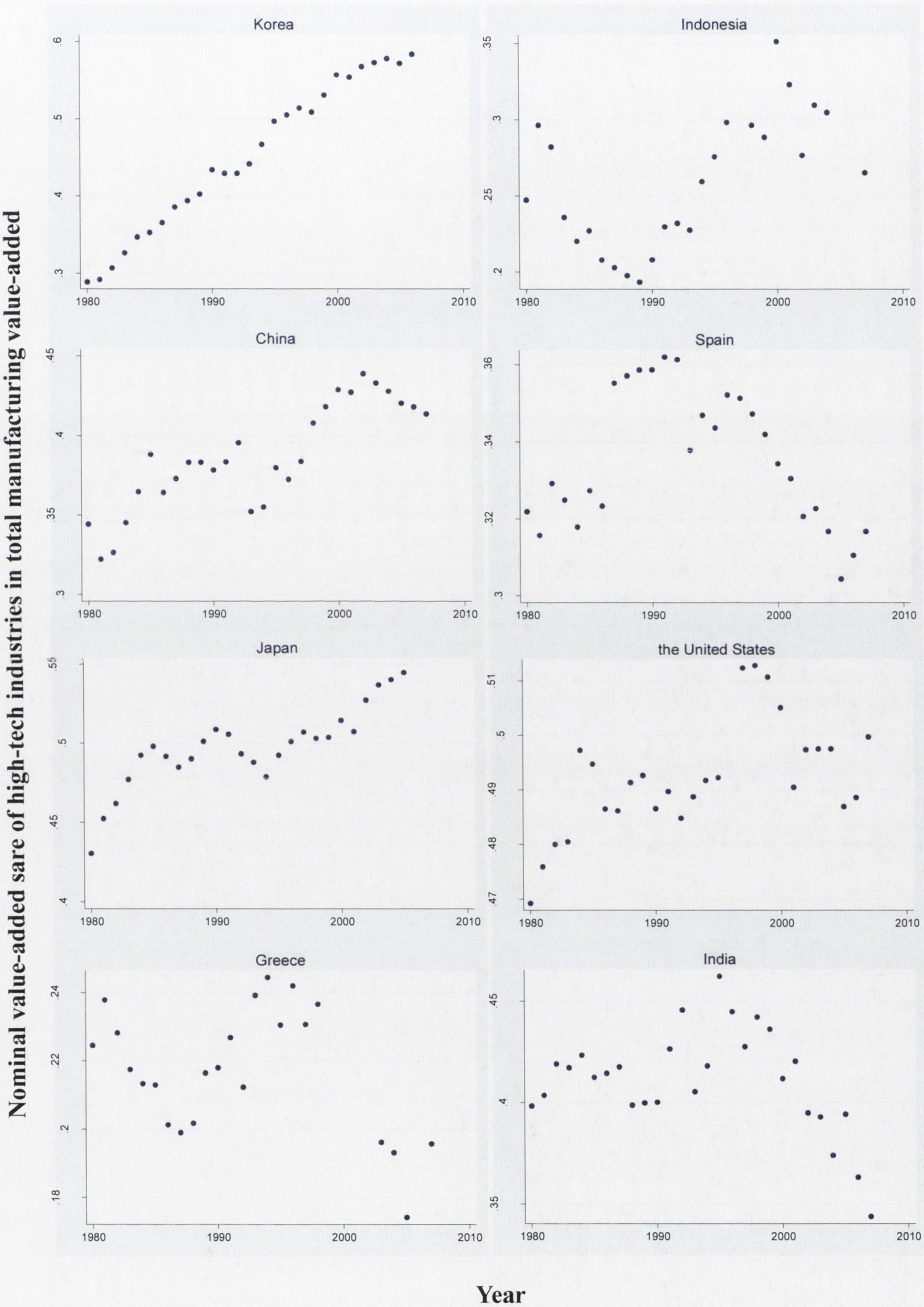
Due to the cross-sectional structure of the sample used in this section, the complementarity between schooling quality and institutional quality or between schooling quality and quantity cannot be examined by the method used in Section 2.7. Notwithstanding the simple estimation strategy here, the results in this section highlight the fact the both tertiary human capital and institutional quality are important for industrial upgrading. Furthermore, not only the quantity of tertiary human capital but also its quality plays a significant role.

2.7 Conclusion

Industrial upgrading has been high on the policy agenda of many developing countries. While the enhancement of human capital and the improvement of institutional quality are often mentioned as being crucial for successful industrial upgrading, the relevant empirical evidence is scarce. Using a panel data for 15 industrial categories in 71 countries over the period 1980-2005, this chapter finds that overall institutional quality and four aspects of it (size of government, access to sound money, freedom to trade and market regulations) are complementary to tertiary human capital in promoting the relative growth of high-tech industries. That is, the impact of increased tertiary human capital on industrial upgrading is contingent on the level of institutional quality. These empirical results suggest that policy strategies directed towards boosting the human capital of the economy should be in conjunction with, rather than precede, policies promoting better institutions, because higher institutional quality will provide an economic environment that delivers greater benefits. Although such institutional reforms can be arduous and politically difficult in the short run, the long-run economic benefits could be tremendous.

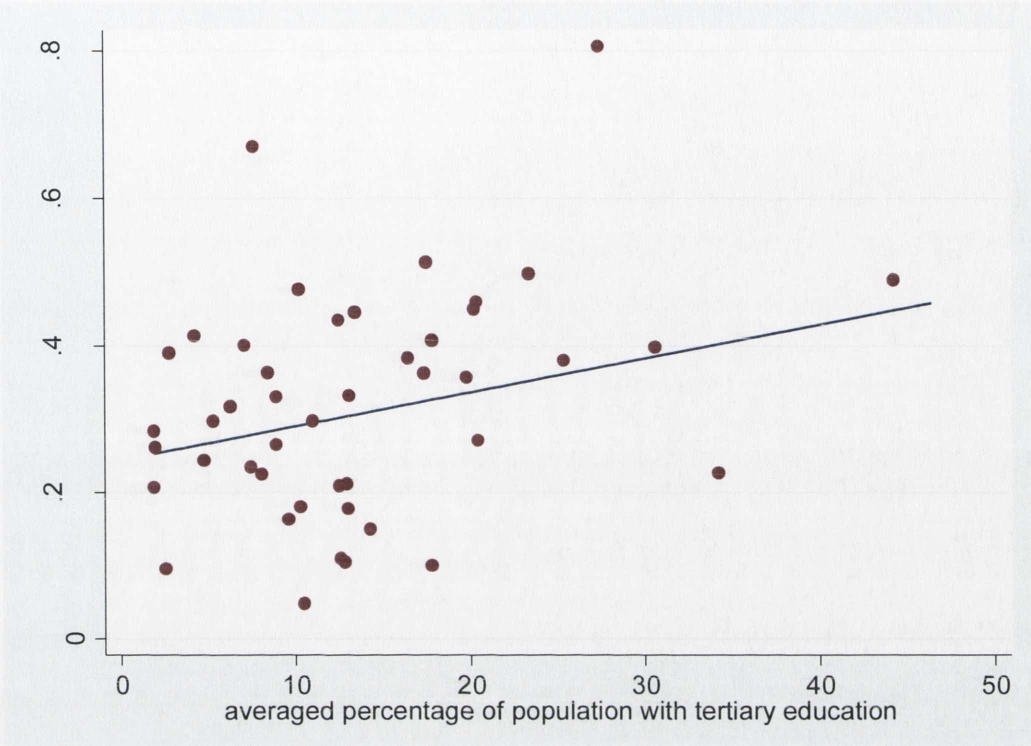
Some explanations of the limitations of the study are in order. First, in this chapter, both tertiary human capital and institutional quality were regarded as exogenous, with a focus on how a change in the level (quantity and quality) of tertiary human capital and institutional quality will induce industrial structure change. Yet, it is also possible that the industrial structure of the economy and the dynamic pattern of changing industrial structure will also influence the demand for tertiary human capital. If this demand shift exerts effects through the labour market, the observed tertiary human capital stock may depend on the industrial structure of the economy. Although the difference GMM framework used in this study has dealt with this endogeneity issue to some extent, it is still important to recognize it and this leaves the possibility for future work. The second limitation is that the interaction term in the model specification of this study forces the impact of tertiary human capital on industrial upgrading to increase (or decrease) monotonically with the level of institutional quality. However, it may be the case that a certain level of institutional quality is required before tertiary human capital can have an impact on industrial upgrading in the sample countries. This suggests the need for a more flexible specification that can accommodate various interactions among tertiary human capital, institutional quality and industrial upgrading.

Figure 2-1 Nominal value-added share of high-tech industries in selected countries



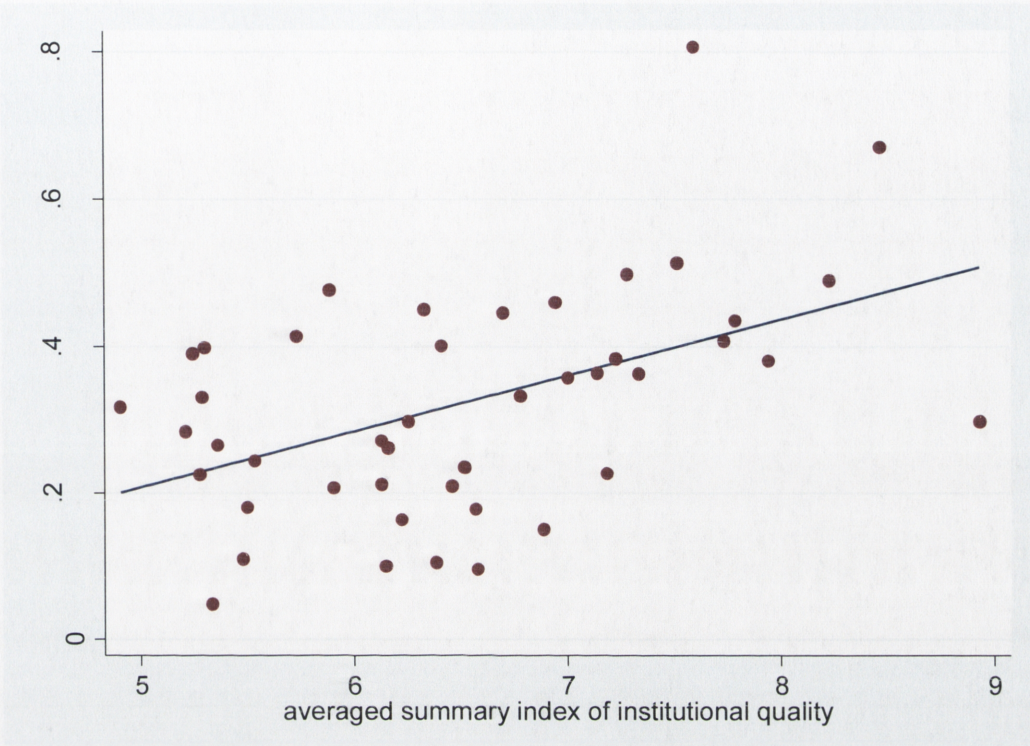
Source: Author's own calculation based on data from INDSTAT2 2011 ISIC Rev. 3 Database.

Figure 2-2 Scatter plot of averaged share of high-tech industries vs. averaged percentage of population with tertiary education



Source: Author's own calculation.

Figure 2-3 Scatter plot of averaged share of high-tech industries vs. averaged summary index of institutional quality



Source: Author's own calculation.

Table 2-1 Industrial categories in our study and corresponding relationships with ISIC 3

Industrial	Description of Industrial Categories	ISIC 3
1	1. FOOD PRODUCTS, BEVERAGES AND TOBACCO	15-16
2	2. TEXTILE, TEXT. PRODUCTS, LEATHER AND	17-19
3	3. WOOD AND PRODUCTS OF WOOD AND CORK	20
4	4. PULP, PAPER, PAP. PRODUCTS, PRINTING &	21-22
5	5. COKE, REFINED PETROLEUM RODUCTS &	23
6	6. CHEMICALS AND CHEMICAL PRODUCTS	24
7	7. RUBBER AND PLASTICS PRODUCTS	25
8	8. OTHER NON-METALLIC MINERAL PRODUCTS	26
9	9. BASIC METALS	27
10	10. FABRICATED METAL PRODCTS, EXCEPT	28
11	11. MACHINERY AND EQUIPMENT,OFFICE,	29-30
12	12. ELECTRICAL MACHINERY AND APPARATUS,	31-32
13	13. MEDICAL, PRECISION AND OPTICAL	33
14	14. MOTOR VEHICLES, TRAILERS AND	34-35
15	15. OTHER MANUFACTURING AND RECYCLING	36-37

Source: As explained in Section 2.5, the author aggregates the data of INDSTAT2 2011 ISIC Rev.3 Database so that the OECD classification of manufacturing industries based on technology intensity can be employed.

Table 2-2 Descriptive statistics of the institutional quality variables in the entire sample

	Chain summary index	Chain area 1 (government size)	Chain area 2 (legal structure and security of property rights	Chain area 3 (access to sound money)	Chain area 4 (freedom to trade internationally)	Chain area 5 (regulation of labour, credit and business)
mean	6.4	5.5	6.4	7.3	6.8	6
medium	6.3	5.7	6.2	7.4	6.9	6
variance	0.9	1.3	1.8	1.6	1.1	1
smallest	4.9	2.8	2.9	2.6	4.2	3.9
largest	8.9	9.3	9.3	9.6	9.7	8.7

Source: Author's own calculation.

Table 2-3 Correlation matrix of the overall indicator, per capita GDP and the five sub-indicators

	Size of Government	Property rights protection	Access to sound money	Trade openness	Regulation of credit, labour and business	Summary	Per capita GDP
Size of Government	1						
Property rights protection	-0.41	1					
Access to sound money	-0.18	0.64	1				
Trade openness	-0.05	0.67	0.62	1			
Regulation of credit, labour, and business	0.15	0.68	0.57	0.72	1		
Summary	0.10	0.79	0.79	0.86	0.89	1	
Per capita GDP	-0.34	0.84	0.63	0.68	0.58	0.72	1

Source: Author's own calculation.

Table 2-4 Effect of tertiary human capital on the share of industries with different technology intensities

Regressors	Coeff.	S.e.	p-value
Initial share (log)	0.5019	0.1734	0.0040
Tertiary human capital stock (TER)	-0.0411	0.0123	0.0010
TER×midtech	0.0382	0.0153	0.0130
TER×hightech	0.0490	0.0157	0.0020
AR(2) test (p-value)		0.8330	
J-test (p-value)		0.4730	
Nubmber of Observations		2387	

Note: S.e. denotes heteroskedasticity-robust error. AR(2) is a test of second-order residual serial correlation. J-test is the Hansen overidentification test. Time dummies are included to capture period specific effects but are not reported.

Source: Author's own calculation

Table 2-5 Specification with interaction between tertiary human capital and overall insitutional quality

Regressors	Coeff.	S.e.	p-value
Initial share (log)	0.3351	0.1365	0.014
Tertiary human capital stock (TER)	0.0172	0.2404	0.474
TER×midtech	0.0514	0.0163	0.002
TER×hightech	0.0241	0.029	0.406
Insititutional quality (INS)	-0.098	0.013	0.056
INS×hightech	0.1663	0.0979	0.089
INS×TER	-0.0071	0.0029	0.013
INS×TER×hightech	0.0245	0.0092	0.008
AR(2) test (p-value)		0.817	
J-test (p-value)		0.287	
Nubmber of Observations		2358	

Note: S.e. denotes heteroskedasticity-robust error. AR(2) is a test of second-order residual serial correlation. J-test is the Hansen overidentification test. Time dummies are included to capture period specific effects but are not reported.

Source: Author's own calculation.

Table 2-6 Specification with interaction between tertiary human capital and institutional quality (various sub-indicators)

Regressors	Index component									
	GOVT		LEGAL		MONEY		TRADE		REG	
	Coeff.	p-value	Coeff.	p-value	Coeff.	p-value	Coeff.	p-value	Coeff.	p-value
Initial share (log)	0.4666	0.0000	0.3883	0.0040	0.4579	0.0120	0.4620	0.0030	0.3793	0.0060
Tertiary human capital stock (TI	-0.0464	0.0200	-0.0234	0.2560	-0.0054	0.7620	-0.0359	0.1010	-0.0350	0.1090
TER×midtech	0.0389	0.0190	0.0373	0.0140	0.0512	0.0010	0.0483	0.0020	0.0431	0.0030
TER×hightech	0.0589	0.0070	0.0554	0.0030	0.0041	0.8700	0.0263	0.2510	0.0524	0.0040
Insititutional quality (INS)	0.0448	0.2950	-0.0287	0.2720	-0.0330	0.1390	0.0163	0.6040	0.0259	0.5170
INS×hightech	-0.0496	0.5930	-0.0279	0.5890	0.1272	0.0160	0.0543	0.3920	0.0331	0.5800
INS×TER	0.0008	0.7810	-0.0007	0.7850	-0.0026	0.0960	0.0001	0.9770	-0.0006	0.8190
INS×TER×hightech	0.0307	0.0480	0.0013	0.7800	0.0074	0.0660	0.0174	0.0350	0.0150	0.0560
AR(2) test (p-value)	0.9190		0.9770		0.7460		0.9040		0.9320	
J-test (p-value)	0.5880		0.5270		0.4190		0.1480		0.2740	
Nubmber of Observations	2372		2298		2372		2318		2344	

Notes: AR (2) is a test of second-order residual serial correlation. J-test is the Hansen overidentification test. Time dummies are included to capture period-specific effect but are not reported. GOVT = government size, LEGAL = legal system and protection of property rights, MONEY = access to sound money, TRADE = freedom to trade internationally, and REG = regulations governing credit, labour and business.

Source: Author's own calculation.

Table 2-7 What influences industrial upgrading?
(two measure of schooling quantity, overall institutional quality and two measures of schooling quality)

Regressant: share in total manufacturing value-added	Regression 1	Regression 2	Regression 3	Regression 4	Regression 5
Regressors	Coeff. (S.e.)	Coeff. (S.e.)	Coeff. (S.e.)	Coeff. (S.e.)	Coeff. (S.e.)
Initial share (log)	-2.3*** (0.52)	-2.2*** (0.52)	-1.99*** (0.53)	-1.98*** (0.53)	-1.98*** (0.53)
TER_PRO×midtech	0.0022 (0.0066)				
TER_PRO×hightech	0.027*** (0.0067)				
TER_YEAR×midtech		0.0076 (0.0094)			
TER_YEAR×hightech		0.04*** (0.0095)			
INS×midtech			0.016 (0.012)		
INS×hightech			0.053*** (0.012)		
QUALITY_1×midtech				0.00023 (0.00015)	
QUALITY_1×hightech				0.00073*** (0.00015)	
QUALITY_2×midtech					0.015 (0.017)
QUALITY_2×hightech					0.09*** (0.017)
Number of Observations	545	545	545	545	545

Note: 1. S.e. denotes heteroskedasticity-robust error. AR(2) is a test of second-order residual serial correlation. J-test is the Hansen overidentification test. 2. Time dummies are included to capture period specific effect but are not reported. 3. QUALITY_1 is the measure of schooling quality of primary education and secondary education together from Table Annex 2 in Altinok et al. (2013). QUALITY_2 is the measure of labour force's cognitive level from Table 11 in Hanushek and Woessmann (2012).

Source: Author's own calculation.

Appendix 2.A Countries in the sample

Table 2.A-1
List of the 71 Countries in the sample and the country codes
(World Bank Classification)

38 Developing Countries		33 High-income OECD Countries	
Name	**Code**	**Name**	**Code**
Argentina	ARG	Australia	ARG
Bolivia	BOL	Austria	AUT
Botswana	BWA	Belgium	BEL
Brazil	BRA	Canada	CAN
Bulgaria	BGR	Chile	CHL
Cameroon	CMR	Czech Republic	CZE
China	CHN	Denmark	DNK
China, Hong Kong Special Administrative	HKG	Estonia	EST
Colombia	COL	Finland	FIN
Costa Rica	CRI	France	FRA
Cyprus	CYP	Germany	DEU
Ecuador	ECU	Greece	GRC
Egypt	EGY	Hungary	HUN
Fiji	FJI	Iceland	ISL
Honduras	HND	Ireland	IRL
India	IND	Israel	ISR
Indonesia	IDN	Italy	ITA
Iran (Islamic Republic of)	IRN	Japan	JPN
Jordan	JOR	Luxembourg	LUX
Kenya	KEN	Mexico	MEX
Kuwait	KWT	Netherlands	NLD
Latvia	LVA	New Zealand	NZL
Malawi	MWI	Norway	NOR
Mauritius	MUS	Poland	POL
Morocco	MAR	Portugal	PRT
Panama	PAN	Slovakia	SVK
Peru	PER	Slovenia	SVN
Philippines	PHL	Spain	ESP
Republic of Korea	KOR	Sweden	SWE
Romania	ROM	Switzerland	CHE
Russian Federation	RUS	Turkey	TUR
Senegal	SEN	USA	USA
Singapore	SGP	United Kingdom	GBR
South Africa	ZAF		
Sri Lanka	LKA		
Taiwan	TWN		
Uruguay	URY		
Venezuela	VEN		

Appendix 2.B Regression results when average year of tertiary schooling is used as the measure of tertiary human capital

Table 2.B-1 Effect of tertiary human capital on the share of industries with different technology intensities

Regressors	Coeff.	S.e.	p-value
Initial share (log)	0.4582	0.1782	0.0100
Tertiary human capital stock (TER)	-0.8783	0.2492	0.0000
TER×midtech	0.7833	0.3082	0.0110
TER×hightech	1.0259	0.3082	0.0020
AR(2) test (p-value)		0.8540	
J-test (p-value)		0.4840	
Nubmber of Observations		2387	

Note: S.e. denotes heteroskedasticity-robust error. AR(2) is a test of second-order residual serial correlation. J-test is the Hansen overidentification test. Time dummies are included to capture period specific effects but are not reported.

Source: Author's own calculation.

Table 2.B-2 Specification with interaction between tertiary human capital and overall institutional quality

Regressors	Coeff.	S.e.	p-value
Initial share (log)	0.4056	0.1469	0.006
Tertiary human capital stock (TER)	0.0172	0.2404	0.474
TER×midtech	0.9955	0.452	0.028
TER×hightech	0.6227	0.6564	0.343
Insititutional quality (INS)	-0.0804	0.0738	0.276
INS×hightech	0.1522	0.0801	0.057
INS×TER	-0.0071	0.0029	0.013
INS×TER×hightech	0.4156	0.18	0.021
AR(2) test (p-value)		0.792	
J-test (p-value)		0.298	
Nubmber of Observations		2358	

Note: S.e. denotes heteroskedasticity-robust error. AR(2) is a test of second-order residual serial correlation. J-test is the Hansen overidentification test. Time dummies are included to capture period specific effects but are not reported.

Source: Author's own calculation.

Table 2.B-3 Specification with interaction between tertiary human capital and institutional quality (various sub-indicators)

Regressors	Index component									
	GOVT		LEGAL		MONEY		TRADE		REG	
	Coeff.	p-value	Coeff.	p-value	Coeff.	p-value	Coeff.	p-value	Coeff.	p-value
Initial share (log)	0.4056	0.0070	0.5312	0.0050	0.4025	0.0130	0.4264	0.0020	0.5328	0.0060
Tertiary human capital stock (TI	-0.0591	0.9460	-1.0513	0.2290	-0.4524	0.4050	-0.3435	0.7550	-0.5752	0.5500
TER×midtech	1.2774	0.0030	0.7999	0.0190	0.9786	0.0190	0.9637	0.0050	0.7997	0.0540
TER×hightech	1.7290	0.0000	1.2087	0.0030	0.7582	0.2040	0.9198	0.0480	0.7405	0.1530
Insititutional quality (INS)	0.1133	0.0460	-0.0257	0.5940	-0.0132	0.7000	0.0553	0.1690	-0.0097	0.8840
INS×hightech	-0.0639	0.2250	-0.0767	0.2510	0.0561	0.0800	0.0000	0.9990	0.0979	0.1660
INS×TER	-0.2071	0.2270	0.0190	0.8720	-0.0404	0.6520	-0.0599	0.7030	-0.0210	0.9010
INS×TER×hightech	0.2973	0.0930	0.0068	0.9520	0.1329	0.0800	0.2990	0.0340	0.3493	0.0520
AR(2) test (p-value)	0.9500		0.9010		0.8400		0.9100		0.8659	
J-test (p-value)	0.2040		0.5830		0.4310		0.2070		0.4170	
Nubmber of Observations	2372		2298		2372		2318		2344	

Notes: AR (2) is a test of second-order residual serial correlation. J-test is the Hansen overidentification test. Time dummies are included to capture period-specific effect but are not reported. GOVT = government size, LEGAL = legal system and protection of property rights, MONEY = access to sound money, TRADE = freedom to trade internationally, and REG = regulations governing credit, labour and business.

Source: Author's own calculation.

Chapter 3: R&D investment of Chinese firms: does institutional quality matter?

3.1 Introduction

Since the late 1970s, China has undergone a significant economic transformation and grown into a manufacturing powerhouse with the per capita income reaching the middle income level. However, new challenges such as global imbalances, demographic shifts, environmental degradation, rising income inequality and weakening of the external markets have forced China to alter the way it industrializes by adopting a new model for growth centering on its strategy of relying more on innovation (McKay and Song, 2010). China's transition towards an innovative and knowledge-intensive economy is also critical to avoiding "the middle income trap" in which a middle income country loses its comparative advantage in labour-intensive goods and yet fails to build up sufficient technological capability to progress to the next phase of development characterized by production of higher value-added and technology-intensive goods.

In recognizing the importance of nurturing innovative capabilities, the Chinese State Council published the "National Medium- and Long-Term Program for Science and Technology Development (2006 – 2020)" on 9 February 2006, which reflects China's ambition to be transformed into one of the world's most important knowledge sources.[13] In this program, the Chinese government emphasizes the role of indigenous innovation and also the importance of R&D activities performed by business enterprises. The guiding principles for science and technology work over the next 15 years are to "innovate independently, achieve development in selected areas by leaps and bounds, support development and guide the future" (Sun and Du, 2010).

While there exist intricate relationships between education, institutional quality, science and technology performance and economic growth, this chapter is focused on one question: how will institutional quality impact on China's innovation performance? This question is fundamentally important in that the answer to this question will influence our understanding about the role of institutional quality for China's growth performance. There has long been the debate about how China has grown so rapidly despite its

[13] Plans related to science and technologies are not new to China. For an introduction to China's innovation policy, Hutschenreiter and Zhang (2007), Serger and Breidne (2007) and Sun and Du (2010) provide good references.

relatively low institutional quality (Huang 2008). Much of the economic growth literature views institutional quality as a fundamental determinant of economic growth and development, and views factors such as physical capital accumulation, human capital accumulation and technological progress as growth itself (Hall and Jones 1999, Acemoglu et al., 2001, 2002, 2005a, 2005b). However, China's growth performance in the past three decades seems to be an outlier of what the theory predicts. In fact, Allen et al. (2005) regard China as a counter-example to the existing literature on law, institutions, and growth by arguing that the system of informal mechanisms and institutions plays an important role in supporting the growth in the informal sector and allows the Chinese economy to grow quickly despite its under-developed legal and financial systems. Yet, one potential reason why China has been able to be an outlier in the past thirty years could be that China's level or stage of development this period has been one that relies less on institutional quality compared with an economy that is nearer to the world technology frontier and strives to innovate by itself. As China relies more and more on innovation for growth, one needs to reassess the importance of institutional quality for this new growth model.

Against this background about China's growth dynamics and institutional quality, this study will add to our understanding of China's growth prospects by examining how variations in institutional quality within China impact on the R&D efforts of firms located in various provincial regions. Since such an analysis will reveal China's innovation prospects and innovation will be the main driver of China's next stage of growth, this study will provide a specific angle to help us understand how institutional quality affects China's future growth performance. The identification strategy exploits regional variation in the quality of institutions to answer the following question: how will institutional quality impact on China's innovation performance? More concretely, will firms invest more in R&D where the institutional quality is higher? If the answer is positive, institutional quality will certainly be a key to the realization of China's science and technology take-off. In order to identify the effect of institutional quality, it is necessary to control other factors that could influence firm-level R&D efforts in the analysis. Therefore, in addition to its focus on institutional quality, this study will provide a thorough analysis of the determinants of R&D activities by Chinese firms. While the importance of institutional quality for R&D investment is relatively well understood in the literature, as discussed in Chapter 1, the responsiveness of institutional quality to firms' needs to conduct R&D investment has been less noticed, yet critical as well. Nee and Opper (2012: p.8) argue that "the rise of capitalist economic institutions rests on bottom-up entrepreneurial action. Informal economic arrangement enabling, motivating, and guiding start-up firms provided the institutional foundations of China's emergent capital economic order". This observation points to the possibility that there may come a shift from informal institutions towards formal institutions as part of how the improvement of institutions impacts on firms' innovation. It is possible that as more and more firms are engaged in R&D activities and as the R&D intensity of firms grows, the incentive of the government to improve institutional quality to accommodate the need of firms grows. Whether institutional quality improvement predates an innovative economy or not has deep implications for the proper policies to be adopted if China hopes to accomplish the transition from imitation to innovation. This study tackles the issue by taking into account potential endogeneity of institutional quality in the robustness analyses.

In summary, I will examine whether higher institutional quality promotes firm-level innovation empirically by taking into account the potential endogeneity of institutional quality. In the next section, I will first look at how various provinces perform in terms of overall R&D intensity and R&D intensity of large- and medium- sized enterprises. That section will provide us with information about the provincial variation of R&D investment and sets the stage for the firm-level econometric analyses. Section 3.3 discusses the determinants of firm-level R&D intensity. The way of constructing the data used in this chapter will be explained in Section 3.4, followed by the econometric specification and difficulties in the estimation procedure in Section 3.5. I then present the baseline results and robustness checks in Section 3.6. Finally, conclusions are drawn in Section 3.7.

3.2 R&D investment: provincial variation

As shown in Figure 3-1, China's national R&D expenditure at current prices has experienced continuous and accelerating growth in the last two decades. While China's annual GDP growth rate during the period 1990 – 2010 was 10.4% (Lin, 2011a), the growth of national R&D expenditure has been at a faster rate and therefore the national R&D intensity (share of R&D expenditure in GDP) of China has been increasing as well (Figure 3-2). The "National Medium- and Long-Term Program for Science and

Technology Development (2006 – 2020)" sets an R&D intensity goal of 2.5% by 2020, a level similar to that of the higher-income countries such as the U.S., Japan and South Korea (Fisher-Vanden and Ho, 2006).

One interesting angle for examining China's "science and technology take-off" (Gao and Jefferson, 2007) is to look more closely at the performance at the provincial level. Through the analysis of variation in regional R&D performance, one may gain deeper knowledge about the forces behind the changing R&D intensity and thus help identify policies that regions with weaker R&D performance could adopt to boost their R&D performance.

Figures 3-3 and 3-4 show the intramural R&D expenditure in China's 31 provincial regions in 1999 and 2010 respectively. While there are considerable variations among the Chinese regions in their R&D expenditure in both years, one interesting observation is that compared with 1999 in which Beijing is the single pole of R&D expenditure, by 2010 several wealthy eastern provinces such as Guangdong, Shandong and Zhejiang had caught up with Beijing, while Jiangsu province had even overtaken it. While Figures 3-3 and 3-4 reveal the changing amount of R&D expenditure in various regions, Figure 3-5 presents changes in R&D intensity in various regions from 1999 to 2010[14]. During this period, China's national R&D intensity increased by about 1% (Figure 3-2), but with significant variation across provinces (Figure 3-5). Tianjin, Zhejiang, Shanghai and Jiangsu realized rapid increases in R&D intensity of about 1.5%. In contrast, the R&D intensity in Hainan decreased and in Shaanxi it barely changed over this period.

China's "National Medium- and Long-Term Program for Science and Technology Development (2006 – 2020)" not only emphasizes the growth of R&D intensity, but also proposes that business enterprises should become increasingly important as the entities that perform R&D. How do the various regions perform in this dimension? To answer the question about business enterprises' R&D performance, I utilize statistics for large and medium-sized enterprises reported in the China Statistical Yearbook on Science and Technology. Figure 3-6 illustrates the share of large and medium-sized enterprises' intramural R&D expenditure in total regional R&D expenditure in 1999 and 2010 respectively and also illustrates the change of the share between these two years.

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[14] R&D intensity is calculated as the ratio between provincial intramural R&D expenditure and provincial GDP in a year.

Among the 31 regions, 25 regions saw their large and medium-sized enterprises' intramural R&D become more important in total regional R&D. In Hubei, Tianjin, Henan, Hunan, Inner Mongolia, the share of large and medium-sized enterprises' intramural R&D in total regional R&D grew by more than 20% between 1999 and 2010. In contrast, in Hainan, this share decreased significantly from 50% to 26%; in Ningxia, Qinghai, Guizhou, Fujian and Guangdong, the respective shares began from more than 70% in 1999 and yet shrank from the original high level. Interestingly, large and medium-sized enterprises' R&D share in Beijing was very low at only 13% in 2010 and higher only than the share in Tibet presumably because of the concentration of universities, government think tanks and research institutes in the capital city.

In order to have regional R&D intensity and the importance of enterprise R&D grow at the same time, it is fundamentally important that business enterprises allocate a larger share of resources towards research and development activities. We can see the changes of the R&D intensity of large and medium-sized enterprises from 1999 to 2012 in Figure 3-7. Due to the fundamental importance of firm-level R&D intensity, the focus of this chapter is to find out the determinants of R&D intensity of large and medium-sized enterprises in China using a firm-level dataset. Researchers have investigated various factors that may induce Chinese firms to carry out R&D activities (Hu et al., 2005; Liu and Buck, 2007). However, this literature has not provided a rigorous study on the importance of institutional quality of the economic environment where the firms are located on firm-level R&D activities. Hence, this chapter examines whether institutional quality plays a critical role in enhancing Chinese firms' R&D intensity.

3.3 Determinants of firm-level R&D intensity

In this section, we first focus on the channels through which the institutional quality of the economic environment in which a firm operates can influence firm-level R&D activities. We then explain the determinants of firm-level R&D activities other than institutional quality.

The channels through which institutional quality influences firm-level R&D activities are as follows. First is the impact of institutional quality on firms' external financing. Some studies show that sound legal systems and efficient financial infrastructures can facilitate firms' access to external finance and thus their ability to fund investment projects (La Porta et al., 1997; Demirguc-Kunt and Maksimovic,1999; Beck and Demirguc-Kunt, 2006). Second is the impact of institutional quality on firms' internal financing. Cull and Xu (2005) find that Chinese firms that are exposed to a greater risk of expropriation by government have a lower reinvestment rate. Lin and Wong (2012) also provide evidence that the provision of good-quality institutions and services by government is positively associated with a firm's investment and sales growth. Third, the characteristics of innovation activities as a form of investment make them particularly sensitive to institutional quality. Jorde and Teece (1990: p.6) argue that "Innovation...involves uncertainty, risk taking, probing and re-probing, experimenting, and testing. It is an activity in which "dry holes" and "blind alleys" are the rule, not the exception". Kaasa et al. (2007) also regard risks and uncertainties as defining characteristics of innovation since technological development is full of unforeseeable contingencies. Hence, they emphasize the importance of formal laws and regulation introduced by the state to help reduce the risk and uncertainty of innovation faced by firms.

One of the key aspects of formal laws and regulation that affects sustained R&D investment and innovation is the strength of intellectual property rights (IPR). It is not clear from the literature whether the strengthening of intellectual property rights promotes or retards technological progress. The relationship between the strength of a country's IPR regime and technological progress is ambiguous from a theoretical standpoint, reflecting the variety of channels through which technology can be acquired and their differing importance at different stages of development (Falvey et al., 2006). For example, Furukawa (2007) finds that tightening of IPR decreases the productivity of the final goods sector and the associated demand for innovation. Manca (2010) finds that the tightening of property rights reduces the ability of countries to achieve technological catch-up. And the negative effect is stronger the farther away the countries are from the frontier. Yet, Kwan and Lai (2003) argue that there is an optimal level of IPR that balances out the loss in current consumption and the gain in consumption growth caused by higher investment in R&D in the face of tightening of IPR. Falvey et al. (2006) show that IPR protection is positively and significantly related to growth for low- and high-income countries, but not for middle-income countries. The rationale for this finding is that although IPR protection encourages innovation in high-income countries and technology flows to low-income countries, middle- income countries may benefit less because of the reduced scope for imitation.

There are also works that support the importance of strengthening IPR for technological progress. For example, in the Romer (1990) model, firms engage in R&D in order to invent new varieties of intermediate goods and obtain their patent rights. When the patent is enforced, the innovation is produced by the inventor under monopolistic conditions and the inventor enjoys monopolistic profit from the output of innovation; if the patent is not enforced, the commodity can be imitated and produced by firms on a competitive fringe and, in this case, the innovator receives no profits. While the Romer (1990) model applies to countries at the world technology frontier that rely on innovation for economic growth, there is also literature that pays attention to how an economy moves from a pure imitation regime to an equilibrium with private R&D. Eicher and García-Peñalosa (2008) show that those countries with initial institutions above a threshold converge to the high-growth/strong-institutions equilibrium with private R&D, and those starting below the threshold will move to the no-growth/ no-IPR protection equilibrium. Moving from the no-growth to the high-growth equilibrium with private R&D is shown to require the adoption of sufficiently strong institutions that overcome the institutional threshold defined by the low growth equilibrium.

Now consider other determinants of firm-level R&D intensity. First, government subsidy may play a role in promoting firm-level innovation activities due to market failures and the under-investment in R&D and innovation activities by private firms. For example, Zúñiga-Vicente et al. (2012) maintain that the use of public funding to foster private R&D activities is common in many countries. They cite the statistics from Eurostat (2009) that the public share in R&D activities from the mid-1990s to the mid-2000s was about 35% in the European Union, 30% in the United States and 18.5% in Japan. A sizable amount of these public R&D funds is actually used to subsidize R&D activities undertaken by private enterprises. Hence, the share of subsidy in industrial sales is a potential determinant of Chinese firms' innovation activities and is included in the regressions below.

Second, the availability of financial funds will impact on R&D activities of firms as well. Financial constraints may be particularly restrictive for R&D investment compared with other forms of investment. According to Unger and Zagler (2003), basic alternatives for the financing of innovation include internal finance (out of profit) and external finance (credit-based or equity-financed systems). Prior work on investment financing at the firm level has demonstrated that firms first resort to internal funds in order to maintain control rights over their innovations. When additional capital to fund R&D expenditure is needed, they turn to external funds, first accessing bank credit and then equity markets (Maskus, Neumann and Seidel 2012). One reason for the priority of internal finance could be that firms with high R&D expenditure tend to have few tangible assets that can serve as collateral for getting credit. R&D expenditures largely go to salaries and wages for scientists and researchers, which are human capital investment that cannot be collateralized (Brown et al., 2009). Furthermore, firms may be unable or unwilling to offer sufficient information about their intended R&D programs to potential funding providers due to the need to protect their proprietary information over innovation (Maskus et al., 2012), which adds to the financial restriction of R&D intensive firms. In order to examine the effect of financial constraints on firms' innovation activities, the share of profit in industrial sales, total debt to total assets ratio and the share of interest payment in industrial sales are included in the regression as potential determinants of firm R&D activities.

Third, closely related to the problems relating to financial constraints are issues about firm size, market structure and firm innovation activities brought into mainstream economics by Schumpeter (Schumpeter, 1942). He argued that large firms operating in a concentrated market are the main engines of technological progress. Symeonidis (1996) explains seven reasons behind Schumpeter's argument. They included the ability of large firms to cover the large fixed costs of R&D projects, scale and scope economies in the production of innovations, larger firms' better position to exploit unforeseen innovations, their stronger ability to spread the risks of R&D by undertaking many projects at one time and better access to external finance. As for firms with greater market powers, these firms are in a better position to finance R&D from their own profit. They also have more incentive to innovate because they can appropriate the returns from innovation more easily. In this study, the number of employees, share of firm sales in the total sales of firms in the same four-digit industry and the four-digit industry level Herfindahl Index are included in the regression as proxies for firm size, market power and market structure respectively.

Fourth, there is evidence in the literature that R&D-intensive firms have, on average, higher wages. Mishra and Smyth (2012) list four possible explanations for this positive relationship between R&D intensity and wages: first, there exists a higher demand for workers in particular occupations or with particular skills in firms with higher R&D intensity; second, there exists a higher demand for the innate ability or other unobserved characteristics of more educated workers in firms with higher R&D intensity; third, there exist quasi-rents generated by R&D intensive firms to be shared with workers with certain characteristics; fourth, firm size of R&D-intensive firms is larger since investing in R&D is likely to involve large fixed costs and wage premium is positively related to firm size. Therefore, the average wage of employees of a firm is included in the regression analysis of this study to see whether there are positive correlations between R&D-intensive firms and wages.

Fifth, firm age could have two distinct effects on R&D. Although Loderer and Waelchli (2009) do not focus on the relationship between firm age and firm R&D, the two different age effects are clearly explained by them. On the one hand, age could help firms become more efficient since firms discover what they are good at and learn how to do things better over time. On the other hand, older age may also make knowledge, abilities, and skills obsolete and induce organizational decay. On balance, it is therefore unclear whether a higher firm age helps a firm innovate or whether it burdens them – an empirical question I will address in the regression analysis below.

Sixth, a firm's export participation may affect its R&D activities as well. This could be because exporting requires prior R&D innovation (Yu and Dai, 2013) and innovation can help a firm maintain a competitive advantage in international markets over potential competitors (Porter, 1990). The causality could also be the reverse. It could also be because firms that export to international markets are more likely to be exposed to world knowledge stock and enjoy larger knowledge spillovers, which in turn promotes R&D activities within the exporting firms. As one of the largest exporting countries in the world market, the relationship between trade participation and innovation performance is vital for China's growth prospects. This question will be fully addressed in Chapter 4 where firm-level production data will be merged with transaction-level trade data. In that merged dataset, we will be able to observe firm-level trade activities such as the number of imported intermediate and capital goods, the unit value of imported good, and the geographical diversification of export markets. Hence we will be able to examine the various channels through which trade activities could impact on a firm's innovation performance in the next chapter.

Seventh, firm ownership may also have an influence on firm-level R&D activities. Earlier empirical studies have identified a productivity gap between the rapidly expanding non-state sector and state-owned firms (Groves et al., 1994; Jefferson and Rawski, 1994; Brandt et al., 2012). It is possible that a firm's R&D performance is affected by a firm's ownership type as well. Since there are information externalities associated with discovering the cost structure of the economy and coordinating externalities in the presence of scale economies, private firms may underinvest in R&D compared with the socially optimal level (Rodrik, 2004). Therefore, government interventions such as the adoption of industrial policies are justified given this potential for market failure. If government intervention takes the form of leaning towards state-owned enterprises rather than subsidizing various types of firms universally, then state-owned enterprises may have higher R&D investment compared with other types of firms. Anecdotal evidence suggests that government support for R&D and resources for R&D are more often channeled towards state-owned enterprises than towards private-owned enterprises in China.

Another reason why state-owned enterprises may be more R&D intensive than private enterprises is given in Bruche (2010). The author argues that when it comes to firms' technological catch-up strategies, "business groups" in India are a dominant and appropriate organizational form because they help firms overcome shortcomings in the institutional context of developing countries. These shortcomings include immature capital markets, insufficient contract security or underdeveloped labour markets. Bruche (2010) further suggests that state-owned enterprises in China could be a functional substitute for business groups because state organizations support catch-up strategies through soft loans and preferential access to government sponsored research. However, it should be noted that whether state ownership benefits firms' growth or not depends on how the effect of inefficient resource allocation under soft budget constraint and the effect of efficiency gains from substituting for lacking institutions balance out.

Another strand of literature that is relevant to the issue of ownership type and R&D focuses on the relationship between foreign direct investment (FDI) and R&D. In terms of R&D by foreign affiliates, some studies in this literature find that there is little incentive for foreign firms to undertake innovation efforts since foreign firms have access to parent firms' technology (Kumar, 1996; Kathuria, 2008). Others suggest that foreign affiliates will perform adaptive R&D to modify technologies that originate in home countries to suit local conditions in host countries (Cassiman and Veugelers, 2002; Tomiura, 2003). Therefore, considering these two opposing effects, whether foreign ownership enhances firm-level R&D is an empirical question to be examined.

Finally, as will be explained in the next section, the identification strategy to be used involves the estimation of a selection equation and an outcome equation. This identification strategy requires at least one variable that appears in the selection equation but not in the outcome equation. I adopt a dummy for advertisement as the variable that is included only in the selection equation. The dummy for advertisement is chosen because marketing expenses and R&D expenses are two of the key inputs that firms effectively manage to improve their competencies (Andras and Srinivasan, 2003). Spending on advertising and R&D can both be viewed as forms of investment in intangible assets with predictably positive effects on future cash flows, and are therefore related – a necessary condition for this variable choice to be valid (Chauvin and Hirschey, 1993).

3.4 Data

The analysis is based on a firm-level panel dataset of the Chinese manufacturing industry for the period 2005-2007. The data were obtained from the Annual Census of Chinese Industrial Firms compiled by the National Bureau of Statistics of China (NBS). This census provides detailed firm-level financial and operational information for state-owned enterprises and all other firms with annual turnover of more than five million US dollars. The NBS requested all these firms to report information to the local statistical offices, which then report to the NBS. The NBS has the final responsibility to process the data and produce the census. This census is considered to be the most comprehensive firm-level dataset ever compiled by the Chinese statistical office, accounting for about 90% of total output in most industries. The NBS has endeavoured to maintain consistency in data collection across time, industries and regions (Yi, Wang and Kafouros, 2013). Tables 3-1 and 3-2 provide a description of the R&D activities of the firms in the dataset from 2005 to 2007.

To measure the institutional quality of China's provincial regions, I adopt the NERI Index of Marketization for China's Provinces published by the National Economic Research Institute (NERI) (Fan et al., 2011). The NERI index is an assessment system for relative progress in marketization for China's provinces (Wang et al., 2004). It assesses marketization performance in five fields with a total of 23 basic indicators. For a certain field, a field index is calculated as the arithmetic average of a few basic indices. And the arithmetic average of the five indices becomes the overall marketization index. The five fields covered are: (1) government and market relation, (2) development of the non-state enterprise sector, (3) development of the commodity market, (4) development of factor markets, and (5) market intermediaries and the legal environment for the market. In this study, two measures of institutional quality are used and they are both from the NERI index system. One measure is the overall marketization index from the NERI index system. The other measure is the basic index for the protection of IPR, which is one of the indices that compose the field index for market intermediaries and the legal environment for the market in the NERI index system.

The two measures of institutional quality are important in their own right. On the one hand, IPR receives much attention in the discussion about a firm's incentives for doing innovation. On the other hand, overall institutional quality will affect the whole production process and hence each firm's ability to enjoy the fruit of R&D investment as well. Therefore, these two measures of institutional quality are both examined in the regression analyses below.

3.5 Model specification and estimation

Based on the discussion about the determinants of firm-level R&D intensity in Section 3.3, we can now conduct the econometric analysis using the firm-level panel dataset constructed in Section 3.4. The outcome equation we are interested in is as follows and the selection equation differs from the outcome equation only by one variable $dummy\_advertise_{i,j,k,t}$. This variable only appears in the selection equation.

$R\&Dintensity_{i,j,k,t} =$

$\beta_0 + \beta_1 * size_{i,j,k,t} + \beta_2 * age_{i,j,k,t} + \beta_3 * profitability_{i,j,k,t} + \beta_4 *$

$exportintensity_{i,j,k,t} + \beta_5 * wage_{i,j,k,t} + \beta_6 * marketshare_{i,j,k,t} + \beta_7 *$

$herfindahl_{j,t} + \beta_8 * debtratio_{i,j,k,t} + \beta_9 * k_{i,j,k,t} + \beta_{10} * subsidy_{i,j,k,t} + \beta_{11} *$

$$interestpayment_{i.j,l,t} + \beta_{12} * institutionalquality_{k,t} + \varepsilon_{i,j,k,t}$$

(3.1)

where i denotes an individual firm in a certain four-digit industry, j denotes a certain four-digit industry, k denotes a certain province, t denotes a certain year.

$R\&Dintensity_{i,j,k,t}$ is the share of a firm's R&D expenditure in its total industrial sales. This is a measure of input into the innovation process. Measures of innovative or technological activity can be classified as measures of either innovation input or output. Measures of innovation output include number of patents, number of significant innovations, and various indices of market value of innovations. The most frequently used measures of inputs into the innovation process are R&D expenditure and personnel involved in R&D (Symeonidis 1996). Since there is no information about innovation output in our dataset, R&D intensity is adopted as the measure of innovative activity here.

$size_{ij,k,t}$ is the natural logarithm of the number of employees in a firm.

$age_{i,j,k,t}$ is the number of years of existence of a firm.

$profitability_{i,j,k,t}$ is the share of profit in total industrial sales of a firm.

$exportintensity_{i,j,k,t}$ is the share of export value in total industrial sales of a firm.

$wage_{i.j,k,t}$ is the average wage of the employees in a firm, ie the sum of wage compensation and welfare compensation divided by the number of employees in a firm.

$marketshare_{i,j,k,t}$ is the share of the industrial sales of a firm in the industrial sales of all firms in the same four-digit industry.

$herfindahl_{j,t}$ is the four-digit industry-level Herfindahl Index. This is calculated as the sum of squared market shares of all the firms in the same four-digit industry. The range of Herfindal Index is between 0 and 1 with 0 denoting perfect competition where each firm's market share is infinitesimally small, and 1 denoting monopoly where one firm takes up the whole market.

$debtratio_{i,j,k,t}$ is the share of a firm's total liabilities in its total assets.

$k_{i,j,k,t}$ is the net value of fixed assets per employee in a firm.

$subsidy_{i,j,k,t}$ is the share of subsidy in a firm's industrial sales.

$interestpayment_{i,j,k,t}$ is the share of interest payment in the industrial sales of a firm.

$institutionalquality_{k,t}$ is the measure of institutional quality (overall or focused on the protection of intellectual property rights) of the province where a firm is located.

$dummy\_advertise_{i,j,k,t}$ is the dummy that takes value 1 if a firm has positive advertisement expenditure and zero otherwise.

The empirical strategy can be summarized as one that relies on provincial variation of institutional quality and locational information of firms to identify the effect of institutional quality on firm-level R&D intensity. Since a firm only reports the location where it registered its capital and there is no information in the dataset about where the R&D activities are conducted, one may argue that a firm may have several subsidiaries across provinces and its R&D activities may be conducted in a different province from where the firm registered its capital. It is possible that what matters for a firm's R&D intensity is the institutional quality of the province where R&D activities are performed and not that of the province where the firm registers its capital. If so, without information on the actual site of R&D, the empirical strategy discussed above will not work.

However, I hope to establish here that this concern is in fact unnecessary and the empirical strategy in this study can address the research question well. The reason is that I am investigating the impact of institutional quality on firm-level R&D intensity from a firm's perspective. The question to be asked is whether the business environment a firm operates in will influence its business strategy about R&D, all other things being equal. A firm should be regarded as an organic whole whose R&D investment decisions should be guided by an overall strategy. Wherever a firm locates its R&D activities, the decision of R&D investment is made at the firm level and responds to the business strategy of the firm as a whole. A firm can choose to establish R&D centers in the same province where its headquarter is located or in the most advanced cities such as Beijing, Shanghai, Guangzhou and Shenzhen in order to gain easy access to human capital, business opportunities and information arising because of industrial agglomeration. Furthermore, a firm can also choose to contract its R&D project to universities or public research institutes and even the R&D facilities of other firms. Wherever the location of R&D activities of a firm, the decision is made at the firm level and serves the profits of the firm as a whole.

Therefore, if we hope to examine how institutional quality could potentially influence firm-level R&D intensity, what matters most is the economic environment that most directly affects a firm's business strategy. The province where a firm registers its capital is undoubtedly the place that most strongly and intensively shapes the firm's business environment. In China, local governments often make efforts to attract firms to register capital and even to establish headquarters and these firms will receive preferential treatment, such as import and export convenience and tax exemptions, lower profit tax, subsidized loans or cash grants offered by governments. On the one hand, when entering the Chinese market, foreign multinational enterprises will choose in which province to register their capital based on consideration of the local business environment. On the other hand, large-scale domestic enterprises often move from hometowns and relocate their headquarters to more developed cities and register capital there. Motivated by the ambition to expand market share and to upgrade product quality, such relocation can help a firm tap into developed industrial clusters, communication and infrastructure facilities for commercial and financial activities, science and technology capabilities and market intermediaries. Hence, where to register capital critically determines the business environment a firm will be faced with, which most strongly influences the business strategy about R&D investment Therefore, the empirical strategy in this study is proper and valid.

The difficulty of the estimation of Equation (3.1) lies in the concentration of the dependent variable $R\&Dintensity_{i,j,k,t}$ on the zero value. It is known that if ordinary least squares (OLS) estimation is used on the non-zero part of the original variable $R\&Dintensity_{i,j,k,t}$, the results could be biased due to the sample selection problem. This problem is made more complex when firms may have unobserved heterogeneity, such as the ability of the entrepreneur. The coexistence of the concentration of the dependent variable on the zero value and the necessity to take into account firm-level fixed effects requires an estimation strategy that can tackle these two problems at the same time. Previous studies on the determinants of Chinese firms' R&D intensity resort to the random-effects Tobit model for panel data. Although this approach pays attention to the fact that the dependent variable is left-censored at zero value, it also assumes that the possibly omitted firm-specific variables are not correlated with variables included in the empirical specification. This assumption is problematic if, for example, the omitted variable is the ability of the entrepreneur, which influences the R&D intensity of the firm and is potentially correlated with other independent variables such as profitability and market share of the firm.

The estimation strategy suggested by Kyriazidou (1997) solves the sample selection problem and the omitted variables problem due to unobserved firm heterogeneity at the same time and is therefore the strategy adopted here. A two-step procedure is adopted to implement the estimation. In the first step, the coefficients of the selection equation are consistently estimated by the Conditional Logit Estimator. In the second step, the estimates of the coefficients of the selection equation are used to construct the weights needed for the estimation of the coefficients of the outcome equation by weighted least squares. Since the construction of the weights requires a choice about bandwidth, the optimal bandwidth as suggested in Kyriazidou (1997) is adopted. There is no existing command or user written program files available for this estimation strategy and therefore it is necessary that I wrote it with certain programming software. Since Kyrizaidou (1997) has presented the derivation in matrix form, Mata in Stata is the ideal tool to be used. I wrote the Mata code for this estimation strategy by Kyriazidou (1997) in the Stata program. The program for estimation in Stata is available upon request.

3.6 Empirical results

Table 3-3 presents the descriptive statistics of the sample for the regression. Tables 3-4 and 3-5 report the regression results of the empirical strategy explained above. In Table 3-4, I examine how intellectual property rights protection influences firm-level R&D intensity and in Table 3-5, the effect of overall institutional quality is considered. It can be seen that the results based on these two different measures of institutional quality are qualitatively similar.[15] Ceteris paribus, a larger firm is more likely to do R&D; a firm that pays higher wages, enjoys higher profitability and has higher export intensity is more likely to do R&D; a firm with a higher debt burden is less likely to do R&D; a firm where received subsidy is of a larger proportion of the industrial sales is more likely to do R&D; when the protection of IPR (overall institutional quality) is stronger in the province where a firm is located, the firm is more likely to do R&D. Finally, a firm that advertises is also more likely to do R&D.

The influences of these variables on the R&D intensity of a firm that indeed conducts R&D activities are as follows. The larger the size of a firm, the less R&D intensive the firm becomes. If the four-digit industry to which a firm belongs becomes less competitive, the more R&D intensive a firm becomes. The higher the debt burden of a firm, the less R&D intensive the firm becomes. The larger the share of interest payments in the industrial sales of a firm, the more R&D intensive the firm becomes. The larger the proportion of exports in the industrial sales of a firm, the less R&D intensive the firm becomes. The role of the share of subsidy in the industrial sales of a firm is not robust. It is positive and significant at 10% level in Table 4 but insignificant in Table 3-5. Similarly, the impact of a firm's market share is not robust. It is negative and significant at 5% level in Table 3-4 but insignificant in Table 3-5.

Comparing how the variables impact on the likelihood of doing R&D and the R&D intensity of firms, the following four points emerge. First, the market share of a firm, capital intensity of a firm, the industrial concentration of the industry to which a firm belongs and the share of interest payment in the industrial sales of a firm influence the R&D intensity of a firm that conducts R&D activities, but not the decision to do R&D or not. Second, profitability and IPR protection positively influence the likelihood to do R&D but do not significantly impact on the R&D intensity of a firm that has already decided to do R&D. Third, the size of a firm and its export intensity exert opposite impacts on the likelihood of doing R&D and the R&D intensity of a firm doing R&D. Fourth, the wage rate, the debt burden of a firm and the share of subsidy received in industrial sales are three variables that influence the likelihood of R&D and the intensity of R&D in the same direction. Firms that pay a higher wage rate, have less debt burden

[15] The only difference is that the coefficient of the variable market share is significant and negative in Table 3-4 but not significant in Table 3-5.

and receive subsidies are more likely to undertake R&D and are also more R&D intensive once having decided to conduct R&D activities.

Stronger protection of IPR clearly boosts the possibility that a firm will invest in innovation. This finding suggests that China is no exception in terms of the importance of institutions that provide protection for the benefits of R&D. If the Chinese government hopes to achieve the goal set in the "National Medium- and Long-Term Program for Science and Technology Development (2006 – 2020)" that firms should become the major agents performing R&D activities, one helpful strategy that the government could adopt is to build up institutions that facilitate the operations of market and strengthen IPR (overall institutional quality) that increase the expected return to R&D investment of firms. Interestingly, IPR (overall institutional quality) does not significantly influence the R&D intensity of a firm that has already decided to do R&D.

This empirical finding suggests that the importance of the protection of IPR probably lies mainly in inducing a phase change of firms from technological imitation to innovation. Once this phase change is completed, the continuous growth of innovative capability may rely on other determinants and dynamics such as market power and market structure. This finding echoes the empirical result in Stenholm, Acs and Wuebker (2013), who examine how four different dimensions of institutions impact on the rate and type of entrepreneurial activities. They find that the institutional dimensions that determine the rate of entrepreneurial activities (on the quantity side) are distinct from those that determine the type of entrepreneurial activities (ie, the quality side: replicative entrepreneurship and high-impact entrepreneurship). Innovative, high-quality and high-impact entrepreneurial activities are not positively influenced by regulative, cognitive and normative institutional arrangements but are nurtured by conducive institutional arrangements such as the availability of venture capital, access to knowledge spillovers and university-industry collabouration.

As for the relationship between firm size, market structure and firm-level innovation, on the one hand, it is found that a firm of larger size is more likely to do R&D but is less R&D intensive and that a firm's profitability enhances its likelihood to do R&D but not its R&D intensity. These findings reflect the complex relationship between firm size, firm profitability and innovation activities. On the other hand, it is found that a firm in a more concentrated industry and a firm with smaller market share are more R&D

intensive, which shows the links between market power and innovation activities. However, the evidence found in this study is not entirely consistent with Schumpeter's argument although there is some consistency with respect to how the degree of concentration of the industry impacts on firm-level R&D intensity. It requires further research on the channels behind the results to provide a convincing explanation. While various hypotheses could be advanced here, I refrain from doing so due to the lack of further evidence about the mechanisms behind the empirical findings.

Regarding the relationship between financial constraints and innovation activities, the finding that a firm with larger debt burden is less likely to do R&D and is less R&D intensive supports the hypothesis that internal funds are a critical funding source of firm-level R&D activities. Interestingly, the share of interest payment in the industrial sales of a firm, a variable that reflects the external funding of the firm, plays an insignificant role in inducing a firm to do R&D but significantly impacts on the R&D intensity of firms that conduct R&D. The share of subsidy in total industrial sales is found to increase the propensity of a firm to do R&D and to enhance the R&D intensity of a firm that is doing R&D. This finding suggests that the role of government in the China's "science and technology take-off" may be important and how government subsidies influence a firm's investment in innovation and innovation output is a question that is highly relevant in China. Also, the fact that institutional quality matters for engaging firms in R&D activities but not for R&D intensity once firms opt into R&D activities further points to the importance of other potential determinants of R&D intensity such as market power and market structure.

With regard to the relationship between firm-level exports and innovation, it is found that a firm that has a higher export intensity is more likely to conduct R&D activities although for a firm that is doing R&D, higher export intensity is negatively associated with R&D intensity which could be caused by the trade regime a firm is engaged in. It is necessary that we analyze what types of trade activities, that is processing trade or ordinary trade, a firm is engaged in to gain deeper understanding about the mechanisms behind the findings about the negative relationship between R&D intensity and export intensity. In Chapter 5, I will make an in-depth analysis about the effects of trade participation on firm-level R&D.

Up until now, we have assumed that institutional quality exerts an exogenous influence on firms' R&D activities. However, this assumption may not be valid because institutional quality may be endogenously determined by the needs of firms, as suggested by Nee and Opper (2012). In this case, firms conduct R&D activities in order to survive in the process of market competition. When more and more firms are engaged in innovation activities, a government's incentive to establish proper institutions to accommodate the changes grows. The more active the firms are in R&D activities, the higher the institutional quality of the province where the firms are located becomes. Hence, in this process, the endogeneity of institutional quality arises from reverse causality. In order to tackle the potential endogeneity caused for the two reasons discussed above, I resort to an instrumental variable that is correlated with institutional quality but not with firms' decision to do R&D and with regards to R&D intensity.

I follow Li et al. (2012) who use the average mortality rate in each province during the great famine in China (1959-1961) as the instrumental variable for institutional quality in the province. As Li et al. (2012) argue, a region's inflexible grain procurement policy when faced with the drop in production in 1959 led to a high mortality rate in that region. Furthermore, the inflexibility of policy was related to its weak institutions. Hence, the average mortality rate in the great famine can capture the institutional quality during that time period. Because institutions are path dependent (Acemoglu et al., 2001), a region with weaker institutions in that period (1959-1961) is likely to have a weaker institutions today. Hence, the average mortality rate during the great famine is correlated with institutional quality today. Unobserved factors that influence firms' R&D activities nowadays should not impact on the average mortality rate at that time. Thus the average mortality rate during the great famine is a valid instrument for institutional quality nowadays.

It is currently not clear how one could make use of instrumental variables to deal with the above endogeneity problem in the estimation strategy of Kyriazidou (1997). In general, the proper way to deal with the endogeneity problem in a censored regression of panel data is not yet mature. Therefore, I resort to cross-sectional data for the year 2007 to examine the endogeneity problem. An instrumental variable Probit model and an instrumental variable Tobit model is performed on the cross-sectional data for the year 2007.[16]

The descriptive statistics of the sample of year 2007 are presented in Table 3-6. We can see that the descriptive statistics in Table 3-6 are close to those in Table 3-3. In Tables 3-7 and 3-8, the results of the instrumental variable Probit model are reported. It can be seen that these are similar whether IPR or overall institutional quality is used. In order to deal with firm heterogeneity, the dummies for the four-digit industries and the dummies for the ownership types of firms are included in the model specification. Therefore, the instrumental variable Probit estimation using cross-sectional data for the year 2007 not only provides some evidence about the endogeneity problem, but also explicitly shows the effects of ownership types and industry effects on firms' R&D activities. In contrast, we have no information about the influence of ownership types from the main results based on Kyriazidou (1997) because the fixed effects are differenced out both in the selection equation and the outcome equation.

We can compare the second and the third columns of Table 3-4 (Table 3-5) with Table 3-7 (Table 3-8). Recall that the second and third columns of Table 3-4 (Table 3-5) report the results of the conditional Logit estimation while Table 3-7 (Table 3-8) reports the results of the instrumental variable Probit estimation. Hence, the values of the coefficients cannot be directly compared but the signs of the coefficients are comparable. It should be noted that the two measures of institutional quality are significant and positive in both the baseline estimation and the instrumental Probit model (Tables 3-4, 3-5, 3-7 and 3-8). Therefore, the finding that higher institutional quality enhances the likelihood that firms conduct R&D activities is robust across various specifications.

In order to take into account the potential endogeneity problem of the outcome equation, an instrumental variable Tobit estimation is performed on the cross-sectional data for the year 2007. The deficiency of this approach is that we assume that the selection process and the outcome process are the same and thus specify the same regressors for the selection equation and the outcome equation, which will not be true if the two mechanisms are not governed by the same process in reality. Tables 3-9 and 3-10 report

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[16] Probit and Tobit models were also estimated for further comparison. The results are available upon request.

the estimation results of the instrumental variable Tobit models. Since the Wald tests of exogeneity of the instrumental Tobit reject the null hypothesis that the ease of doing business index is exogenous at the 1% level, the results indicate that there may be an endogeneity problem and therefore that the results from the instrumental variable Tobit model is reliable. A comparison of these two tables with the fourth and the fifth columns of Table 3-4 and Table 3-5 indicates that the two sets of results are not totally consistent since the significance and signs of the coefficients of the variables representing firm size, age and capital intensity are different. However, we can see that the coefficient of the institutional quality variable is still not significant in the instrumental variable Tobit estimation. This suggests that the finding that institutional quality will not influence the R&D intensity of firms that have already decided to do R&D is a robust one.

The Heckman two-step estimation is the counterpart of the estimation strategy in Kyriazidou (1997) for cross-sectional data. Like the estimation strategy in Kyriazidou (1997), the Heckman two-step estimation involves the estimation for a selection equation and an outcome equation. I perform the Heckman two-step estimation on cross-sectional data of 2007 as a comparison with the Kyriazidou (1997) estimation on panel data. In order to control fixed effects, dummies for industries and dummies for ownership types are included in both the selection equation and the outcome equation in the Heckman two-step estimation.

The results are reported in Tables 3-11 and 3-12. The results of the selection equation using Kyriazidou (1997) and those of the selection equation using the Heckman two-step have several discrepancies. However, the results of the outcome equation using Kyriazidou (1997) and those of the outcome equation using the Heckman two-step are very similar. The only two differences are: first, the variable profitability is insignificant for Kyriazidou (1997) (Tables 3-4 and 3-5) but is positive and significant for Heckman two-step (Tables 3-13 and 3-14); second, capital intensity is negative and significant in Table 3-4 and Table 3-5 but positive and significant in Table 3-11 and Table 3-12. When the Heckman two-step estimation is used on cross-sectional data of 2007, it is found that higher institutional quality is significantly and positively associated with the likelihood of firms to do R&D but does not significantly influence the R&D intensity of firms that have already decided to perform R&D. This finding is consistent with the finding of the Kyriazidou (1997) estimation on panel data.

In all of the above analyses, the measures of institutional quality in various provinces are from the NERI Index of Marketization for China's Provinces. As a robustness check, I employ the indicator of a business-friendly environment provided by the World Bank Report "Doing Business in China 2008" (the World Bank Group, 2008). This indicator is the 'ease of doing business index', which is calculated as the simple average of each city's percentile rankings on each of the four topics covered in the report. These four topics are four areas of business regulation and their enforcement: (1) "starting a business", (2) "registering property", (3) "getting credit", and (4) "enforcing contract". Therefore, the ease of doing business index can reflect how encouraging regulations are to business activities.

Since the ease-of-doing-business index is for the capital cities in 30 province-level administrative divisions, I need to filter firms located in these 30 capital cities from the original cross-sectional data of 2007. This goal is achieved by using the first three and four digits of the 12-digit address code in the dataset to identify the 30 capital cities.[17]

In both the instrumental Probit and instrumental Tobit models, the coefficient of the-ease-of-doing-business index is significant and positive. Since the Wald tests of exogeneity of both the instrumental variable Probit and the instrumental variable Tobit reject the null hypothesis that the ease of doing business index is exogenous at the 5% level, the results of instrumental Probit and instrumental Tobit may be more reliable. It should be noticed that the finding that the ease of doing business index is significant and positive in the instrumental Tobit estimation is not consistent with the baseline result.[18]

[17] In order to identify Shanghai, Beijing and Guangzhou, the first three digits are used. In order to identify the other 27 capital cities, the first four digits are required.

[18] I also perform instrumental Probit, Probit, instrumental Tobit, Tobit and Heckman two-step estimations on the sample of firms in capital cities of 30 province-level administrative divisions. The instrumental variable used is still the average mortality rate in a province during the great famine. The results are available upon request. The results are mostly consistent with the corresponding estimation results for the cross-sectional data of the year 2007 where the NERI index system is adopted for measures of institutional quality.

One side product of the above analyses performed on the two sets of cross-sectional data is that we can examine the role of firm ownership type in determining firm R&D activities. Summarizing the findings from various methods performed on the full cross-sectional data of 2007 and the cross-sectional data of firms in the 30 capital cities in 2007, we can see that state-owned enterprises enjoy the highest likelihood of doing R&D and the highest R&D intensity. Private enterprises, Hong Kong, Macau and Taiwan- -owned (HMT-owned) enterprises and foreign-owned enterprises are less likely to do R&D and are less R&D intensive compared with state-owned enterprises. The finding here support the argument made in Bruche (2010) as discussed above.

The empirical findings show that better institutional quality enhances firms' possibility of engaging in R&D investment. Since the growing innovation capability of firms is a critical part of China's transitions towards an innovative economy, improving institutional quality so that more firms are induced to perform R&D is a worthwhile effort by the government to promote growth. Institutional quality improvement measures include, for example, reforming the financial system and integrating financial markets into the regional and global structures, and strengthening property rights protection and fairness by reducing corruption).[19][20] Besides these measures, the government could seek ways to improve institutional quality based on the determinants of institutional quality. As suggested by Alonso and Garcimartín (2013), these determinants include: further promoting growth since growth itself will enhance institutional quality, improving income distributions and tax systems, and promoting education.

Difference in regional levels of development is one feature of the Chinese economy that is worth special attention. The significant regional variation of institutional quality and innovative activities reflected in this study highlights the need to pay attention to this dimension. As Nee (1996) suggests, due to the regional nature of China's political

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[19] Financial reform measures include: (1) interest rate liberalization and reduction of entry barriers to the banking sector, which will promote domestic savings, (2) promotion of prudential regulations and scaling down of direct credit, which can lead to more efficient capital allocation, and (3) opening up the domestic financial markets to foreign investors and liberalizing capital accounts, which can attract more productive money that contributes to the overall pool of funds available for domestic investment.

[20] According to Eesley (2009), in post-Soviet and formerly-Communist countries, insecure property rights have been argued to be more inhibiting to entrepreneurship than capital constraints.

system and reforms, institutional change and economic development have not been uniform across China. When we think about government taking actions to improve institutional quality or the bottom-up dynamics of firms demanding better institutions, we will inevitably meet with the regional nature of the Chinese economy. It is important that the gaps in institutional quality across different regions are narrowed to move towards a unified and consistent institutional framework that is applied to all regions, so that the competitiveness and agglomeration of advanced regions are strengthened and the development of lagging regions is improved.

3.8 Conclusion

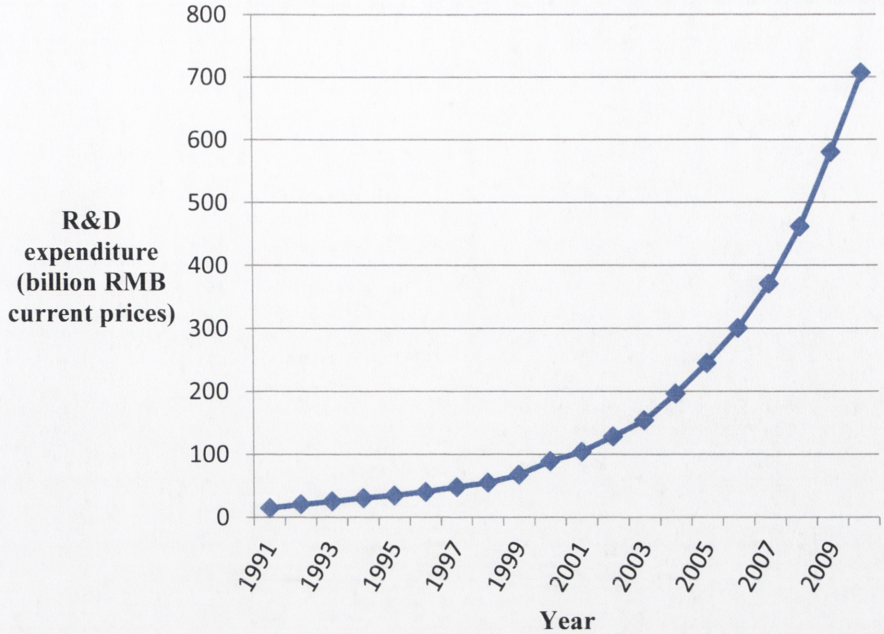
While some studies argue that China has been able to grow rapidly despite its relatively low institutional quality (Huang, 2008; Allen et al., 2005), the findings in this chapter suggest that institutional quality is critical to China's innovative performance and hence to the economy's economic growth in the future.

This chapter employed a firm-level panel dataset covering the period 2005–2007 and including all state-owned enterprises and all enterprises with an annual turnover of more than 5 million RMB. Based on the estimation strategy suggested by Kyriazidou (1997), which takes into account the sample selection problem and firm-level fixed effects at the same time, the study shows that higher levels of overall institutional quality and higher levels of IPR protection of the province where a firm is located increase the likelihood that a firm will conduct R&D activities, controlling for other potential determinants of a firm's R&D participation. However, these two measures of institutional quality are not found to be significantly related to a firm's R&D intensity once the firm has already decided to invest in R&D.

These findings suggest that institutional quality at the provincial level positively affects the entry decision of firms into R&D activities. But once firms start to do R&D, the subsequent expansion of firm-level R&D intensity depends on other factors such as market power and market structure. Therefore, sorting out domestic institutional quality is just the first step towards the goal of building a knowledge-intensive economy, becoming a global R&D player and contributing to the world pool of knowledge and technology. A better understanding of other factors that influence the R&D intensity of firms after they begin to invest in R&D is important for ensuring continuous growth of a firm's innovative capabilities.

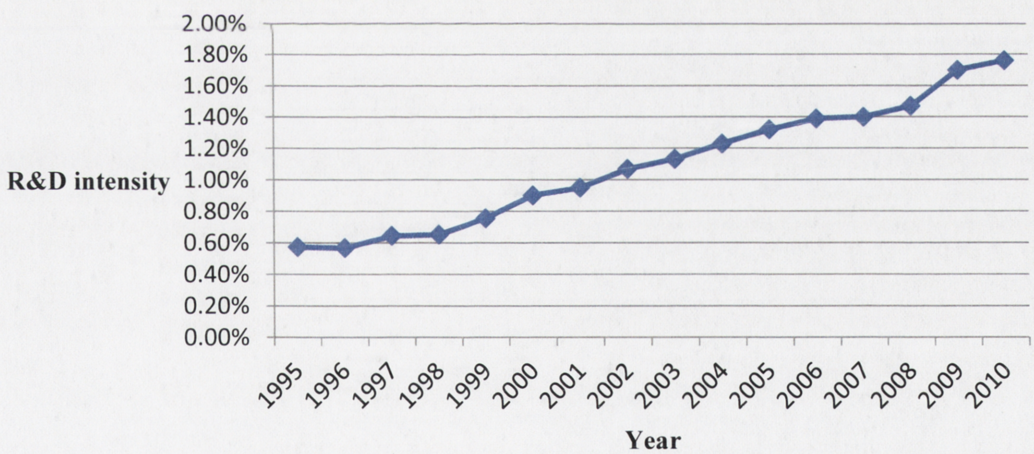
For example, trade-related factors could be very important for the R&D intensity of firms since there are complex relationships between trade and innovation suggested by the existing literature. Although export intensity, the only trade-related factor in this study, is found to enhance a firm's likelihood of doing R&D but reduce the R&D intensity of the firm, we need more trade-related measures for a complete study on the effects of firm-level trade on innovation activities. This remains the task of Chapter 4.

Figure 3-1 China's national R&D expenditure



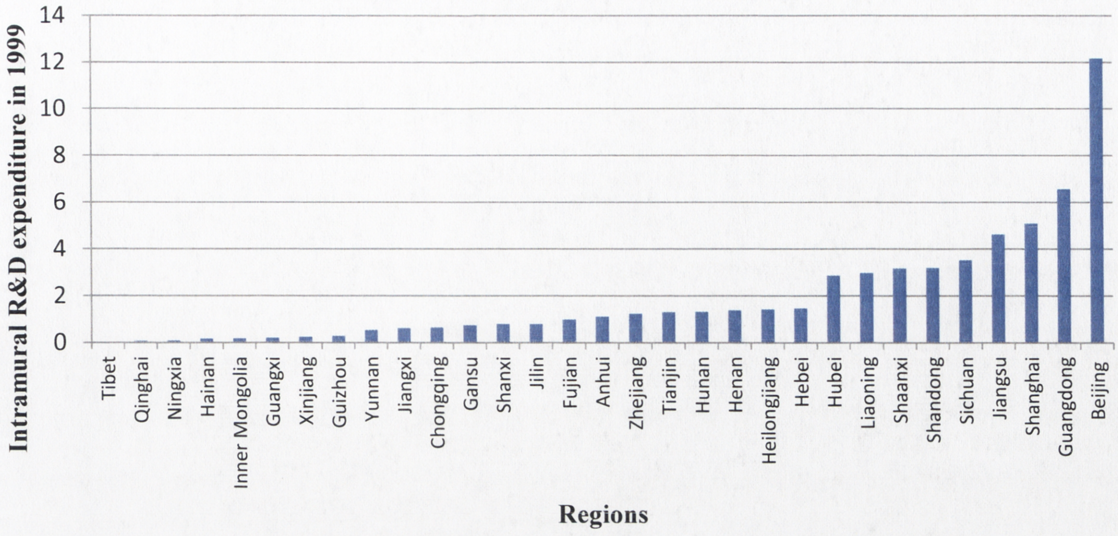
Source: China Statistical Yearbook on Science and Technology (various issues).

Figure 3-2 China's national R&D intensity (the ratio of R&D expenditure in GDP) from 1995-2010



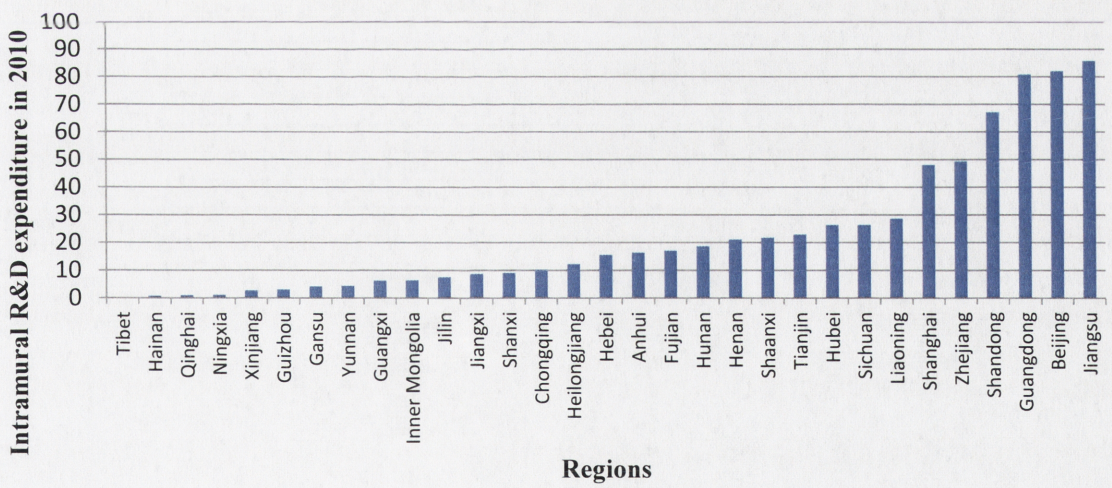
Source: Author's calculation based on data from China Statistical Yearbook on Science and Technology (various issues).

Figure 3-3 Intramural R&D expenditure of 31 provincial regions in 1999 (billion RMB)

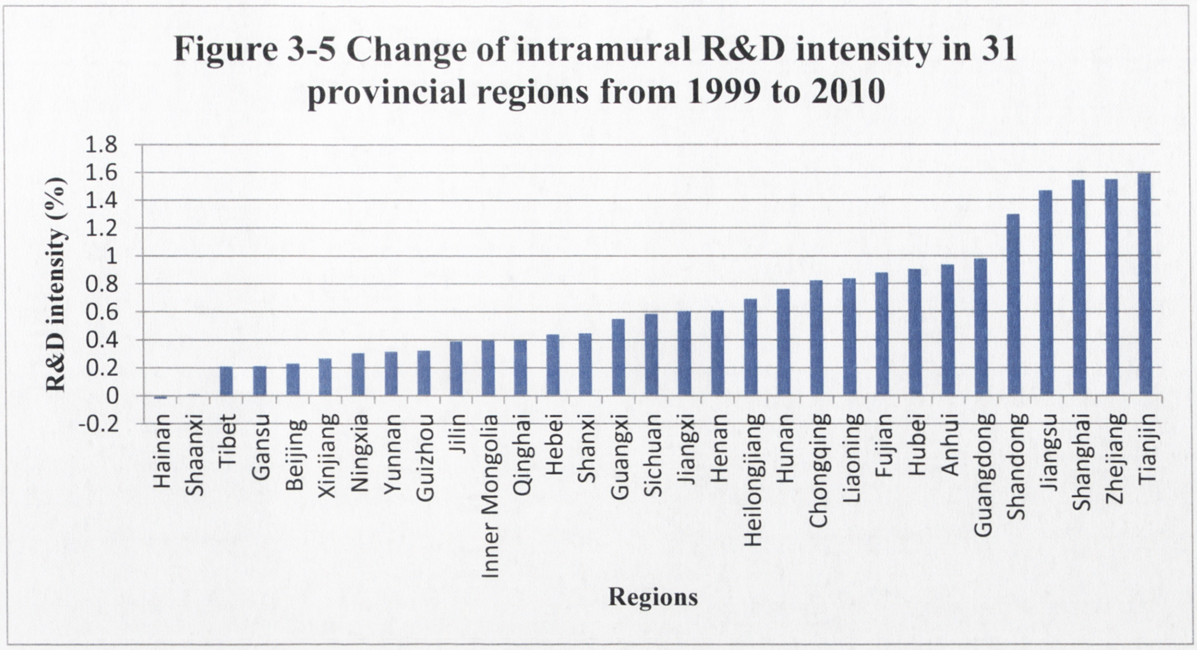


Source: China Statistical Yearbook on Science and Technology (2000, 2011).

Figure 3-4 Intramural R&D expenditure of 31 provincial regions in 2010 (billion RMB)

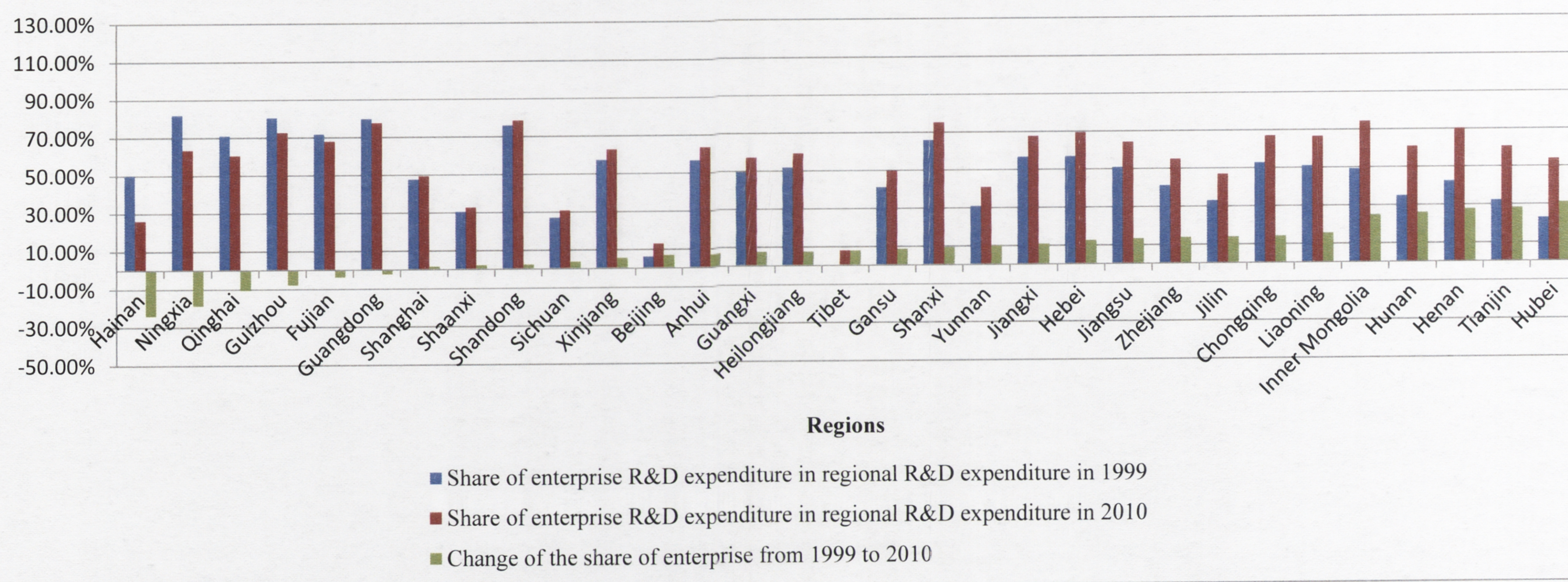


Source: China Statistical Yearbook on Science and Technology (2000, 2011).



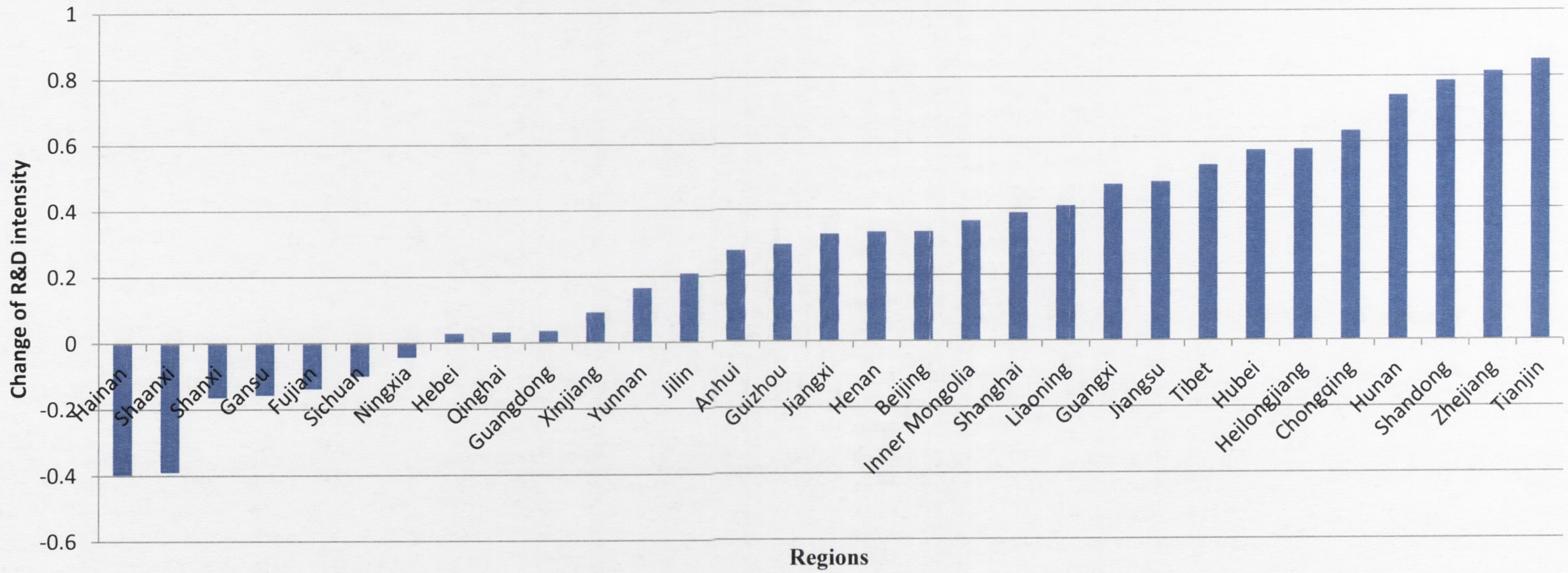
Source: China Statistical Yearbook on Science and Technology (2000, 2011).

Figure 3-6 Share of R&D expenditure performed by large- and medium-sized enterprises in regional R&D expenditure in 1999 and 2010 and changes of this share from 1999 to 2010



Source: China Statistical Yearbook on Science and Technology (2000, 2011).

Figure 3-7 Change of R&D intensity (share of R&D expenditure in gross output) of large- and medium-sized enterprises in 31 provincial regions from 1999 to 2010



Source: China Statistical Yearbook on Science and Technology (2000, 2011).

Table 3-1 Number of all firms and number of firms with non-zero R&D expenditure

Year	N	Number of observations with nonzero R&D	Percentage
2005	241,188	24,123	10.00%
2006	267,883	27,848	10.40%
2007	302,526	33,089	10.94%

Source: Author's own calculation.

Table 3-2 Number of all firms, number of firms with non-zero R8D expenditure, average R&D intensity and average subsidy share in various industries (2005, 2006 and 2007 as a pooled sample)

Code	Industry name	N	Number of observations with non-zero R&D	Percentage of non-zero R&D	R&D intensity	Subsidy as a share of gross product current (%)
13	Food processor	47,934	3,311	6.9%	0.05%	0.35%
14	Food producer	17,392	2,317	13.3%	0.13%	0.25%
15	Beverage	11,541	1,383	12.0%	0.10%	0.32%
16	Tobacco	466	176	37.8%	0.18%	0.69%
17	Textile	74,219	4,094	5.5%	0.05%	0.13%
18	Clothing & Accessories	38,740	1,684	4.3%	0.03%	0.10%
19	Leather and fur clothing and goods	20,080	1,330	6.6%	0.04%	0.10%
20	Wooden products	19,194	700	3.6%	0.02%	0.30%
21	Furnishings	10,470	701	6.7%	0.05%	0.13%
22	Paper producer and products	23,102	1,008	4.4%	0.03%	0.31%
23	Publishing	14,450	720	5.0%	0.06%	0.42%
24	Education and sport products	10,741	822	7.7%	0.07%	0.14%
25	Petrochemical	5,957	489	8.2%	0.08%	0.29%
26	Chemical materials	60,385	7,991	13.2%	0.18%	0.35%
27	Medicals and pharmaceuticals	15,538	5,625	36.2%	0.93%	0.44%
28	Chemical fiber producer	4,040	389	9.6%	0.10%	0.18%
29	Rubber products	9,668	988	10.2%	0.13%	0.26%
30	Plastic products	39,545	2,359	6.0%	0.06%	0.19%
31	Nonmetallic products	64,616	4,480	6.9%	0.08%	0.66%
32	Black metal smelting	19,389	959	4.9%	0.35%	0.24%
33	Nonferrous metal smelting	16,600	1,384	8.3%	0.08%	0.62%
34	Metal products	44,889	2,852	6.4%	0.07%	0.16%
35	Industrial machinery	66,398	7,647	11.5%	0.19%	0.22%
36	Specialty machinery	32,962	5,907	17.9%	0.48%	0.33%
37	Commercial vehicles & trucks	36,214	6,205	17.1%	0.29%	0.34%
39	Electrical enginering and equipment	49,370	7,954	16.1%	0.28%	0.24%
40	Computers and telecommunications	28,205	7,059	25.0%	0.97%	0.35%
41	Meters and instruments	11,399	3,347	29.4%	1.10%	0.41%
42	Other equipment manufacturers	16,616	1,131	6.8%	0.11%	0.20%
43	Recycling	1,477	48	3.2%	0.04%	0.50%

Source: Author's own calculation.

Table 3-3 Descriptive statistics of the sample for regression on the three-year unbalanced panel data

	Descriptive Statistics				
Variables	**Mean**	**Medium**	**Standard Deviation**	**Min**	**Max**
RnDintensity	0.0018	0	0.0146	0	0.9906
size	4.7	4.6	1.1	0	12.1
age	9.2	7	9.0	1	180
k	100.2	45.3	383.8	1.1E-03	209520.5
herfindahl	0.015	0.0071	0.028	1.0E-03	0.95
market_share	0.0018	3.2E-04	0.0095	1.5E-09	0.98
wage	2.72	2.69	0.57	-5.3	8.6
profitability	0.0093	0.026	8.9	-7710.8	628.8
exportintensity	0.17	0	0.34	0	1.4
debtratio	0.56	0.57	0.31	-7.2	22.9
interestpayment	0.0097	0.0014	0.21	-17.6	158.7
subsidy	0.0029	0	0.038	-0.35	17.2
intellectual property protection	13.2	8.6	10.6	-0.02	41.5
overall institutional quality	8.4	8.6	1.6	0.29	10.9
dummy_advertise	0.5	0	0.5	0	1
average_mortality_rate_during_famine	14.4	13.2	5.8	7.2	38.9

Source: Author's own calculation.

Table 3-4 Regression results (three-year unbalanced panel data, intellectual property rights protection)

	Likelihood of conducting R&D activities		**R&D intensity (share of R&D expenditure in total industrial sales)**	
Regressors	Coefficients	Standard Error	Coefficients	Standard Error
size	0.47***	2.6E-02	-2.4E-03***	8.7E-04
age	-2.1E-03	3.3E-03	9.0E-05	7.5E-05
k	-1.7E-05	4.0E-05	-3.7E-06*	2.1E-06
herfindahl	-0.50	7.0E-01	0.12***	3.2E-02
market_share	-1.9	2.1	-0.074**	3.0E-02
wage	0.36***	2.1E-02	5.9E-03***	1.5E-03
profitability	0.073***	2.57E-02	1.1E-03	3.0E-03
exportintensity	0.29***	6.6E-02	-6.5E-03***	1.7E-03
debtratio	-0.17***	4.9E-02	-8.2E-03***	2.8E-03
interestpayment	0.33	2.1E-01	0.067***	3.0E-02
subsidy	0.68***	2.6E-01	0.13*	7.9E-02
intellectual property protection	0.027***	2.6E-03	1.4E-04	1.9E-04
dummy_advertise	1.2***	2.1E-02		
year2006	0.07***	1.8E-02	2.7E-03***	8.4E-04
year2007	-0.63***	2.9E-02	-2.3E-03	1.9E-03

Note: regression results on constants and industry dummies are not reported due to space limit.

***, ** and * indicate significance level of 1%, 5% and 10% respectively.

Source: Author's own calculation.

Table 3-5 Regression results (three-year unbalanced panel data, overall institutional quality)

	Likelihood of conducting R&D activities		**R&D intensity (share of R&D expenditure in total industrial sales)**	
Regressors	Coefficients	Standard Error	Coefficients	Standard Error
size	0.47***	2.6E-02	-2.4E-03**	1.1E-03
age	-1.9E-03	3.3E-03	1.0E-04	1.1E-04
k	-1.8E-05	4.0E-05	-6.4E-06*	3.3E-06
herfindahl	-0.51	7.0E-01	0.16***	5.3E-02
market_share	-2.1	2.1	0.11	1.8E-01
wage	0.36***	2.1E-02	6.0E-03***	2.2E-03
profitability	0.073***	2.6E-02	7.5E-03	4.6E-03
exportintensity	0.29***	6.6E-02	-8.3E-03***	2.1E-03
debtratio	-0.16***	4.9E-02	-8.3E-03**	3.7E-03
interestpayment	0.34	2.1E-01	0.073*	4.2E-02
subsidy	0.68***	2.6E-01	0.17	1.0E-01
Overall institutional quality	0.34***	4.2E-02	-1.6E-03	2.5E-03
dummy_advertise	1.2***	2.9E-02		
year2006	-0.04**	2.9E-02	4.1E-03**	1.7E-03
year2007	-0.77*	4.7E-02	-1.9E-04	3.2E-03

Note: regression results on constants and industry dummies are not reported due to space limit.

***, ** and * indicate significance level of 1%, 5% and 10% respectively.

Source: Author's own calculation.

Table 3-6 Descriptive statistics of the sample for regression on the cross-sectional data for the year 2007

	Descriptive Statistics				
Variables	**Mean**	**Medium**	**Standard Deviation**	**Min**	**Max**
RnDintensity	0.0020	0	0.015	0	0.99
size	4.6	4.5	1.1	0	12.1
age	9.0	7	8.5	1	180
k	108.2	49.1	498.3	0.0011	209520.5
herfindahl	0.014	0.0069	0.026	0.0010	0.94
market_share	0.0016	0.00029	0.0087	1.5E-09	0.97
wage	2.9	2.8	0.57	-4.0	8.6
profitability	0.021	0.029	3.0	-1248	148.8
Exportintensity	0.16	0	0.33	0	1
Debtratio	0.56	0.57	0.30	-1.6	15.5
Interestpayment	0.0087	0.0012	0.099	-17.6	43.3
Subsidy	0.0024	0	0.027	-0.35	5.0
intellectual property protection	16.7	15.5	12.4	0.22	41.5
Overall institutional quality	8.9	8.6	1.6	1.6	10.9
Dummy_advertise	0.99	1	0.07	0	1
Average_mortality_rate_during_famine	14.4	13.2	5.8	7.2	38.9

Source: Author's own calculation.

Table 3-7 Regression results of IV Probit (cross-sectional data for the year 2007, intellectual property rights protection)

	Likelihood of conducting R&D activities	
Regressors	Coefficients	Standard Error
size	0.063***	1.4E-02
age	1.7E-03	1.5E-03
k	-2.2E-06	1.1E-05
herfindahl	0.92**	3.7E-01
market_share	-0.72	0.92
wage	0.31***	2.5E-02
profitability	0.056***	1.9E-02
exportintensity	-0.11***	5.5E-02
debtratio	-0.23***	5.5E-02
interestpayment	0.49***	1.5E-01
subsidy	0.58***	1.4E-01
intellectual property protection	4.3E-03*	2.3E-03
dummy_advertise	0.33	0.40
Wald test of exogeneity	Chi2(1)=0.03	Prob>chi2=0.87

Table 3-7 continued Regression results of IV Probit (cross-sectional data for the year 2007, intellectual property rights protection)

	Likelihood of conducting R&D activities	
Regressors	Coefficients	Standard Error
Firm_type120	-0.43***	0.14
Firm_type130	-0.32**	0.15
Firm_type141	-0.07	0.51
Firm_type142	-0.12	0.51
Firm_type143	-0.20	0.44
Firm_type149	-0.41	0.65
Firm_type151	-0.096	0.15
Firm_type159	-0.05	0.08
Firm_type160	3.5E-04	0.10
Firm_type171	-0.50***	0.11
Firm_type172	-0.44**	0.18
Firm_type173	-0.16*	0.086
Firm_type174	-0.21	0.14
Firm_type190	-0.38	0.37
Firm_type210	-0.20*	0.11
Firm_type220	-0.43*	0.26
Firm_type230	-0.46*	0.11
Firm_type240	-0.21	0.34
Firm_type310	-0.19*	0.10
Firm_type320	-0.49*	0.26
Firm_type330	-0.44***	0.10

Firm_type340	0.033	0.22

Note: 1. The dummy indicating state-owned enterprises is omitted. Therefore, the coefficients of the dummies indicating ownership types above show the difference between enterprises of various types and state-owned enterprises.

2. Dummies indicating two-digit industries are included in the regression. Regression results on constants and industry dummies are not reported due to space limit.

3. ***, ** and * indicate significance level of 1%, 5% and 10% respectively.

Source: Author's own calculation.

Table 3-8 Regression results of IV Probit (cross-sectional data for the year 2007, overall institutional quality)

	Likelihood of conducting R&D activities	
Regressors	Coefficients	Standard Error
size	0.066***	1.4E-02
age	1.7E-03	1.5E-03
k	1.7E-07	1.2E-05
herfindahl	0.96***	3.7E-01
market_share	-0.76	0.92
wage	0.30***	2.6E-02
profitability	0.057***	1.8E-02
exportintensity	-0.13**	5.7E-02
debtratio	-0.24***	5.5E-02
interestpayment	0.50	1.5E-01
subsidy	0.62***	1.4E-01
Overall institutional quality	0.047**	2.4E-02
dummy_advertise	0.33	3.9E-01
Wald test of exogeneity	Chi2(1)=2.6	Prob>chi2=0.11

Table 3-8 continued Regression results of IV Probit (cross-sectional data for the year 2007, overall institutional quality)

	Likelihood of conducting R&D activities	
Regressors	Coefficients	Standard Error
Firm_type120	-0.45***	0.14
Firm_type130	-0.35**	0.15
Firm_type141	-0.091	0.51
Firm_type142	-0.14	0.51
Firm_type143	-0.20	0.44
Firm_type149	-0.43	0.65
Firm_type151	-0,.094	0.15
Firm_type159	-0.069	0.086
Firm_type160	-0.013	0.10
Firm_type171	-0.53***	0.11
Firm_type172	-0.47***	0.18
Firm_type173	-0.19**	0.09
Firm_type174	-0.24*	0.14
Firm_type190	-0.41	0.37
Firm_type210	-0.24**	0.11
Firm_type220	-0.46*	0.26
Firm_type230	-0.49***	0.11
Firm_type240	-0.24	0.34
Firm_type310	-0.21**	0.10
Firm_type320	-0.51*	0.26
Firm_type330	-0.47***	0.10

Firm_type340	0.014	0.22

Note: 1. The dummy indicating state-owned enterprises is omitted. Therefore, the coefficients of the dummies indicating ownership types above show the difference between enterprises of various types and state-owned enterprises.

2. Dummies indicating two-digit industries are included in the regression. Regression results on constants and industry dummies are not reported due to space limit.

3. ***, ** and * indicate significance level of 1%, 5% and 10% respectively.

Source: Author's own calculation.

Table 3-9 Regression results of IV Tobit (cross-sectional data for the year 2007, intellectual property rights protection)

	R&D intensity (share of R&D expenditure in total industrial sales)	
Regressors	Coefficients	Standard Error
size	1.1E-02***	1.8E-03
age	2.7E-04***	2.0E-05
k	-3.5E-08	2.6E-07
herfindahl	6.9E-02***	5.9E-03
market_share	-6.0E-03	1.4E-02
wage	2.1E-02***	3.3E-04
profitability	7.8E-03***	4.7E-04
exportintensity	-3.7E-03***	6.1E-04
debtratio	-1.1E-02***	6.4E-04
interestpayment	0.075***	3.0E-03
subsidy	6.4E-02***	4.3E-03
Intellectual property rights protection	2.0E-05	2.8E-05
Number of left-censored observations	266379	
Number of uncensored observations	32424	
Log likelihood	-1088721.2	
Wald test of exogeneity	Chi2(1)=73.9	Prob>chi2=0.000

Table 3-9 continued Regression results of IV Tobit (cross-sectional data for the year 2007, intellectual property rights protection)

	Likelihood of conducting R&D activities	
Regressors	Coefficients	Standard Error
Firm_type120	-0.026***	1.6E-03
Firm_type130	-0.015***	1.8E-03
Firm_type141	5.6E-03	7.1E-03
Firm_type142	-1.5E-02**	7.2E-03
Firm_type143	-1.2E-02**	6.2E-03
Firm_type149	-1.8E-02***	6.8E-03
Firm_type151	0.012***	2.4E-03
Firm_type159	-1.2E-04	1.2E-03
Firm_type160	5.2E-03***	1.4E-03
Firm_type171	-0.019***	1.3E-03
Firm_type172	-2.3E-02***	1.9E-03
Firm_type173	-5.6E-03***	1.2E-03
Firm_type174	-8.1E-03***	1.7E-03
Firm_type190	-2.2E-02***	3.8E-03
Firm_type210	-8.1E-03***	1.7E-03
Firm_type220	-2.0E-02***	2.7E-03
Firm_type230	-2.6E-03***	1.4E-03
Firm_type240	-5.8E-03	4.5E-03
Firm_type310	-5.0E-03***	1.3E-03
Firm_type320	-1.7E-02***	2.7E-03
Firm_type330	-2.4E-02***	1.4E-03

Firm_type340	-1.4E-04	3.7E-03

Note: 1. The dummy indicating state-owned enterprises is omitted. Therefore, the coefficients of the dummies indicating ownership types above show the difference between enterprises of various types and state-owned enterprises.

2. Dummies indicating two-digit industries are included in the regression. Regression results on constants and industry dummies are not reported due to space limit.

3. ***, ** and * indicate significance level of 1%, 5% and 10% respectively.

Source: Author's own calculation.

Table 3-10 Regression results of IV Tobit (cross-sectional data for the year 2007, overall institutional quality)

	R&D intensity (share of R&D expenditure in total industrial sales)	
Regressors	Coefficients	Standard Error
size	1.1E-02***	1.8E-04
age	2.7E-04***	2.0E-05
k	-1.5E-08	2.6E-07
herfindahl	6.9E-02***	5.9E-03
market_share	-5.7E-03	1.4E-02
wage	2.2E-02***	3.5E-04
profitability	8.5E-03***	6.4E-04
exportintensity	-3.0E-03***	6.4E-04
debtratio	-1.1E-02***	6.5E-04
interestpayment	0.075***	3.0E-03
subsidy	6.4E-02***	4.3E-03
Overall institutional quality	2.0E-04	2.8E-04
Number of left-censored observations	266379	
Number of uncensored observations	32424	
Log likelihood	-503148.96	
Wald test of exogeneity	Chi2(1)=11.8	Prob>chi2=0.0006

Table 3-10 continued Regression results of IV Tobit (cross-sectional data for the year 2007, overall institutional quality)

	R&D intensity (share of R&D expenditure in total industrial sales)	
Regressors	Coefficients	Standard Error
Firm_type120	-0.027***	1.6E-03
Firm_type130	-0.017***	1.7E-03
Firm_type141	3.2E-03	7.1E-03
Firm_type142	-1.6E-02**	7.1E-03
Firm_type143	-1.2E-02**	6.0E-03
Firm_type149	-1.9E-02***	6.8E-03
Firm_type151	0.012***	2.3E-03
Firm_type159	-1.2E-03	1.2E-03
Firm_type160	4.3E-03***	1.4E-03
Firm_type171	-0.021***	1.3E-03
Firm_type172	-2.3E-02***	1.9E-03
Firm_type173	-7.0E-03***	1.2E-03
Firm_type174	-9.0E-03***	1.7E-03
Firm_type190	-2.3E-02***	3.8E-03
Firm_type210	-8.2E-03***	1.4E-03
Firm_type220	-2.2E-02***	2.7E-03
Firm_type230	-2.8E-03***	1.4E-03
Firm_type240	-7.5E-03*	4.5E-03
Firm_type310	-6.3E-03***	1.3E-03
Firm_type320	-1.9E-02***	2.7E-03
Firm_type330	-2.5E-02***	1.3E-03

Firm_type340	-1.4E-03	3.7E-03

Note: 1. The dummy indicating state-owned enterprises is omitted. Therefore, the coefficients of the dummies indicating ownership types above show the difference between enterprises of various types and state-owned enterprises.

2. Dummies indicating two-digit industries are included in the regression. Regression results on constants and industry dummies are not reported due to space limit.

3. ***, ** and * indicate significance level of 1%, 5% and 10% respectively.

Source: Author's own calculation.

Table 3-11 Regression results of Heckman two-step estimation (cross-sectional data for the year 2007, intellectual property rights protection)

	Likelihood of conducting R&D activities		**R&D intensity (share of R&D expenditure in total industrial sales)**	
Regressors	Coefficients	Standard Error	Coefficients	Standard Error
size	0.29***	3.4E-03	-3.4E-03***	9.7E-04
age	0.0074***	3.9E-04	-1.2E-05	2.9E-05
k	5.1E-08	5.1E-06	1.6E-06**	7.5E-07
herfindahl	1.1***	1.2E-01	0.041***	8.1E-03
market_share	2.5***	0.34	-0.021*	1.3E-02
wage	0.40***	6.1E-03	8.2E-03***	1.4E-03
profitability	0.14***	1.1E-02	5.5E-03***	1.0E-03
exportintensity	-0.058***	1.2E-02	-4.1E-03***	8.2E-04
debtratio	-0.22***	1.2E-02	-7.6E-03***	1.1E-03
interestpayment	1.5***	8.1E-02	0.055***	6.2E-03
subsidy	0.47***	9.3E-02	0.13***	6.1E-03
Intellectual property rights protection	0.0036***	3.0E-04	1.7E-04***	2.2E-05
dummy_advertise	0.47***	7.5E-02		

Table 3-11 continued Regression results of Heckman two-step estimation (cross-sectional data for the year 2007, intellectual property rights protection)

	Likelihood of conducting R&D activities		**R&D intensity (share of R&D expenditure in total industrial sales)**	
Regressors	Coefficients	Standard Error	Coefficients	Standard Error
Firm_type120	-0.53***	3.1E-02	-9.4E-03***	2.8E-03
Firm_type130	-0.30***	3.4E-02	-9.0E-03***	2.4E-03
Firm_type141	0.18	0.14	-8.2E-03	7.4E-03
Firm_type142	-0.38***	0.14	3.8E-03	1.1E-02
Firm_type143	-0.31***	0.12	6.9E-04	7.8E-03
Firm_type149	-0.31**	0.13	-0.020**	8.7E-03
Firm_type151	0.52***	5.4E-02	6.3E-04	2.4E-03
Firm_type159	-1.3E-03***	2.4E-02	-3.0E-03**	1.3E-03
Firm_type160	0.17***	2.9E-02	-2.6E-03*	1.6E-03
Firm_type171	-0.34	2.6E-02	-0.014***	2.0E-03
Firm_type172	-0.42***	3.7E-02	-0.010***	3.1E-03
Firm_type173	-0.10***	2.4E-02	-6.0E-03***	1.3E-03
Firm_type174	-0.12***	3.3E-02	-8.8E-03***	2.1E-03
Firm_type190	-0.43***	7.4E-02	-7.7E-03	5.5E-03
Firm_type210	-0.12***	2.8E-02	-8.2E-03***	1.6E-03
Firm_type220	-0.43***	5.2E-02	-0.011***	3.8E-03
Firm_type230	-0.53***	2.8E-02	-0.010***	2.4E-03
Firm_type240	-0.049	0.090	-0.0097**	4.7E-03

Firm_type310	-0.080***	2.7E-02	-7.5-03***	1.5E-03
Firm_type320	-0.34***	5.2E-02	-1.3E-02***	3.5E-03
Firm_type330	-0.47***	2.7E-02	-1.1E-02***	2.2E-03
Firm_type340	-0.16**	7.7E-02	1.4E-02***	4.2E-03

Note: 1. The dummy indicating state-owned enterprises is omitted. Therefore, the coefficients of the dummies indicating ownership types above show the difference between enterprises of various types and state-owned enterprises.

2. Dummies indicating two-digit industries are included in the regression. Regression results on constants and industry dummies are not reported due to space limit.

3. ***, ** and * indicate significance level of 1%, 5% and 10% respectively.

Source: Author's own calculation.

Table 3-12 Regression results of Heckman two-step estimation (cross-sectional data for the year 2007, overall institutional quality)

	Likelihood of conducting R&D activities		**R&D intensity (share of R&D expenditure in total industrial sales)**	
Regressors	Coefficients	Standard Error	Coefficients	Standard Error
size	0.28***	3.4E-03	-3.4E-03***	9.7E-04
age	0.0074***	3.9E-04	-1.2E-05	2.9E-05
k	1.6E-08	5.2E-06	1.6E-06**	7.5E-07
herfindahl	1.1***	1.2E-01	0.041***	8.1E-03
market_share	2.5***	0.34	-0.021	1.3E-02
wage	0.40***	6.1E-03	8.2E-03***	1.4E-03
profitability	0.14***	1.1E-02	5.5E-03***	1.0E-03
exportintensity	-0.058***	1.2E-02	-4.1E-03***	8.2E-04
debtratio	-0.22***	1.2E-02	-7.6E-03***	1.1E-03
interestpayment	1.5***	8.1E-02	0.055***	6.2E-03
subsidy	0.47***	9.3E-02	0.13***	6.1E-03
Overall institutional quality	0.022***	2.3E-03	2.4E-04	1.6E-04
dummy_advertise	0.47***	9.3E-02		

Table 3-12 continued Regression results of Heckman two-step estimation (cross-sectional data for the year 2007, overall institutional quality)

	Likelihood of conducting R&D activities		**R&D intensity (share of R&D expenditure in total industrial sales)**	
Regressors	Coefficients	Standard Error	Coefficients	Standard Error
Firm_type120	-0.53***	3.1E-02	-1.0E-02***	2.8E-03
Firm_type130	-0.30***	3.4E-02	-1.0E-03	2.4E-03
Firm_type141	0.18	0.14	-9.0E-03	7.4E-03
Firm_type142	-0.38***	0.14	2.2E-03	1.1E-02
Firm_type143	-0.31***	0.12	-1.6E-03	7.8E-03
Firm_type149	-0.31**	0.13	-0.021**	8.7E-03
Firm_type151	0.52***	5.4E-02	7.5E-04	2.4E-03
Firm_type159	-1.3E-03***	2.4E-02	-3.5E-03***	1.3E-03
Firm_type160	0.17***	2.9E-02	-2.8E-03*	1.6E-03
Firm_type171	-0.34	2.6E-02	-0.014***	2.0E-03
Firm_type172	-0.42***	3.7E-02	-0.011***	3.1E-03
Firm_type173	-0.10***	2.4E-02	-6.9E-03***	1.3E-03
Firm_type174	-0.12***	3.3E-02	-9.0E-03***	2.0E-03
Firm_type190	-0.43***	7.4E-02	-8.3E-03	5.5E-03
Firm_type210	-0.12***	2.8E-02	-9.4E-03***	1.6E-03
Firm_type220	-0.43***	5.2E-02	-0.012***	3.8E-03
Firm_type230	-0.53***	2.8E-02	-0.012***	2.4E-03
Firm_type240	-0.049	0.090	-0.011**	4.7E-03
Firm_type310	-0.080***	2.7E-02	-8.5E-03***	1.5E-03
Firm_type320	-0.34***	5.2E-02	-1.5E-02***	3.5E-03

Firm_type330	-0.47***	2.7E-02	-1.1E-02***	2.2E-03
Firm_type340	-0.16**	7.7E-02	1.3E-02***	4.2E-03

Note: 1. The dummy indicating state-owned enterprises is omitted. Therefore, the coefficients of the dummies indicating ownership types above show the difference between enterprises of various types and state-owned enterprises.

2. Dummies indicating two-digit industries are included in the regression. Regression results on constants and industry dummies are not reported due to space limit.

3. ***, ** and * indicate significance level of 1%, 5% and 10% respectively.

Source: Author's own calculation.

Appendix 3.A Codes of registered types

Table 3.A-1 Codes of Registered Types

Code	Registered Type	Code	Registered Type
100	**Domestic-owned enterprise**	172	Private-owned joint venture
110	State-owned enterprise	173	Private-owned limited liability company
120	Collective-owned enterprise	174	Private-owned joint stock limited liability company
130	Cooperative shares corporation	190	Other domestic-owned enterprise
140	Joint venture	200	**Hong Kong-Macau-Taiwan invested enterprise**
141	State-owned joint venture	210	Equity joint venture with Hongkong-Macao-Taiwan investors
142	Collective-owned joint venture	220	Contractual joint venture with Hongkong-Macao-Taiwan investors
143	State- and collective- owned joint venture	230	Hongkong-Macao-Taiwan invested sole proprietership
149	Other joint venture	240	Hongkong-Macao-Taiwan invested joint stock limited liability company
150	Limited liability company	300	**Foreign invested enterprise**
151	State-owned limited liability company	310	Equity joint venture with foreign investors
159	Other limited liability company	320	Contractual joint venture with foreign investors
160	Joint stock limited liability company	330	Foreign-owned enterprise
170	Private-owned enterprise	340	Foreign invested joint stock limited liability company
171	Private-owned sole proprietorship		

Chapter 4: Trade and innovation: Evidence from Chinese firms

4.1 Introduction

Opening up to international trade is one of the major explanations for China's rapid growth in the past thirty-five years. China's growth performance has benefited from the significant efficiency gains from specialization in industries of national comparative advantage at every phase of development (Lin, 2011b). While China has successfully established a strong manufacturing sector and has essentially become the "world factory" for producing a large range of goods, a recent concern for China's long-term growth prospects is whether the growth momentum will taper off if it gradually loses its comparative advantage in low-cost labour as wage costs rise (Cai, 2007). Can China master more advanced technologies and proprietary knowledge and enhance the value added of its products and thus compensate for losing the advantage in low labour cost?

Due to the importance of trade for the rapid growth of the Chinese economy up until now, a natural question that arises in this context is how international trade impacts on China's technological progress. Since technological progress is the engine of long-term growth and has an enduring effect on welfare gains, the effect of trade on technological progress is a dynamic effect of trade on economic growth. While this channel through which trade could exert impact on growth performance has been examined by works using aggregate cross-country data (Coe et al., 1997, 2009; Acharya and Keller, 2009; Eaton and Kortum, 2001; Almeida et al., 2007), more firm-level evidence has also emerged in recent years (Amiti and Konings, 2007; Kasahara and Rodrigue, 2008; Kugler and Verhoogen, 2009; Fernandes and Paunov, 2010; Goldberg et al., 2010; Halpern et al., 2011; Wang, 2012). Firm-level studies have two advantages compared with studies at a more aggregate level. First, firms are the ultimate agents that make decisions about the adoption of new technologies and about the commitment of resources to innovation. Therefore, it is important to understand how technological progress of firms is related to trade activities. Second, understanding the effects of trade activities and trade policies at the firm level is vital for understanding their effects on industry-level productivity and aggregate productivity (Melitz, 2003; Bernard et al., 2003).

In this study, I aim to examine how trade influences a firm's investment in Research and Development (R&D) activities. Since R&D is a critical input into the production and the digestion of new knowledge and thus a critical input into technological progress, this study focuses on this specific channel through which trade will affect a firm's technological progress. A large-scale Chinese firm-level production dataset for the manufacturing sector and a Chinese transaction-level customs dataset will be merged to obtain a sample that contains large and medium-sized firms that are engaged in trade. Variables that reflect various aspects of trade are used in the regression analysis, which explores the relationship between firm-level trade activities and firm-level R&D investment.

While most of these hypothesized relationships between trade and R&D investment are derived from the existing literature on trade and innovation, a major new contribution of this chapter is to study and underline the role of processing trade in firm-level innovation performance. As discussed in Chapter 1, processing trade is a significant form of trade in China. Processing trade takes advantage mainly of the relatively low labour cost and is often associated with low value-added production. Firms involved in processing trade may be less likely to rely on innovation for survival in market competition and hence less likely to develop innovative capacity. Therefore, it is critical to control the form or the regimen of trade a firm is engaged in when we study the effect of trade on firm-level innovation performance. Empirical evidence on this channel remains scarce in the literature and therefore this study aims to add knowledge in this aspect. In addition to the trade related factors, other factors that could influence firm-level R&D are included as control variables in the regression analysis. These potential determinants are based on the literature on firm-level R&D activities. Chapters 1 and 3 have already provided a thorough review of this literature.

The remainder of the chapter proceeds as follows. Section 4.2 explains how this chapter is connected with the relevant literature. Section 4.3 provides details of the Chinese firm-level production data and the transaction-level customs data and the process of merging these two datasets. Section 4.4 defines the regressors and presents the empirical specification. Section 4.5 recognizes the major estimation problems and discusses the choice of estimator, before documenting the main empirical findings. Section 4.6 summarizes the findings and suggests directions for future work.

4.2 Firm-level trade and innovation

This study is focused on firm-level R&D investment and examines how trade and other potential determinants influence this investment. Since the motivation of this study is to explore the relationship between trade and innovation as shown in Section 4.1, it is important to explain in more detail why we choose to understand this question by focusing on firm-level R&D activities. In order to do so, we need to link this study with the relevant literature that examines the effect of trade on technological progress at firm level.

In this literature, one major framework is based on the trade literature on heterogeneous firms (Eckel and Neary, 2010; Nocke and Yeaple, 2006). This literature generally emphasizes the multi-product and multi-destination characteristics of firms engaged in international trade, which makes their response to trade more complex than the representative firm assumed in traditional trade literature that focuses on industries and countries (Bernard et al., 2012). Of particular relevance to this study are two strands of research within the trade literature on heterogeneous firms. One strand explores how firm-level total factor productivity (TFP) reacts to trade liberalization, with TFP growth being often regarded as reflecting technological progress. The other strand looks at how the product quality of a firm changes when the firm is faced with changing international trade conditions, with quality improvement reflecting technological progress.

This study takes a different approach from the above two strands of research, which look at firm-level TFP and product quality respectively, and focuses instead on firm-level R&D investment for the following reasons. In terms of the first strand of literature, while TFP is a good proxy for technological progress, it has certain limitations. First, changes in TFP could derive from sources other than technological progress. For example, some works examine how trade influences a firm's choice over its product range and find that a firm reorients towards its core competency when faced with fiercer competition. Since the firm can produce its core competency products more efficiently, the firm's TFP will increase. This shows that TFP change does not necessarily come from technological change, as already pointed out in Chapter 1. In contrast to the fact that many factors other than technological progress could impact on TFP, firms' R&D activities directly reflect the resources firms invest in innovation activities. So examining how firms' R&D activities are related to trade will clearly reflect how trade affects long-term technological progress of firms through influencing firms' R&D investment. In fact, to focus on firm-level R&D investment rather than firm-level TFP will help us identify one particular channel of influence from trade on technological progress and firm productivity.

The second reason to choose R&D investment as the main interest of this study is that it is a major input-based indicator of innovation. Innovation can be measured by input or output-based indicators. Since there is no information that enables one to link output-based indicators such as patent numbers at the firm level to firm-level production data, one has to rely on output-based measures other than patent numbers or input-based indicators to examine firm-level innovation activities. One advantage of using input-based indicators is that firms may not patent all their innovation output in order to avoid revealing their knowledge to competitor firms, which renders output-based indicators less accurate in this regard. R&D investment is an often-used input-based indicator and is therefore adopted as the indicator of innovation in this study.

In the second strand of literature, product quality upgrading is the focus (Fernandes and Paunov, 2010; Wang, 2012). Fernandes and Paunov (2010) argue that product upgrading reflects incremental innovation, which is of higher relevance for developing countries compared with more radical types of innovation. Therefore, they choose to examine how firms' product quality is associated with international trade. While it is true that most producers in developing countries lie within the world's technology frontier and often conduct incremental improvement on technology advances made by foreign producers, this does not mean that R&D activities will not matter for producers in developing countries. As pointed out by Cohen and Levinthal (1989, 1990) and Griffith et al. (2004), R&D has both the function of promoting innovation and the function of enhancing the absorption and assimilation of foreign technologies. While access to new knowledge stock plays a significant role, a firm's own R&D investment is essential for it to benefit from technology diffusion. After all, to focus on product quality alone does not clarify the means through which a firm can achieve product quality upgrading. Also, as discussed above, the transition from an economy that mainly relies on imitation and imported technologies towards an economy with innovative capabilities has deep implications for the growth prospects of China. Therefore, R&D, instead of product quality, is the focus of this study.

The next issue is how trade participation, both importing and exporting, could affect firm-level innovation activities. In terms of imports, since intermediate goods and capital goods have advanced technologies and R&D efforts of other countries embodied in them, a country can absorb embodied knowledge by importing these goods (Coe et al., 1997; Coe et al., 2009). Firm-level imports have been found to matter for firm-level productivity in a number of recent studies (Amiti and Konings, 2007; Kasahara and Rodrigue, 2008; Goldberg et al., 2010; Kugler and Verhoogen, 2009; Halpern et al., 2011; Wang, 2012). Kasahara and Rodrigue (2008) show that past import status has a positive impact on current productivity, thus providing evidence for the dynamic "learning by importing" effect arising from the use of imported intermediate goods. Halpern et al. (2011) examine whether the positive impact from imports on firm-level productivity comes from the import quality channel or the import variety channel. They find that two-thirds of the effect on a firm's productivity from imports is attributable to the variety channel. Goldberg et al. (2010) differentiate between the price channel and the variety channel. They conclude that input tariff reductions promote domestic product growth not only by making imported inputs that are already in use cheaper but, more importantly, by relaxing technological constraints via the introduction of new imported input varieties that were previously unavailable. Kugler and Verhoogen (2009) argue that it is important to distinguish between the number of imported inputs and the quality of those inputs since gaining access to high-quality inputs is often stressed in developing countries. They use the unit values of all inputs and outputs to measure quality and suggest that quality differences between imports and domestic inputs are an important factor that influences firm-level productivity. Not only does the import of intermediate goods bring in new knowledge, the import of final goods for domestic consumption can also help a country obtain knowledge. This is because firms can gather information about new products and new product designs by observing the imported final goods.

There is one more strand of literature that is relevant to this chapter, which explores the relationship between technology imports and firm-level intramural R&D (Katrak, 1991, 1994, 1997). The central question in this literature is whether a firm's technology imports and its intramural R&D are substitutes or complements. For instance, Kathuria (2008) shows that, since 1991, Indian reforms have made import of technology cheaper and easier. After the reforms, domestic firms more often buy or license new technologies from abroad instead of investing resources in their own R&D. India's R&D to GNP ratio was declining or nearly stagnant in the 1990s while its technology import intensity and FDI inflows rose, which suggests increasing reliance on technologies from abroad. Other studies show that technology imports and in-house R&D could be complements since in-house R&D is required for the adaption of imports to the local economic environment (Katrak, 1997). However, in the literature that discusses the "learning by importing" hypothesis, not much attention has been paid to the issue of the complementarity or substitutability between intermediate goods and capital goods imports and R&D. The reason for less attention on this issue may be that most of the studies on the "learning by importing" hypothesis are focused on firm-level productivity rather than firm-level innovation.

In terms of exports, there could be "learning-by-exporting" effects. That is, exporting firms are better informed about the conditions of international markets and may need to upgrade their operations to meet the criteria of consumers in more advanced countries (Rhee et al., 1984, Westphal et al., 1984; Grossman and Helpman, 1991, Silva et al., 2010). Technical standards and consumers' demand for quality are higher in high-income countries. In order to break into export markets in high-income countries, a firm needs to solve new problems such as adopting stringent technical standards to satisfy consumers, which may intensify the need for R&D activities. Also, by establishing contact with consumers in high-income countries, a firm could have easier and faster access to the changing conditions of international markets. This spillover effect from foreign consumers to exporting firms could help increase the productivity of R&D investment and hence promote the R&D investment by a firm.

Another mechanism through which exporting to international markets may stimulate a firm's innovation activities is the pressure to retain its competitive edge. Baum et al. (2012) find that geographical sales diversification across different regions of the world induces UK firms to increase their R&D expenditures due to the need to maintain a competitive advantage when faced with more vigorous competition and differing consumer preferences in foreign markets. Therefore, the more geographically diversified a firm's sales structure is, the higher the demand for firm-level R&D to enable the firm to survive in international competition.

While the above mechanisms through which trade could impact on innovation are obtained from the existing literature, one observation of the Chinese economy motivates me to propose a new channel through which trade affects R&D investment and hence technological progress. This channel has not yet received much attention in the literature and to my knowledge there has been no firm-level evidence on this topic up until now. The observation is that processing trade is very important in China compared with in most other countries, which implies that China's structure of trade is distinct from most other countries. Therefore, the special case of China inspires me to raise one novel hypothesis on trade and innovation: the forms of trade that a firm is engaged in matter for the depth and potential of technological learning the firm can gain from trade participation.

Processing trade is the process where a domestic firm imports raw materials or intermediate inputs from abroad and, after local processing, exports the goods that contain value added produced by the firm.[21] Processing exports have accounted for over 50% of China's total exports since 1992 (Yu, 2011). Furthermore, recent evidence suggests that China plays a primary role as a final product assembler engaged in processing trade. Several studies have drawn attention to the implication of processing trade for the technological catch-up of China (Lemoine and Unal-Kesenci, 2004; Steinfeld, 2004). Yu (2011) finds that firms that are engaged in processing trade have lower total factor productivity (TFP) compared with firms that are engaged in ordinary trade in China.

The mechanism behind the weak TFP performance of firms engaged in processing trade could be that the "learning by importing" effects from imported intermediate goods vary across different end purposes. Among all forms of imports, three types of imports forms are more likely to provide in-depth technological learning: first, ordinary trade; second, intermediate goods and capital goods imports as equipment imports for foreign direct investment (FDI); and third, intermediate goods and capital goods imports for processed export production. Ordinary imports may happen when a firm needs to import equipment, machinery or critical intermediate goods for the production of a product otherwise impossible using domestics inputs only. When these ordinary imports enter the production process of the firm, they may trigger learning about more advanced production technologies embodied in the imports, which will enhance the firm's technological capability and possibility of doing R&D. Also, the application of the imported equipment or machinery in joint-ventures or for the production of processed exports may meet unexpected difficulties due to the fact that the imported equipment is

[21] The Chinese government encourages processing trade by making all the imported goods for processing trade duty free. Among Chinese firms, two important types of processing trade are "processing assembly" with 100% duty free imports and "processing with inputs" with 100% rebate on the cost of imports when the products are exported in the end (Yu, 2011).

designed for a foreign economy with different endowment and business environment. In this case, R&D investment may be required to help solve technical problems in adapting the imported equipment to local conditions. Also, through the adoption of imported equipment, firms can take advantage of R&D abroad to relax technological constraints and improve efficiency of production. Therefore, these three forms of imports are likely to enable firms to expand their production technology possibility sets and enhance their technological capabilities.

In contrast, since processing trade takes advantage mainly of the relatively low labour costs in developing countries and is often associated with low value added, firms involved in processing trade may be less likely to be urged to develop innovative capacity for their survival in market competition. Intermediate goods and capital goods imported for processing trade are less likely to be used for the purpose of relaxing the technology constraints in production and of changing the production technologies of a firm and are therefore likely to be linked to technological learning in a shallow manner.

4.3 Data

In order to explore the impact of trade on a firm's R&D activities, I mainly rely on two panel datasets: China's Annual Manufacturing Survey Dataset and China's Customs Dataset. China's Annual Manufacturing Survey Dataset is a firm-level dataset that covers all state-owned enterprises and firms of other types of ownership with annual sales above the 5 million RMB threshold. This firm-level dataset provides the base for the aggregate data on the industrial sector in China's Statistical Yearbook. It covers information on firms' industry classification, geographical location and three major accounting statements (ie, balance sheet, profit and loss account, and cash flow statement) (Yu, 2011). Annual R&D investment is required to be reported by firms if they conduct R&D activities.

The second major dataset needed for this study is China's customs dataset. In this dataset, product-level trade information is available at the HS 8-digit level. For each trade transaction that takes place, information about the eight-digit HS product code, exporter/importer identity, quantity, total value, export destination/import origin country, form of trade, transportation method and ownership type of the exporter/importer is reported.

Since the firm-level production data and the transaction-level trade data are at different frequencies, with the former being yearly and the latter being monthly, it is necessary that the monthly observations in the product-level data are aggregated into yearly observation in order to be merged with the firm-level production data. Therefore, I aggregate the monthly trade-transaction observations into yearly observations defined by exporter/importer identity, whether the transaction is export or import, trade form, 8-digit HS-code and export destination/import origin country.[22]

In order to merge the firm-level production data and the trade data, I use the firm name as the common identifier for both datasets.[23] The merged panel covers the year 2005 and 2006 since we have both the R&D variable and trade variables only in these two years. Table 4-1 presents the comparison of key variables in the matched sample and the full-sample firm-level production data. On average, firms in the matched sample have higher annual sales, more employees, higher labour productivity, higher capital intensity and higher R&D intensity.[24] It should be noticed that the matched sample may not include all firms that have international trade activities (ie, export only, import only or both export and import) in the original firm-level production data. In fact, approximately 20% of unmatched firms in the firm-level production data report non-zero export value in 2005 and 2006. The summary statistics in Table 4-1 are for the matched sample that covers three types of firms: firms that only import, firms that only export and firms that both export and import.

In Table 4-2, the summary statistics are for the matched sub-sample that includes only firms that both export and import. This sub-sample is the one used in the regression analysis in Section 4.4 since both export and import-related variables are included in the empirical specification. The summary statistics for the trade-related variables in the sub-sample used in the regression analysis are shown in Table 4-3. We can see from Table 4-3 that processing trade is significant among Chinese firms. The mean share of intermediate goods in total imports value is about 77% while the mean share of intermediate goods in total exports value is about 50%. The mean total share of ordinary trade, goods imported as equity investment in joint ventures, and capital goods imported for the production of processed exports together is only 14% and 20% in total import

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[22] The technical details of the procedures are available upon request.
[23] Wang (2012) also uses firm name as the common identifier for merging the two datasets.
[24] Based on the OLS regression of firm R&D intensity on two-digit industry dummies and an indicator of firms that are in the matched sample, I find that, on average, firms that are in the matched sample devote a higher share of total sales to R&D than non-trading firms in the same industry.

value in 2005 and 2006 respectively.

4.4 Model specification

The empirical specification captures the major channels through which trade could influence a firm's R&D activities identified in the literature and also explores how the forms of trade a firm engages in will influence firm-level R&D activities, a channel not studied by others before.

The equation to be estimated is as follows:

$$R\&D\_intensity = \beta_0 + \beta_1 * size + \beta_2 * age + \beta_3 * profitability + \beta_4 * export\_intensity + \beta_5 * wage + \beta_6 * market_{share} + \beta_7 * industry\_herfindahl\_index + \beta_8 * debt\_ratio + \beta_9 * capital\_intensity + \beta_{10} * IPR\_protection + \beta_{11} * interest\_payment + \beta_{12} * subsidy + \beta_{13} * percapita\_GDP + \beta_{14} * export\_highincome + \beta_{15} * export\_diversification + \beta_{16} * unit\_value\_import + \beta_{17} * import\_highincome + \beta_{18} * intermediate\_and\_capital\_variety + \beta_{19} * learning\_depth + \gamma_1 * ownership\_dummies + \gamma_2 * two\_digit\_industry\_dummies + \gamma_3 * year\_dummies + \varepsilon \quad (4.1)$$

Among the explanatory variables, $industry\_herfindahl\_index$ is the four-digit industry-level Herfindahl Index and $IPR\_protection$ is the measure of the strength of protection of intellectual property rights in the province where the firm is located. Except these two variables, industry dummies and year dummies, all other variables are at the firm level. Here, I will focus on the trade-related variables since the motivations for the inclusion of other variables have been explained in the Chapter 3.

On the export side, two variables are considered. The first is $export\_highincome$, the share of export value to high-income countries in the total export value of a firm. I follow Wang (2012) to classify twenty countries as high-income countries. They include: Luxembourg, Norway, the United States, Singapore, Switzerland, Netherlands, Austria, Canada, Iceland, Denmark, Australia, Belgium, Germany, Japan, France, Sweden, Italy, Britain, Finland and Spain.

The second variable on the export side is $export\_diversification$, a measure of the geographical diversification of export by a firm. In this study, I adopt the method of constructing the measure of export geographical diversification in Baum et al. (2012) and obtain the variable $export\_diversification$. It is a transformation of the Herfindahl-Hirschmann concentration index defined as follows:

$$\text{Export\_diversification}_{i,t} = 1 - \sum_{r=1}^{n} x_{r,i,t}^2 \tag{4.2}$$

where i denotes the firm, t denotes the time period, r denotes a specific region of export sales, $x_{r,i,t}$ is the share of sales in region r in total sales of firm i in year t. I group export destination countries into 10 groups. The United States and Canada are grouped into G1; Latin American countries are grouped into G2; European Union member countries are grouped into G3; three Asian newly industrialized countries, Japan, Korea and Singapore, are grouped into G4; The remaining Asian countries are grouped into G5; Australia and New Zealand are grouped into G6; the remaining countries in Oceania are grouped into G7; African countries are grouped into G8; G9 are other destinations; and G10 is domestic sales. Since firms report their total annual sales in the firm-level production dataset, domestic sales are obtained as the difference between total annual sales and total export values.

On the import side, four variables are considered. The first is $unit\_value\_import$, the average unit value of imports; the second is $import\_highincome$, the share of import from high-income countries in total import value; the third is $intermediate\_and\_capital\_variety$, the number of varieties of imported intermediate goods and capital goods; the fourth is $learning\_depth$, the total share of the three trade forms: ordinary trade (10), goods imported as equity investment in joint-ventures (25) and imported equipment by export processing zones (35) in total intermediate goods and capital goods import value.

The way to construct the average unit value of imports is similar to that in Wang (2012). The first step is to remove the year specific means from the log of unit values of eight-digit HS products.[25] The second step is to calculate the weighted average across eight-digit imports within a firm. The weight is the share of import value of a certain eight-digit product in the total import value of the firm. The construction of the share of import value from high-income countries follows the same method used for the

[25] HS refers to Harmonized System.

construction of the share of export value to high-income countries as discussed above. The variety of intermediate goods and capital goods imported is the total number of different eight-digit product intermediate goods and capital goods imported by a firm. To define intermediate goods and capital goods, I follow the United Nations' Classification by Broad Economic Categories (BEC). Since China's customs data are reported by HS code, I first make concordance between the six-digit HS code and BEC code and then can identify the intermediate goods and capital goods in China's customs data.[26]

The fourth variable on the imports side is $learning\_depth$, which is defined as the share of the three trade regimes in total: ordinary trade (10), equipment investment by foreign-invested enterprises (25), and imported equipment by export processing zone (35) in total intermediate goods and capital goods import value.[27] The reason to aggregate these three sets of imports is that among all forms of imports, these three are more likely to provide in-depth technological learning, as explained in Section 4.2.

In order to examine the influence of ownership type on firm-level R&D, I classify firms into six ownership types: state-owned, collective-owned, private-owned, foreign-owned, Hong Kong, Macau and Taiwan-owned (HMT-owned) and others. State-owned enterprises are chosen as the base and dummy variables are created for the other five ownership types. Finally, two-digit industry dummies are included in the regression due to the fact that there are wide variations in technological possibilities and R&D intensities across industries.

4.5 Empirical results

In the matched sample, a large proportion (around 81%) of firms report zero R&D investment. This can be seen from Table 4-5 where it is shown that the number of left-censored observations is 36,291 and the number of total observations is 44, 808. Therefore, the proportion of firms that report zero R&D investment is around 81%. The

[26] The concordance table is available from United Nations' website: http://unstats.un.org/unsd/trade/conversions/HS%20Correlation%20and%20Conversion%20tables.htm

[27] Classification by China's customs shows 19 types of trade regimes: ordinary trade (code: 10), aid or donation from government or from international organisations (11), donations from Chinese overseas or Chinese with foreign citizenship (12), compensation (13), processing with assembly (14), processing using imported inputs (15), goods on consignment (16), border trade (19), contracting projects (20), equipment imported for processing and assembly (22), goods on lease (23), equipment investment by foreign-invested enterprises (25), outward processing (27), barter trade (30), duty-free commodities (31), customs warehousing trade (33), entrepot trade by bonded area (34), imported equipment by export processing zone (35), and others (39) (Yu and Tian, 2012).

fact that the dependent variable is left-censored at zero value must be taken into account for consistent estimation of the coefficients. Therefore, the Tobit estimator is adopted in the estimation. Since the panel covers two continuous years and some firms exist in both years, each firm is defined as a group and the standard errors are adjusted across groups. The correlation matrix of the variables in the regression is shown in Table 4-4. In Table 4-5, the estimation results are reported. When discussing the empirical findings, I will focus on the trade-related variables here since the effects of most other non-trade variables have been discussed in the previous chapter.

Consistent with Baum et al. (2012), geographical diversification of export markets is positively and significantly associated with firm-level R&D intensity. Exports to high-income countries, however, do not significantly affect firm-level R&D intensity, which is a different finding from Wang (2012). The coefficient of imports from high-income countries is found to be positive and significant at the 1% level. The coefficient of the average unit value of imports is also found to be positive and significant at the 1% level. Imports from high-income countries are embodied with R&D from these countries and the more advanced technologies embodied in these imports may enhance an importing firm's technological capability and R&D investment. The unit value of imports is often used in the literature to proxy for import quality. The positive relationship between the unit value of imports and firm-level R&D intensity suggests that high-quality imports may help ease the technological constraints of the importing firm and thus promote R&D investment by the firm.

The coefficient of the number of intermediate goods and capital goods import is negative and significant at the 1% level. This result, together with the results about imports from high-income countries and unit value of imports, provides support for Kugler and Verhoogen (2009), who argue that import quality is more important than import variety number for developing countries. Moreover, the negative coefficient of the number of intermediate goods and capital goods suggests that the effect of import variety on firm-level innovation could be negative while Kugler and Verhoogen (2009) only find it to be less than the effect from import quality but still positive. The finding that import variety negatively affects firm-level innovation seems to differ from findings in some works on intermediate goods and capital goods imports and productivity growth where intermediate goods and capital goods imports are found to help firms break technological constraints, enable the production of new products and promote firm-level TFP. How do we reconcile the finding in this study with previous ones? One potential answer lies in the fact that this study is focused on firm-level R&D investment rather than on firm-level productivity. Intermediate goods and capital goods import may be beneficial for firm-level productivity but may act as a substitute for firm-level innovation and are therefore negatively associated with firm-level R&D investment. The empirical results in this study raise the hypothesis that the relaxation of technological constraints through expanding import varieties may be a substitute for intramural R&D of Chinese firms.

The coefficient of the variable $learning\_depth$ is positive and significant at the 1% level. This result supports the hypothesis that the trade regime of the firm matters for the depth of technological learning. Recall that the current pattern of trade of China is that processing trade dominates other forms of trade. Such a trade regime may have a negative influence on the R&D performance of the Chinese firms.

Finally, consider the coefficients of the dummy variables for ownership types of firms. The base ownership type is state-owned enterprises. The coefficient of collective-owned enterprises is not significant, which suggests those enterprises are not different from state-owned enterprises in R&D intensity, other things being equal. The coefficient of private-owned enterprises is negative and significant at the 10% level. This indicates that private-owned enterprises are less R&D intensive than state-owned enterprises ceteris paribus. The coefficients of foreign-owned enterprises, Hong Kong, Macau and Taiwan-owned (HMT-owned) enterprises and firms of other ownership types are all negative and significant at 1% level. Also, the coefficients are about four times the magnitude of the coefficient of private-owned enterprises. This suggests that private enterprises are second only to state-owned enterprises in participating in innovation and are more active in innovation than foreign-owned enterprises, HMT-owned enterprises and enterprises of other ownership types. The coefficients of HMT-owned, foreign-owned and others are of the same magnitude and sign, which suggests that the impacts on R&D intensity of these three ownership types are similar. The finding that state-owned and collective-owned enterprises enjoy the highest R&D intensity all else being equal suggests that further research on the strategy and pattern of technological catch-up of China in comparison with other newly industrialized countries such as Japan and Korea will be interesting. This is because it is often suggested the state has played an important role in the technological catch-up of Japan and Korea historically

(Johnson, 1982; Kim et al., 1995). Whether the state can and will also play a major role in the technological catch-up of China and, if so, how it will influence the future trend of China's technological progress is a valuable question for future research.

4.6 Conclusion

As China continues to converge towards the countries on the world technological frontier, concerns have arisen about whether the country will achieve the necessary transition from technology imitation towards technology innovation in order to sustain its growth momentum. Since trade participation has played such a significant role in China's growth performance in the last three decades or more, how trade participation will influence China's transition towards an innovative economy is of high interest. This chapter tackles this question with a firm-level study, which analyzes how trade participation influences firm-level R&D investment.

Various channels through which trade activities could potentially influence firm-level R&D investment have been explored with regression analysis in which variables capturing these channels were included as regressors. The empirical results shed light on these specific mechanisms and deepen our understanding about the relationship between trade participation and innovation. Being engaged in trade involves several mechanisms at the same time, which may bring about both forces that promote and forces that hinder technological learning and innovation. Knowing how each mechanism works will help us better understand the innovation prospect of the economy faced with certain trajectories of trade performance.

Furthermore, this study tackles one very important question not well researched before: how will the current pattern of trade, characterized by a large share of processing trade, influence China's transition towards a technologically advanced economy? Under such a structure of trade, will there be dynamic growth benefits from trade through stimulating indigenous innovation? The firm-level evidence in this study provides some clues to answer these questions. This study finds that imports for various purposes (ie, for processing trade, ordinary trade, equity investment by foreign-invested enterprises, imported equipment by export processing zone and others) do not promote indigenous innovation to the same extent as each other. Ordinary trade, equipment investment by foreign-invested enterprises and imported equipment by export processing zone boost indigenous innovation more effectively compared with processing trade and other forms of trade. If the organisation of production is constantly based on processing trade and the advantage of relatively low-cost labour, then firms may be locked in a production mode with low technological learning potential. In this case, the difficulty of R&D activities will be increased and the incentive to move up the value-chain will be even weaker. This further retards the upgrading of production organization and hence forms a vicious cycle.

What is needed to help domestic firms, industries and the market break out of this trap of technological catch-up? The answer lies in the factors that affect the incentives of firms to invest in R&D in order to produce new and high-quality products. Low protection of property rights or low institutional quality can reduce the incentive to invest in R&D since this type of investment is particularly sensitive to institutional quality as a consequence of the long gestation process and the fact that knowledge is a non-rival good. Also, credit market imperfections could affect a firm's chosen production activities and position in the global value chain as well. For example, Manova and Yu (2013) found that since conducting production activities with higher value-added requires working capital, the under-development of China's financial system has precluded firms from pursuing more profitable opportunities. This point links back to Chapter 3 where it is found that institutional quality affects the entry decision of firms into R&D activities.

Therefore, the implications of the finding about the relationship between the forms of trade a firm is engaged in and its R&D investment goes beyond trade policies themselves and reaches policies regarding institutional quality. It is necessary for governments to nurture institutions such as strong intellectual property rights protection mechanisms and a well-functioning financial market. These institutions will increase the net benefit of investment in R&D and will align firms' incentives towards moving up the value chain when competition is fierce. This, in turn, will help the country make the transition from technology imitation to innovation successfully and achieve better long-term growth prospects.

Besides these policies for improving institutional quality, another aspect of policy that is worth noticing is the existing policy setting for promoting processing trade. For example, processing assembly is 100% duty free; processing using imported inputs is full duty rebate. Also, the prevalence of processing trade in China can be directly attributed to the establishment of various free-trade zones—such as special economic zones, economic and technological development zones, high-technology industrial development zones and export-processing zones. According to Yu and Tian (2011), total processing imports in these free-trade zones accounted for more than 22% of China's processing import. Firms in these free-trade zones often enjoy tax tariff exemptions, and reduced income taxes. In the export processing zones, in particular, only processing firms were allowed in the zones and enjoyed privileges such as freedom from duties and minimal administrative restrictions. While participation in global production sharing has allowed for a rapid expansion and diversification of China's manufacturing export capacities at a stage of development featuring low labour cost, the findings in this study suggest that heavy reliance on processing trade may have a negative impact on the rise of innovation capacity as China needs to grow into a new stage of development emphasizing technological competitiveness in the global market. Therefore, it is important that policymakers are informed of this point when making policies regarding the promotion of processing trade.

Table 4-1 Data summary for the merged dataset (including all firms that export, import or both export and import) and the full sample of production dataset

				2005						
Panel A: merged dataset										
total number of firms				38853						
sales	medium	38373	mean	174532	min	190	max	1.25E+08	std	1199450
number of employees	medium	180	mean	192	min	9	max	93901	std	3
natural logarithm of capital-labor ratio	medium	3.7	mean	3.7	min	-6	max	9.4	std	1.4
natural logarithm of labor-productivity	medium	5.4	mean	5.5	min	0.7	max	11.7	std	1
R&D intensity	medium	0	mean	0.3%	min	0	max	73.0%	std	1.6%
Panel B: full-sample production dataset										
total number of firms				241025						
sales	medium	19590	mean	86051	min	0	max	1.25E+08	std	745853
number of employees	medium	100	mean	110	min	9	max	106938	std	3
natural logarithm of capital-labor ratio	medium	3.6	mean	3.5	min	-6.4	max	10.1	std	1.4
natural logarithm of labor-productivity	medium	5.3	mean	5.4	min	-3.3	max	11.7	std	1
R&D intensity	medium	0	mean	0.2%	min	0	max	92.0%	std	1.3%

Among the matched 38853 firms in year 2005, 9756 of them reported zero export in the firm production dataset yet turn out to have export value.
Among the 202172 unmatched firms in year 2005, 43501 of them reported non-zero export values in the firm production dataset yet fail to be matched with the customs data.

Table 4-1 continued Data summary for the merged dataset (including all firms that export, import or both export and import) and the full sample of production dataset

				2006						
Panel A: merged dataset										
total number of firms				48018						
sales	medium	42720	mean	197106	min	164	max	1.57E+08	std.	1402532
number of employees	medium	174	mean	187	min	9	max	131926	std.	3
natural logarithm of capital-labor ratio	medium	3.8	mean	3.8	min	-4.2	max	10.1	std.	1.4
natural logarithm of labor-productivity	medium	5.5	mean	5.6	min	0.9	max	12.0	std.	1.0
R&D intensity	medium	0	mean	0.3%	min	0	max	91.0%	std.	1.8%
Panel B: full-sample production dataset										
total number of firms				267863						
sales	medium	22020	mean	97538	min	0	max	1.57E+08	std.	861993
number of employees	medium	96	mean	106	min	9	max	135944	std.	3
natural logarithm of capital-labor ratio	medium	3.7	mean	3.6	min	-6.7	max	10.1	std.	1.3
natural logarithm of labor-productivity	medium	5.5	mean	5.5	min	-4.3	max	12.0	std.	1.0
R&D intensity	medium	0	mean	0.2%	min	0	max	96.3%	std.	1.5%

Among the matched 48018 firms in year 2006, 13043 of them reported zero export in the firm production dataset yet turn out to have export value.
Among the 219845 unmatched firms in year 2006, 41146 of them reported non-zero export values in the firm production dataset yet fail to be matched with the customs data.

Source: Author's own calculation.

Table 4-2 Data summary for the sample for regression analysis

				2005						
total number of firms that both import and export				20704						
sales	medium	49114	mean	230317	min	1150	max	1.25E+08	std.	1525771
number of employees	medium	228	mean	245	min	20	max	94149	std.	3
natural logarithm of capital-labor ratio	medium	3.8	mean	3.8	min	-3.5	max	9.4	std.	1.4
natural logarithm of labor-productivity	medium	5.4	mean	5.5	min	1.4	max	11.1	std.	1
R&D intensity	medium	0	mean	0.3%	min	0	max	73.0%	std.	1.6%
				2006						
total number of firms that both import and export				24117						
sales	medium	57335	mean	271083	min	510	max	1.57E+08	std.	1844731
number of employees	medium	226	mean	245	min	9	max	131795	std.	3
natural logarithm of capital-labor ratio	medium	3.9	mean	3.9	min	-4.2	max	10.1	std.	1.4
natural logarithm of labor-productivity	medium	5.5	mean	5.6	min	0.9	max	12	std.	1
R&D intensity	medium	0	mean	0.4%	min	0	max	91.0%	std.	2.0%

Among the matched 38853 firms in year 2005, 9756 of them reported zero export in the firm production dataset yet turn out to have export value.
Among the 202172 unmatched firms in year 2005, 43501 of them reported non-zero export values in the firm production dataset yet fail to be matched with the customs data.

Among the matched 48018 firms in year 2006, 13043 of them reported zero export in the firm production dataset yet turn out to have export value.
Among the 219845 unmatched firms in year 2005, 41146 of them reported non-zero export values in the firm production dataset yet fail to be matched with the customs data.
Source: Author's own calculation.

Table 4-3 Summary statistics for trade-related variables

	2005					2006				
number of observations	20704					24117				
	medium	mean	min	max	std	medium	mean	min	max	std
1. number of HS8 products exported	4	8	1	418	11	4	7	1	349	11
2. number of HS8 products imported	7	19	1	710	34	6	17	1	649	32
3. number of export destination countries	5	9	1	140	11	5	10	1	161	12
4. number of import origin countries	3	4	1	57	5	3	4	1	62	5
5. share of intermediate goods in total imports value	97%	77%	0	1	34%	97%	76%	0	1	35%
6. share of intermediate goods in total exports value	44%	50%	0	1	47%	58%	52%	0	1	47%
7. share of capital goods in total exports value	0	13%	0	1	31%	0	14%	0	1	31%
8. share of capital goods in total imports value	0	15%	0	1	29%	0	16%	0	1	30%
9. share of ordinary trade, goods imported as equity investment in joint-venture, and capital goods imported for the production of processed exports	14%	41%	0	1	44%	20%	43%	0	1	45%
10. share of exports to high-income countries in total exports value	77%	61%	0	1	40%	76%	61%	0	1	39%
11. share of imports from high-income countries in total imports value	81%	61%	0	1	42%	81%	61%	0	1	41%
12. export diversification index	36%	34%	3.58E-07	84%	23%	34%	33%	1.19E-07	84%	23%
13. average unit value of export	-0.03	0.04	-6.8	11.7	1.1	-0.03	0.06	-8.9	11.5	1.1
14. average unit value of import	-0.13	-0.11	-6.9	7.7	1.2	-0.10	-0.08	-6.90	7.70	1.2

Source: Author's own calculation.

Table 4-4 Correlation matrix

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1. R&D intensity	1															
2. number of import origin countries	0.04	1														
3. import variety	0.02	0.62	1													
4. average unit value of import	0.09	0.09	0.12	1												
5. share of capital goods in total imports	0.09	-0.01	0.05	0.18	1											
6. share of intermediate goods in total imports	-0.06	0.06	0.00	-0.13	-0.78	1										
7. share of ordinary trade, goods imported as equity investment and capital goods imported for the production of processed exports in total imports	0.12	-0.08	0.00	0.15	0.39	-0.25	1									
8. share of import from high-income countries in total import value	0.06	-0.07	0.06	0.24	0.09	-0.08	0.24	1								
9. number of export destination countries	0.03	0.22	0.12	-0.02	0.02	-0.01	0.01	-0.05	1							
10. export variety	0.00	0.23	0.30	0.04	-0.03	0.01	-0.09	0.00	0.32	1						
11. average unit value of export	0.10	0.06	0.13	0.24	0.09	-0.08	0.14	0.19	-0.02	0.04	1					
12. share of capital goods in total exports	0.11	0.09	0.11	0.00	0.23	-0.15	0.09	0.00	0.07	0.03	0.11	1				
13. share of intermediate goods in total exports	0.02	0.01	0.00	0.00	0.03	0.13	0.20	0.07	-0.08	-0.19	-0.05	-0.36	1			
14. share of ordinary trade in total exports	0.09	-0.34	-0.24	0.11	0.21	-0.22	0.56	0.26	0.05	0.03	0.12	0.02	0.05	1		
15. share of export to high-income countries in total export value	-0.03	-0.07	0.03	0.03	-0.05	-0.02	-0.08	0.24	0.04	0.10	0.09	-0.08	-0.19	0.09	1	
16. export diversification	-0.05	0.11	0.08	-0.07	-0.08	0.04	-0.20	-0.09	0.48	0.23	-0.04	0.01	-0.16	-0.09	0.15	1

Source: Author's own calculation.

Table 4-5 Regression results

R&D intensity	Coef.	P-value
size	0.01***	0.00
age	5.4E-05	0.10
profitability	-0.005	0.40
export_intensity	-0.009***	0.00
wage	0.02**	0.01
market_share	-0.006	0.80
industry_herfindahl_index	0.05***	0.00
debtratio	-0.009***	0.00
capital_intensity	-1.26E-06	0.30
IPR_protection	0.0002***	0.01
interest_payment	0.1***	0.00
subsidy	0.2***	0.00
percapita_GDP	-5.10E-08	0.40
export_highincome	0.0005	0.60
export_diversification	0.007***	0.00
unit_value_import	0.002***	0.00
import_highincome	0.006***	0.00
intermediate_and_capital_variety	-7.7E-05***	0.00
learning_depth	0.01***	0.00
collective-owned	0.002	0.40
private-owned	-0.005*	0.07
HMT-owned	-0.02***	0.00
foreign-owned	-0.02***	0.00
others	-0.02**	0.02
year dummies	0.0005	0.40
industry dummies	F (27, 44754)=12.55	0.00
N	44808	
	36291	left-censored
	8517	uncensored

Note: Numbers in bracket are of negative values.

Source: Author's own calculation.

Chapter 5: Globalization of R&D investment: insights from U.S.-based multinational enterprises in manufacturing industries

5.1 Introduction

Multinational enterprises (MNEs) are constantly looking for the most favourable conditions for the internationalisation of their activities along the value chain. Activities that were previously locally integrated and locally concentrated have increasingly been relocated into other countries (Kaplinsky, 2000; Fujita and Thisse, 2006; Roper et al., 2008; Hummels et al., 2001; Hanson et al., 2005; Helpman, 2006; Rugman et al., 2010). R&D is one of them. R&D globalization is a pattern of R&D location that differs radically from the patterns of the 1950s and 1960s and challenges the traditional view that R&D activities by MNEs are undertaken mainly at home. For example, the World Intellectual Property Report (2011) highlights an increase in overseas R&D out of total R&D investment by MNEs. According to this report, annual overseas R&D investment by U.S.-based MNEs increased from almost USD 600 million in 1966 to around USD 28.5 billion in 2006. In terms of the absolute amount, high-income countries are still the dominant locations of R&D activities by U.S.-based MNEs, accounting for about 80% of total overseas R&D investment. In terms of the increase in R&D shares, however, some high-performing East Asian economies such as China, Malaysia, the Republic of Korea and Singapore, and also India, have experienced the most rapid growth in recent years.

Not only has the geographical spread of R&D investment become much wider, the importance of MNEs in global R&D investment has grown as well. MNEs are responsible for a large and growing share of global R&D activities. For instance, in 2010, the world's top 1,400 companies ranked by their R&D investment increased their investments by 4% to EUR 456 billion, accounting for around 52% of global R&D investment (European Commission, 2011). A combination of a wider geographical spread of R&D resources and a larger absolute amount of these resources creates a favourable situation for countries below the world technology frontier to utilise this international source of knowledge. The existing literature finds that inward R&D-intensive foreign direct investment (FDI) works as a powerful mechanism for international technology transfer and can enable host locations to integrate more advantageously into global value chains (Carlsson, 2006). Thus R&D investment by

MNEs is regarded by many governments as an important part of the national innovation system. Competition among governments for internationally-allocated R&D resources has grown accordingly (Mudambi and Mudambi, 2005; Zanatta et al., 2006).

Against this backdrop, one may wonder what the prerequisites are for countries below the world technology frontier to attract the R&D investment of MNEs. Understanding how MNEs decide where to locate their overseas R&D investment is vital for answering this question. Therefore, the purpose of this chapter is to explore the determinants of R&D investment undertaken by MNEs. To tackle the question, this study narrows its focus onto MNEs from the U.S, which accounts for the highest percentage of global R&D investment by MNEs. The empirical analysis makes use of a panel dataset of overseas R&D investment by U.S.-based MNEs during 1999–2008 constructed at the two-digit level of NAICS. Since the U.S. is one of the countries, if not the country, at the world technology frontier, clarifying what drives the R&D investment of U.S.-based MNEs may help countries formulate effective policies to attract R&D investment of MNEs from other advanced countries as well.

The regression analysis is performed using a sample composed of 23 countries due to data limitations. Among these 23 countries, 22 are OECD countries and the remaining one is Mexico, a developing country. It would be ideal if a full sample covering both developed countries and developing countries were available. We could then examine the determinants of R&D investment by U.S.-based MNEs in the full sample and in the developing and developed subsamples respectively. Unfortunately, this ideal dataset cannot be amassed due to the lack of industry R&D expenditure data in developing countries. Despite this limitation, the implications of this study may still apply to the case of developing countries if R&D activities by MNEs are globally planned.

A brief discussion about previous works that explore the determinants of the location of R&D investment by U.S.-based MNEs will help clarify the contribution of this study to the existing literature. Works based on country-level data have captured the importance of economy-wide variables such as domestic technological capability and domestic market size (Hedge and Hicks, 2008; Athukorala and Kohpaiboonb, 2010). For example, Athukorala and Kohpaiboonb (2010) find that the R&D intensity of operations of U.S.-based MNE affiliates is determined mainly by the domestic market size (ie, market-seeking hypothesis), overall R&D capability (ie, technology-seeking hypothesis) and the cost of hiring R&D personnel (ie, the human capital effect). Yet, at the country-level, since the industrial composition of a country will influence the aggregate country-level R&D intensity of MNEs affiliates, it needs to be controlled in the analysis. When country-level data are used, this issue has to be addressed by incorporating an index that reflects the industrial composition of the country, which is an indirect proxy. When industry-level data are employed, this will not be an issue since the analyses are conducted on individual industries. Hence, this chapter provides a comparison with the previous findings from country-level studies in this respect. Another possible way in which this study is differentiated from country-level studies is how it captures the technology-seeking motives of MNEs. In country-level studies, aggregate country-level R&D variables such as R&D expenditure as a share of GDP and the number of patents normalised by the population size are adopted to reflect the domestic technology capability of the host country. However, as suggested by Hansen and Lovas (2004), to focus on firms in the same industry is important because knowledge spill-overs that are closely related to the local subsidiary's own knowledge base are likely to be more useful than less related knowledge. In the case of industry-level data, direct observation of the technological capability of the relevant industry and country where the multinational firm operates can be made. Therefore, the results in this study could complement country-level studies in answering whether the technology-seeking motive is a determinant of R&D investment of MNEs.

In terms of individual firm-level studies, Feinberg and Gupta (2004) use individual firm data to explore the determinants of the location of U.S.-based MNEs' R&D. The benefit of individual firm data is that it allows the inclusion of firm-level operating variables that potentially influence the firm's absorptive capacity of external knowledge. As control variables, Feinberg and Gupta (2004) use country and industry dummies to proxy for the effects of economy-wide factors such as institutional quality and abundance of researchers. However, these variables are in fact changing throughout time and therefore may be improper to be regarded as fixed effects when the time period is long enough. Also, considering that the impact of these economy-wide variables on the R&D investment decision of MNEs are of high policy relevance, the results from Feinberg and Gupta (2004) may not provide a complete answer to the question about the determinants of R&D investment of MNEs. This study takes into account these changing economy-wide factors and hence can explore some issues of high interest to policymakers.

The chapter is organised as follows. Section 5.2 provides a brief review of the current understanding about overseas R&D activities of MNEs. Section 5.3 examines the trends and patterns of R&D expenditure of U.S.-based MNEs. Section 5.4 presents the empirical specification and the econometric method used. Section 5.5 reports and interprets the results of the baseline regression analysis and those of robustness checks. Section 5.6 concludes and summarizes the implications of inter-country and inter-industry differences in the R&D intensities of U.S.-based MNEs.

5.2 Motivation and determinants of overseas R&D investment

In this section, we first look at the motivations for MNEs' overseas R&D activities, ie, the reasons why MNEs undertake overseas R&D activities. Then we examine the determinants of overseas R&D activities by MNEs, that is, the factors that determine where overseas R&D activities are located. Both the motivations and determinants will affect the outcome of overseas R&D location and will be incorporated in the regression analysis in Section 5.4.

Two motivations for overseas R&D investment by MNEs have been identified in the literature. The first stems from the technology-seeking hypothesis, which argues that MNEs are increasingly trying to capture knowledge internationally. In order to remain competitive, firms often need to tap into different centers of excellence around the world. Given that knowledge spillovers tend to be geographically localized (Jaffe et al., 1993; Audretsch and Feldman, 1996; Branstetter, 2001; Keller, 2002), spillovers from local to foreign firms may occur when foreign investors take advantage of local technological capability and human capital that would not exist or would be obtained at a higher cost in their home market (Zhao and Liu, 2008).

According to this perspective, the globalization of R&D activities should be seen as a conscious strategy of technology-seeking firms that try to profit from globally-dispersed reservoirs of knowledge by establishing R&D activities abroad. Recent evidence suggests that overseas R&D investment has already become a vehicle for accessing foreign technological and scientific strengths and creating new technologies ("home base augmenting" or "innovative" R&D) (von Zedtwitz and Gassman, 2002; Shimizutani and Todo, 2008; Griffith et al., 2008; Belderbos et al., 2008; Branstetter et al., 2006).

The second motive stems from the technology adaptation hypothesis. According to this hypothesis, R&D conducted in foreign affiliates can focus on the adaptation of home-developed technologies to suit foreign markets ("home base exploiting" or "adaptive" R&D) and thus increase sales in the host country. According to Athukorala and Kohpaiboon (2010), there are two elements to this hypothesis: distance and domestic market orientation. On the one hand, a longer distance of the host country from the home country can either increase or decrease the R&D intensity of affiliates of MNEs. Longer distance may intensify the need to conduct R&D for adaptation to the local market. However, it may also increase the impact of market segregation associated with transportation costs, which will increase the cost of FDI and thus decrease the R&D investment of affiliates of MNEs. The impact of domestic market orientation on local R&D effort can go either way as well. If MNE affiliates located in a given country produce for wider regional or global markets in addition to serving the domestic market, it can feature both a low domestic market orientation and a high R&D intensity. In contrast, an affiliate serving mostly the local market may have different demands for technological inputs than one having a global production orientation. Therefore, an affiliate with a high domestic market orientation may require more adaptations and hence a high R&D intensity (Kumar, 1996).

Human capital and institutional quality in a host country are two potential determinants of overseas R&D investment by MNES since they are critical components of the investment environment for R&D activities. On the one hand, the attractiveness of a given country as a location for R&D activities can depend on how well the country meets the human capital requirements for undertaking R&D activities. On the other hand, institutional quality may also matter if one views firm R&D decisions as responses to the "rules of the game in society" that structure incentives in human exchange (North, 1990; Tebaldi and Elmslie, 2008). As basic rules in a market economy, institutions such as property rights (including intellectual property rights, IPR) protection and the effectiveness of contract enforcement affect corporate incentives for investments of all kinds, both in tangible and intangible assets. While IPR protection laws and their enforcement provide necessary protection to the fruits of R&D (patent, copyrights, trademarks, etc.), broader institutions are complementary to R&D expenditures, especially during the post-R&D stage, and hence help realize the commercial values of R&D (Lin et al., 2010). Therefore, overall institutional quality is likely to positively influence the R&D investment of MNEs.

Finally, the FDI stock of the MNE affiliates in a host country may also be a determinant of R&D investment in the host country. The FDI stock can reflect the duration of MNE operations in a given country (Lipsey, 2000) and also the significance of the host country as an investment location. How the FDI stock impacts on R&D investment reflects the evolving pattern over time of R&D activities in a given country. R&D-intensive FDI may occur through the expansion of existing subsidiaries rather than through greenfield investments (Mudambi and Mudambi, 2005; UNCTAD, 2005). In this case, R&D-intensive FDI emerges from an evolutionary process whereby the manufacturing or marketing units already located in the country become engaged in R&D after some time, and later may increase the quality and scope of their R&D (Guimón, 2009). Under these circumstances, the FDI stock has a positive impact on R&D intensity. However, R&D intensive FDI may also occur as greenfield investment in which case the FDI stock does not significantly influence the R&D intensity of MNE affiliates. Therefore, there is not a definite expectation about the direction of influence from the FDI stock on R&D intensity of MNE affiliates.

5.3 Trends and patterns of the globalization of R&D by U.S.-based MNEs

In order to set the stage for the regression analysis, this section surveys the trends and patterns of overseas R&D investment by U.S.-based MNEs. The data used in this section is from the Bureau of Economic Analysis, the Department of Commerce (BEA). This dataset contains information about U.S.-based MNEs' R&D investment in a wide range of developed and developing countries and therefore provides an accurate gauge of the globalization of R&D by U.S.-based MNEs. In the regression analysis discussed later in Section 5.4, however, mainly due to the need to capture the technology-seeking motive with the industry-level R&D data from the OECD ANBERD Database, the sample is limited to 23 countries.[28] While the regression analysis can generate insights into the determinants of overseas R&D investment based on the experience of these countries, it is still worthwhile to present a thorough picture of global R&D investment by U.S.-based MNEs in both developed and developing countries with the data from BEA.

[28] These 23 countries are: Australia, Austria, Belgium, Canada, Czech Republic, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Japan, Korea, Mexico, Netherlands, New Zealand, Norway, Poland, Portugal, Spain, Switzerland and United Kingdom.

The annual overseas R&D expenditure of U.S.-based MNEs more than doubled from around U.S. $ 18 billion in 1999 to around US$ 42 billion in 2008. The share of overseas R&D expenditure in total corporate R&D expenditure increased from about 13% to 17%, which suggests that the globalization of R&D by MNEs is an ongoing and deepening process. In terms of the industrial structure of R&D investment, the share of manufacturing's R&D expenditure in total R&D expenditure decreased from 84% in 1999 to 76% in 2008 and the share of manufacturing's R&D expenditure in overseas R&D expenditure decreased from 90% in 1999 to 76% in 2008 (Table 5-1), which suggests a reduced importance of the manufacturing sector in R&D activities. In fact, the contraction of manufacturing's share of R&D expenditure mirrors the expansion of the service's share of R&D expenditure in the last decade, as can be seen in Table 5-2. Service sectors such as "Wholesale trade", "Information" and "Professional, scientific, and technical services" experienced increases in their relative importance as industrial destinations of U.S.-based MNEs' overseas R&D expenditure. Notwithstanding this trend of shifting towards service sectors, it should be noted that manufacturing's share of R&D is still dominant by far. The econometric analysis in Section 5.4 will only be focused on the manufacturing industries due to the difficulty of making concordance between the service sectors in ISIC rev.3 used in the OECD ANBERD Database and the service sectors in NAICS used in the data from BEA.

Table 5-3 summarizes two aspects of information. The first is the R&D expenditure by U.S.-based MNEs in the manufacturing sector of the host country as a share of global overseas R&D expenditure in the manufacturing sector by U.S.-based MNEs. These data can show the dispersion of overseas manufacturing R&D of U.S.-based MNEs across various countries or regions. For example, in 2008, the total amount of U.S.-based MNEs' R&D expenditure in China was 3% of U.S.-based MNEs' global R&D expenditure in manufacturing, while the corresponding share in 1999 was 2%.

Europe as a whole absorbed more than 67% of the overseas R&D investment by U.S.-based MNEs in 1999 and maintained this proportion in 2008. Germany and the U.K. were the two countries where R&D resources from the U.S. were most concentrated. The Republic of Korea experienced an increased share of R&D investment from the U.S. from 0.6% to 3% of the world total while Japan's share fell from 8% to 5%. Both China and India have become more important destinations of

R&D investment from the U.S. in terms of the absolute scale, which is consistent with the findings in Moncada-Paternò-Castello, Vivarelli and Voigt (2011).

While the shares of R&D can inform us of one aspect of the global position of a host country, R&D intensity (R&D expenditure as a share of value-added) in manufacturing is an indicator of how technology intensive or R&D intensive the activities conducted by U.S-based MNEs in the host country are. This is the major concern of developing countries that hope to enhance their technological capability by attracting R&D investment from advanced countries. The third and fourth columns of Table 5-3 present the R&D intensity (R&D expenditure as a share of value-added) of U.S.-based MNEs in the manufacturing industry of a country or region. The world average R&D intensity in manufacturing by U.S.-based MNEs increased from 5% in 1999 to 6% in 2008. The R&D intensity in manufacturing in Europe also grew from 6% to 7%. U.S.-based MNEs increased their R&D intensity in both the manufacturing sectors of the Republic of Korea and Japan. Yet, the extent of growth of R&D intensity is larger in the Republic of Korea than that in Japan. Interestingly, unlike the absolute amount of R&D, the R&D intensity of U.S.-based MNEs in India and that in China had different trends. India enjoyed an increase in R&D intensity of U.S-based MNEs from 2.3 % in 1999 to 12.9 % in 2008. China, in contrast, experienced a decrease in R&D intensity of U.S.-based MNEs from 9.6 % in 1999 to 6.5 % in 2008, which suggests that R&D investment may have not been able to keep pace with the output expansion of U.S.-based MNEs in China. R&D intensity is preferable to R&D shares in global manufacturing R&D expenditure for understanding the impact of R&D activities of MNEs on technological catch-up of countries. Hence, in the regression analysis in Section 4, R&D intensity of U.S-based MNEs in the host country industry is the dependent variable of interest.

Apart from inter-country differences in R&D intensity, there are significant inter-industry differences in R&D intensity (Table 5-4). Among the world average values of R&D intensity of U.S.-based MNEs in seven industries, the world average values of R&D intensity in "Food" and "Metals" are lowest and those in "Computers" and "Transports" are highest. These inter-industry differences in R&D intensity imply that industry-level data will be more suitable for examining the globalization of R&D of U.S-based MNEs than country-level data. Section 5.4 will further discuss how to deal with the issue of inter-industry differences in R&D intensity in the regression analysis.

5.4 Model specification, data and econometric method

It has been observed in the previous section that there are considerable inter-country and inter-industry differences in the R&D intensity of U.S.-based MNEs. I now examine formally the factors that contribute to the inter-country and inter-industry pattern of R&D intensity. In this section, model specification will be first presented. The reasons for the inclusion of the independent variables will be briefly explained, mainly to echo the discussions made in Section 5.3. The data and the econometric method used will then follow.

Based on the discussion in Section 5.3, the estimation equation is specified as follows:

$$MNER\&Dintensity_{ij,t} - \mathrm{MNE}R\&Dintensity_{ij,t-1} = a_1 + (a_2 - 1)MNER\&Dintensity_{ij,t} + a_3 local\_R\&Dintensity_{ij,t} + a_4 * salesratio_{ij,t} + a_5 * researchers_{j,t} + a_6 * distance_j + a_7 * investmentposition_{ij,t} + a_8 * insquality_{j,t} + a_9 * year_t + a_{10} * id_i + e_{ij,t} \quad (5.1)$$

Or equivalently,

$$MNER\&Dintensity_{ij,t} = a_1 + a_2 * \mathrm{MNE}R\&Dintensity_{ij,t-1} + a_3 * local\_R\&Dintensity_{ij,t} + a_4 * salesratio_{ij,t} + a_5 * researchers_{j,t} + a_6 * distance_j + a_7 * investmentposition_{ij,t} + a_8 * insquality_{j,t} + a_9 * year_t + a_{10} * id_i + e_{ij,t} \quad (5.2)$$

$$e_{ij,t} = u_{ij} + \varepsilon_{ij,t} \quad (5.3)$$

where i is the industry index, j is the country index, t is the time index.

The error term $e_{ij,t}$ consists of a country-industry fixed effect u_{ij} and an observation specific error $\varepsilon_{ij,t}$.

The independent variable $MNER\&Dintensity$ is the R&D intensity of the affiliates of U.S.-based MNEs. Empirically, two measures could be used to proxy for the R&D intensity variable. One is the share of R&D expenditure in value-added of the affiliates in the industry, and the other is the share of R&D expenditure in total sales of the affiliates in the industry. According to the BEA, compared to total sales, value added is a preferable measure of production because it indicates the extent to which a firm's sales result from their own production rather than from production that originates elsewhere, whereas sales data do not distinguish between these two sources of production. Therefore, the regression results using the share of R&D expenditure in value-added as the independent variable are regarded as the main empirical results (Tables 5-8 and 5-9), while the regression results with the share of R&D expenditure in total sales as the independent variable (Tables 5-10 and 5-11) provide some robustness checks. Industry dummy id_i and year dummy $year_t$ are included to reflect how differences in the global average R&D intensity of various industries will influence the R&D intensity of U.S.-based MNEs. This is necessary due to the consideration that industries can be different in terms of their average R&D intensity.[29]

Based on the technology-seeking hypothesis, the domestic technological capability of the relevant industry in the host country, $local\_R\&Dintensity$, can be an important consideration in MNEs' R&D location decision. This variable is measured as R&D expenditure as a percentage of output (value added) in a given industry. If the R&D investment of MNEs is partly driven by the technology-seeking motive, then a higher $local\_R\&Dintensity$ will imply a higher $MNER\&Dintensity$, which is the R&D intensity of U.S.-based MNEs in industry i of country j in year t. In other words, in the case that the technology-seeking motive exists, the coefficient of $local\_R\&Dintensity$ is expected to be positive.

A major difference between this study and previous country-level studies is that I use industry-level R&D intensity of host countries instead of the country-level R&D intensity of host countries to capture the technology-seeking motive of U.S.-based MNEs. The key to this industry-level approach is to obtain the R&D intensity across various industries and countries. I use the share of industry R&D expenditure data of the host country in the industry value-added data as the R&D intensity measure of that industry in the host country. The industry value-added data are from STAN Database for Structural Analysis. The industry-level R&D data are from OECD Analytical Business Enterprise Research and Development (ANBERD) Database. To link back to the discussion of the measure of R&D intensity of U.S.-based MNEs, the definition adopted for R&D intensity of host country industries implies that it will be more

[29] This point can be seen from Table 5-4 where the values of R&D intensity by U.S.-based MNEs in various industries and countries are presented.
Although not shown in this paper, the R&D intensity data calculated from the ANBERD database also show wide variation across different industries.

consistent to use the share of R&D expenditure in value added of U.S.-based MNEs as the independent variable in the regression analysis.[30]

Two variables are included to capture the importance of adapting products and production processes to suit domestic market conditions in determining inter-country and inter-industry variation in R&D intensity, or the market-seeking motive. They are the geographic distance between the U.S. and a given host country $distance$, and the domestic market orientation of U.S.-based MNE affiliates measured by the sales as a percentage of global sales $salesratio$.[31] In this industry-level study, the share of sales in industry i of country j in global sales in industry i is used to measure the relative market size of industry i of country j. In contrast, in a country-level study, the share of sales in country j in global sales will be used to measure the relative market size of country j.

As discussed in Section 5.2, longer distance to the home country $(distance)$ can either increase or decrease R&D intensity of foreign affiliates. The impact of domestic market orientation on local R&D effort can go either way as well. Therefore, the signs of the coefficients for these two variables are uncertain. Two variables are used to capture the conduciveness of the economic environment for R&D activities. They are researchers in R&D per thousand population $(researchers)$ and institutional quality $(insquality)$. The aggregate FDI stock of U.S.-based MNE affiliates in each industry of each host country $(investmentposition)$ is employed to capture the effect from the existent FDI stock on the R&D investment by MNEs.

The explanatory variables are listed in Table 5-5 with the expected signs of the regression coefficient of each variable given in brackets.

Data compilation is composed of three parts. First, I obtain respectively from the OECD ANBERD Database and the STAN Database for Structural Analysis the R&D expenditure and value added in seven manufacturing industries. The business enterprise R&D expenditure is then divided by the value-added variable, which gives the R&D intensity of each industry in each country. Second, the chain-linked summary index of

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[30] This is one more reason why regression results presented in Table 5-7 and Table 5-8 are the main results of the study.

[31] In this industry-level study, the share of sales in industry i of country j in global sales in industry i is used to measure the relative market size of industry i of country j. In contrast, in a country-level study, the share of sales in country j in global sales will be used to measure the relative market size of country j.

institutional quality published in the Economic Freedom of the World database is used to proxy for the overall insitutional quality of an economy.[32] This overall index measures institutional quality in terms of five criteria: (1) size of government, (2) legal structure and property rights, (3) access to sound money, (4) freedom to trade internationally, and (5) regulation of credit, labour and business. It ranges from zero to ten, with higher values indicating stronger institutional quality. The chain-linked sub-indicator for the second area "legal structure and property rights" is also used as a measure of institutional quality in the regression analysis. This is because property rights protection itself has received much attention in the literature about FDI and the literature about firm R&D activities. The sub-indicator is also on a scale of zero to ten.

Third, the number of researchers in R&D per thousand population is obtained from the World Bank. Fourth, the distance is measured as the great-circle distance between the capital city of the given country to Washington DC. Lastly, the previous four variables are merged with the direct investment abroad data of majority-owned nonbank foreign affiliates from the U.S. from the Bureau of Economic Analysis, the Department of Commerce. The dependent variable $(MNER\&Dintensity_{ij,t})$ and the two explanatory variables $(salesratio_{ij,t},\ investmentposition_{ij,t})$ are from this database.

Twenty-three countries and seven manufacturing industries are covered in the final sample, which is a compilation of six data sources. The seven industries are “Food", “Chemicals", “Metals", “Machinery", “Computers", “Electrics" and “Transports". Bureau of Economic Analysis follows North American Industry Classification System (NAICS) when reporting the data on direct investment abroad for majority-owned nonbank foreign affiliates. In order to use the R&D information in the OECD ANBERD database, which follows the International Standard Industrial Classification rev. 3 (ISIC rev.3), I correspond NAIC with ISIC rev.3, which requires that some industries under ISIC rev.3 are grouped into the seven industries used in the final sample.

The time period of the study is from 2000 to 2008. This study period is chosen because the data on direct investment abroad by U.S. multinational enterprises are consistently compiled according to the North American Industry Classification System (NAICS) by the BEA for this period. According to the BEA website, there is a discontinuity in the time series at 1999 where the industry classifications are changed from Standard

[32] Chain-linked measures are suitable for comparison across countries and time.

Industrial Classification (SIC) to the North American Industry Classification System (NAICS). Besides this problem, the institutional quality measures used in this study are only available for each year from the year 2000 onwards. These two conditions lead to the choice of the years 2000-2008 as the study period.

The inclusion of the lagged dependent variable on the right hand side of Eq. 5.2 creates a dynamic structure. Under this structure, the error term, which includes country-industry fixed effects, may co-vary with the lagged dependent variable. Hence, an OLS estimator will be inconsistent. A fixed-effect estimator is also biased since within transformation will make the transformed error and lagged dependent variable correlated. Also, the two variables $salesratio$ and $investmentposition$ may be endogenous[33]. Therefore, instrumental variables are required to deal with this problem as well as the endogeneity of other explanatory variables.

A consistent estimator under these circumstances is the system GMM estimator (Blundell and Bond 1998). Holtz-Eakin, Newey, and Rosen (1988) and Arellano and Bond (1991) first proposed the difference GMM estimator. Later, Blundell and Bond (1998) augment Arellano-Bond (1991) with an additional assumption that first differences of instrumenting variables are uncorrelated with the fixed effects, which then allows the introduction of more instruments and can dramatically improve efficiency. The "system GMM estimator" that combines the variables in differences and levels also has better asymptotic properties. By using internal instruments (lagged variables and differenced variables), the dynamic panel estimation applied in the analysis allows for the likely weak endogeneity of the main regressors.

I apply the two-step system GMM estimator, which is asymptotically more efficient than the one-step estimator in the presence of heteroskedasticity of the error terms (Roodman 2006). Also, to avoid downward bias of the two-step standard error, the robust standard errors proposed by Windmeijer (2005) are adopted. Whether the GMM estimator is consistent or not crucially depends on the validity of the instruments. To ensure this is the case in the specification, I conduct two specification tests: a test of over-identifying restrictions based on the Hansen J-statistics and the Arellano-Bond test for second-order serial correlation in the error term (Wooldridge, 2002; Roodman, 2006). The autocorrelation test and the robust estimates of the coefficient standard

[33] It is possible that R&D intensity of the affiliate may in turn influence the sales in the industry of the host country and the FDI stock there as well.

errors assume no correlation across individuals in the idiosyncratic disturbances. Time dummies and industry dummies make this assumption more likely to hold since the correlation due to the common time trend and industry trend is thus captured. Therefore, time dummies and industry dummies are included in the specification.

5.5 Empirical results

The summary statistics of the variables used in the regression analysis are shown in Table 5-6. In Table 5-7, the Ordinary Least Square estimation result using overall institutional quality measure is reported for comparison with the main results in Tables 5-8 and 5-9. The main regression results presented in these two tables are obtained with the sub-indicator of legal structure and property rights and the overall institutional quality measure, to reflect the effect from institutional quality on R&D intensity (share of R&D expenditure in value-added) respectively. It can be seen that the result of OLS estimation is close to the results of the system GMM estimation.

As can be seen from Table 5-8, the coefficient of $local\_R\&Dintensity$ is positively signed and statistically significant at the 1% level. This result is consistent with the hypothesis that increased R&D intensity by U.S.-based MNEs may be for the purpose of benefiting from the knowledge in the host economy. In other words, there is evidence to support the technology-seeking motive behind the R&D investment of MNEs. The coefficient of $local\_R\&Dintensity$ is 0.073, which means that, ceteris paribus, a 1% increase in the R&D intensity of the industry in the host country is, on average, associated with a 0.073% increase in the R&D intensity of U.S.-based MNEs in the industry of this country. Note that a 0.073% increase is not small relative to the mean R&D intensity of U.S.-based MNEs, which is equal to 1.1% (Table 5-8).

To examine the "technology adaption hypothesis", we need to look at the variable $salesratio_{ij,t}$ which proxies for market size and the variable geographical distance. The coefficient of $salesratio_{ij,t}$ is positive and significant at the 5% level. The coefficient of $salesratio$ is 0.93, which implies that, ceteris paribus, a 1% increase of the share of market will increase the R&D intensity of U.S.-based MNEs by 0.93 %, which supports the hypothesis that market size is important for the return to R&D investment and hence larger market size tends to accommodate more intensive R&D activities. Geographic distance is not found to be significant in explaining the R&D

intensity of U.S.-based MNEs. The insignificance of geographic distance is consistent with the finding in Athukorala and Kohpaiboon (2010).

As for the role of human capital, the variable $researchers_{j,t}$ is found to exert a positive influence on the R&D intensity of U.S.-based MNEs and is significant at the 1% level. Other things being equal, for each one more researcher in a thousand people, the R&D intensity of U.S.-based MNEs will be induced to increase by 1.1 %. This is consistent with the hypothesis that the abundance of available researchers is a main driver of multinational R&D investment. FDI stock $(investmentposition_{ij,t})$ is found to be negatively associated with the R&D intensity of U.S.-based MNES and is significant at the 10% level, which implies that the R&D investment process may not be one where the production units already located in the country become engaged in R&D after some time, and later enhance the quality and scope of their R&D. As to the institutional quality in terms of legal structure and property rights, it is surprisingly found to exert a negative impact on R&D intensity of U.S.-based MNEs and is significant at 10% level. The negative relationship holds when Mexico, the only developing country is dropped out of the sample.[34] The finding about the role of institutional quality and its implications require further thinking and research.

In Table 5-9, the overall institutional quality is adopted and the results are similar to the ones in Table 5-8. In Tables 5-10 and 5-11, the independent variable is the share of R&D expenditure in total sales. I apply the same econometric model and the results are largely consistent[35]. However, unlike the results in Tables 5-7 and 5-8, the institutional quality variable is not significant at the 10% level in Tables 5-10 and 5-11. The institutional quality variable is still not significant at the 10% level when Mexico is dropped out of the sample. But the coefficients of host country R&D intensity, ratio of local sales to world sales and the number of researchers are still all positively signed and significant at the 5% level.

The validity of the estimation results is checked as follows. I use the Hansen test of over-identification to test for the validity of the instruments. The null hypothesis is that the instruments as a group are exogenous. The results are reported for each regression

[34] The minimum value of the legal structure and property rights sub-indicator appears in Mexico in 2001. The minimum value of the overall institutional quality measure appears in Poland in 2001. The second smallest value of the overall institutional quality measure appears in Mexico and Poland in 2001 and 2000 respectively.

and none of them rejects the null hypothesis that the moment conditions are valid at the 10% confidence level. This result indicates that the estimations are not subject to substantial endogeneity bias. Furthermore, the Arellano-Bond test for autocorrelation in first differences, which has a null hypothesis of no autocorrelation, is performed on the regression. The test result, as reported in Table 5-8, cannot reject the non-presence of second order autocorrelation in all the regression at conventional confidence levels. These two specification tests point out the validity of internal instruments and the assumption of zero autocorrelation of error term, thus testifying to the validity of the estimation results.

We have seen the results based on the empirical specification in Eq. 5.2 and the system GMM estimator, which considers both the lagged dependent variable and the endogeneity of the independent variables. However, if one takes a close look at the R&D intensity of U.S.-based MNEs, it will be seen that a number of industries report zero value of R&D intensity (Table 5-4). To confront this issue, the random-effects Tobit estimator is performed on the following specification:

$$MNER\&Dintensity_{ij,t} = b_1 + b_2 local\_R\&Dintensity_{ij,t} + b_3 * salesratio_{ij,t} + b_4 * researchers_{j,t} + b_5 * distance_j + b_6 * investmentposition_{ij,t} + b_7 * insquality_{j,t} + b_8 * year_t + b_9 * id_i + e_{ij,t} \quad (5.4)$$

The result of the estimation is presented in Table 5-12. It is found that the coefficients of host country industry R&D intensity, market share of host country industry and the number of researchers per population in the host country are still positive and significant, which are consistent with the findings for the system GMM estimator of Equation 5.3.[36] However, under this specification, distance becomes positive and significant at the 5% level and the FDI stock becomes insignificant, which is different from the previous conclusions. Like the case in Tables 5-10 and 5-11, institutional quality is not significant here. Therefore, the random effect Tobit estimation strengthens the findings about the technology-seeking and the market-seeking motives and about the positive impact of human capital. Yet the roles of the FDI stock, geographical distance and institutional quality are less clear and robust.

[36] The coefficients of host country industry R&D intensity, market share of host country and number of researchers per thousand population are significant at the 10%, 1% and 1% level respectively.

5.6 Conclusion

Multinational firms continue to expand their R&D activities outside their home countries in response to competitive pressures and an increasingly global trade and investment environment. With proper policies that facilitate diffusion of technologies and knowledge from foreign affiliates, host countries can link MNEs′ R&D activities with local innovation systems to enhance domestic innovation capabilities. Hence, the R&D activities of MNEs deserve attention due to their implications for long-term growth prospects of economies and their connection to the broader growth and development literature. Also, policymakers worldwide are interested in how to attract R&D activities by MNEs to enhance local technological capabilities.

The first step towards effectively attracting and utilizing this international resource is to gain a deep understating of what drives this type of investment by MNEs. By focusing on the R&D investment in seven manufacturing industries of 23 countries by MNEs from the U.S., this chapter examined the drivers of overseas R&D investment by U.S.-based MNEs in the period 2000-2008. The empirical findings of this study suggest that first, the technology-seeking motive is important since higher growth of R&D intensity in the relevant industry of the host country induces higher level of R&D intensity of MNEs; second, access to an abundant pool of researchers promotes the R&D intensity of MNEs; third, the market-seeking motive matters; fourth, the role of institutional quality is not robust but sometimes found to be negative; fifth, the impacts of the investment position of MNEs and distance are not clearly identified and not robust. In other words, how institutional quality, the investment position and distance influence the R&D intensity of MNEs are questions that require further consideration and research.

While it is not definitive that R&D investment by MNEs will be driven by the same mechanism in developing countries, the above findings in this study may still be informative for developing countries if R&D activities by MNEs are becoming truly global. This study points to a need for policies that strengthen domestic R&D and the stock of knowledge, enhance human capital endowments and support a domestic market that is open to the world. When a country does well in these aspects, this may trigger a virtuous cycle of attracting more foreign sources of R&D, benefiting from and building upon it, further improving the three aspects and drawing even more foreign sources of

R&D. This is the main message that the chapter conveys based on the empirical findings.

Further research is needed to examine how institutional quality impacts on the R&D intensity of MNEs by, for example, adopting a better measure of institutional quality. While the institutional quality of the host country doesn't appear to matter to, or may even exert a negative impact on, the R&D intensity by U.S.-based MNEs in the sample used here—one that is largely composed of only developed countries with the only exception being Mexico—this does not mean that institutional quality will not matter when more developing countries are taken into account. The much greater variation in the institutional quality of developing countries is likely to be more significant in determining the R&D intensity of U.S-based MNEs (or MNEs from other developed countries) in the host country.

Table 5-1 R&D expenditure of U.S.-based MNEs during 1999-2008

	All sectors			Manufacturing			Manufacturing share	
	Total	Foreign affiliates		Total	Foreign affiliates		Total	Foreign affliates
	$ bn	$ bn	% of total	$ bn	$ bn	% of total	%	%
1999	144	18	13	121	16	13	84	90
2000	156	20	13	128	18	14	82	90
2001	163	20	12	133	17	13	81	88
2002	158	21	13	129	19	15	81	89
2003	163	23	14	133	20	15	81	87
2004	190	26	14	152	22	15	80	87
2005	205	28	13	167	24	14	81	85
2006	214	30	14	171	24	14	80	82
2007	238	34	14	187	28	15	79	81
2008	240	42	17	182	32	17	76	76

Source: Author's own calculation based on data from Bureau of Economic Analysis, the Department of Commerce.

Table 5-2 Industrial distribution of overseas R&D expenditure, 1999-2008

	All countries (% of total)	
	1999-2001	2006-2008
All industries	100	100
Mining	0.05	0.18
Manufacturing	89.33	79.02
Food	1.47	1.43
Chemicals	23.45	22.64
Primary and fabricated metals	0.74	0.97
Machinery	3.95	3.33
Computers and electronic products	24.78	16.49
Electrical equipment, appliances, and components	1.44	1.55
Transportation equipment	28.55	26.68
Wholesale trade	3.29	4.33
Information	1.65	4.23
Finance (except depository institutions) and insurance	0.01	0.01
Professional, scientific, and technical services	4.34	11.88

Source: Author's own calculation based on data from Bureau of Economic Analysis, the Department of Commerce.

Table 5-3 R&D share (%) and R&D intensity (%)				
Country	R&D expenditure by U.S.-based MNEs in the manufacturing sector of the country as a share of global overseas R&D expenditure in the manufacturing sector by U.S.-based MNEs (%)		R&D intensity (R&D expenditure as a share of value-added) by U.S.-based MNEs in the manufacturing sector of a country (%)	
	1999	2008	1999	2008
All Countries Total	**1**	**1**	5.2	6.1
Canada	9.8	6.3	3.9	3.9
Europe	67.5	67.1	5.6	6.8
Austria	0.5	1.0	4.4	9.9
Belgium	1.5	2.8	2.6	6.8
Czech Republic	0.0	0.3	0.6	2.2
Denmark	0.3	..	5.5	..
Finland	0.4	0.6	7.5	11.6
France	8.6	6.6	6.3	6.8
Germany	20.4	22.7	7.3	11.6
Greece	0.0	0.1	1.2	1.2
Hungary	0.1	..	1.6	..
Ireland	1.5	2.7	1.9	2.9
Italy	2.9	1.6	2.7	2.6
Netherlands	2.1	4.0	3.2	6.3
Norway	..	0.1	..	1.3
Poland	0.2	0.1	3.4	0.6
Portugal	0.1	0.1	1.3	3.5
Russia	0.0	0.1	-3.0	0.6
Spain	..	1.7	..	4.9
Sweden	6.3	4.7	35.8	32.3
Switzerland	..	2.3	..	6.4
Turkey	0.0	0.2	0.5	0.9
United Kingdom	19.8	14.1	6.1	7.1
Latin America	3.2	4.3	1.6	2.1
Argentina	0.1	0.2	0.5	0.8
Brazil	1.7	2.4	2.6	2.8
Chile	0.0	..	0.2	..
Colombia	..	0.0	..	0.9
Mexico	1.1	..	1.3	..
Africa	0.1	0.1	1.2	1.3
Egypt	0.0	0.0	2.1	1.1
South Africa	0.1	0.1	1.6	2.1
Israel	1.1	3.4	18.7	36.8
Asia and Pacific	18.3	18.8	7.0	6.9
Australia	1.7	2.6	3.4	5.7
China	1.9	3.3	9.6	6.5
Hong Kong	..	0.2	..	2.9
India	0.1	1.4	2.3	12.9
Indonesia	0.0	0.0	0.4	0.4
Japan	8.3	5.0	10.8	12.7
Korea, Republic of	0.6	3.0	6.4	14.6
Malaysia	1.0	1.2	5.4	9.0
New Zealand	0.0	0.1	1.0	3.3
Philippines	0.2	..	1.9	..
Singapore	..	1.6	..	4.4
Taiwan	0.7	..	7.2	..
Thailand	0.0	0.2	0.4	1.2

(1)Source: Author's own calculation based on data from Bureau of Economic Analysis, Department of Commerce.
(2)".." means data are unavailable.

Table 5-4 R&D intensity (R&D expenditure as a share of value-added) by U.S.-based MNEs in various manufacturing industries and countries (%)

Country	Food		Chemicals		Primary and fabricated metals		Machinery		Computers and electronic products		Electrical equipment, appliances, and		Transportation Equipment	
	1999	2008	1999	2008	1999	2008	1999	2008	1999	2008	1999	2008	1999	2008
All Countries Total	2.0	1.7	7.4	8.1	1.2	1.6	4.0	3.9	10.0	15.0	2.9	4.7	11.6	16.3
Canada	1.0	0.9	9.2	9.0	0.5	0.9	1.3	1.3	4.7	23.3	2.0	2.8	7.3	7.0
Europe	2.3	2.4	8.2	9.6	1.6	2.1	4.1	4.4	9.2	14.7	3.4	4.5	16.3	22.5
Austria	1.3	0.9	4.2	9.9	1.9	0.0	1.6	14.1	1.7	5.2	9.4	..	0.4	..
Belgium	0.7	0.4	5.4	20.5	..	1.6	1.9	2.7	0.0	..	3.2	6.8	2.9	1.0
Czech Republic	..	..	2.9	4.3	0.0	1.3	0.0	0.9	0.0	2.0	0.0	0.0	2.0	5.2
Denmark	3.0	0.0	..	4.9	2.8	2.3	..	..	..	54.7	..	..	0.0	0.0
Finland	0.0	5.9	1.7	20.3	6.1	2.2	0.0	..	..	..	0.0	10.3	5.1	0.0
France	3.3	2.7	12.3	7.2	1.8	2.3	4.4	3.8	13.1	26.3	1.6	4.1	8.6	16.5
Germany	1.3	7.1	6.5	12.7	1.7	1.7	5.3	6.1	7.2	21.1	5.6	7.7	20.9	34.5
Greece	1.8	0.0	1.6	6.1	0.0	9.1	..	0.0	..	..	..	..	..	..
Hungary	..	0.9	6.3	3.1	..	1.8	0.0	0.3	..	..	..	..	..	0.2
Ireland	..	1.7	1.6	2.7	..	0.0	..	0.0	4.4	6.7	..	0.0	1.0	3.1
Italy	0.7	1.4	7.8	8.0	0.7	2.4	4.3	2.3	6.3	5.9	2.3	0.8	6.2	7.1
Netherlands	1.5	3.7	4.5	15.5	1.6	0.4	0.6	4.2	12.0	3.3	..	..	..	..
Norway	..	0.0	6.0	4.4	0.0	..	3.4	0.9	..	..	0.0	0.0	0.0	0.0
Poland	2.7	1.6	1.0	1.3	0.0	..	0.0	1.7	0.0	0.4	..	..	..	1.5
Portugal	0.7	..	1.4	9.6	0.0	0.0	..	1.5	..	0.0	0.0	0.0	3.5	1.2
Russia	0.0	1.0	-1.1	0.7	0.0	..	0.0	..	0.0	..	0.0	0.0	0.0	0.6
Spain	0.8	0.4	..	5.5	0.4	1.8	1.3	0.6	..	..	..	2.9	2.9	2.1
Sweden	..	0.6	..	5.2	3.2	2.4	8.0	2.6	..	77.6	..	..	..	..
Switzerland	..	0.0	2.1	5.7	0.0	4.1	9.8	7.9	1.8	18.1	..	2.4	..	..
Turkey	3.8	..	1.3	4.1	0.0	15.4	..	0.0	0.0	..	0.0	0.0	2.3	..
United Kingdom	4.1	2.1	15.2	21.9	2.5	4.2	3.9	3.9	16.6	14.8	1.1	4.8	16.8	25.7
Latin America	0.8	0.4	1.5	2.5	0.2	0.5	1.3	1.2	13.6	8.1	..	..	2.7	5.1
Argentina	0.4	0.1	1.7	1.8	0.0	0.0	..	0.0	0.0	..	0.0	0.0	0.3	3.0
Brazil	1.2	0.2	1.5	2.7	0.3	0.5	1.6	1.8	..	..	..	..	4.5	7.3
Chile	..	..	..	..	..	0.0	0.0	0.0	..	..	0.0	..	0.0	0.0
Colombia	1.2	1.0	..	0.7	0.0	0.0	..	..	..	0.0	0.0	0.0	..	..
Mexico	0.7	1.1	0.7	2.3	..	0.4	1.0	0.4	..	0.7	..	..	2.1	3.4
Africa	1.0	0.4	2.6	2.0	..	0.0	2.8	0.4	0.0	..	0.0	0.0	..	4.5
Egypt	..	..	1.9	0.7	..	..	1.4	..	..	0.0	0.0	0.0	0.0	..
South Africa	..	0.8	3.2	3.5	0.0	0.0	4.5	..	0.0	..	0.0	0.0	..	..
Israel	0.0	..	3.8	..	0.0	0.0	10.5	..	21.5	66.4	0.0	0.0	0.0	..
Asia and Pacific	3.3	2.5	8.6	..	1.2	1.1	8.2	..	11.0	12.1	..	..	6.6	..
Australia	2.6	3.2	6.1	9.5	1.3	..	0.8	1.0	..	2.6	0.0	..	..	..
China	0.0	0.4	3.5	..	..	..	0.0	1.5	..	18.9	..	7.0	..	5.6
Hong Kong	0.0	..	1.6	4.7	..	..	1.1	0.0	..	2.2	5.5	-7.9	..	0.0
India	..	..	1.8	6.7	0.0	0.0	2.2	..	12.5	..	0.0	1.4	5.5	14.9
Indonesia	0.0	..	..	2.0	0.0	0.0	0.0	0.0	0.0	0.0	..	..	..	..
Japan	18.6	3.9	16.1	18.2	3.8	3.3	21.9	6.9	12.0	13.3	7.5	..	5.8	15.0
Korea, Republic of	1.4	2.6	0.7	7.2	0.0	1.1	5.3	4.4	..	11.8	..	..	..	..
Malaysia	0.0	1.8	0.7	0.8	0.0	0.0	0.0	..	6.5	11.8	..	..	..	0.0
New Zealand	..	..	..	2.4	0.0	0.0	0.0	7.1	0.0	..	0.0	19.4	0.0	0.0
Philippines	3.4	1.9	2.1	..	0.0	0.0	4.1	..	2.1	1.9	..	1.4	..	..
Singapore	0.0	..	0.5	0.8	..	0.0	0.8	0.1	8.9	10.6	0.0	0.9	..	0.3
Taiwan	..	..	1.4	..	..	2.9	8.7	0.8	12.0	6.1	0.0	5.7	..	..
Thailand	3.8	3.9	0.5	1.2	0.0	..	2.4	2.6	0.0	1.3	0.0	0.0	-11.1	5.7

(1) Source: Author's own calculation based on data from Bureau of Economic Analysis.
(2) ".." means data are unavailable.

Table 5-5 List of variables in the regression and their respective expected signs

$MNER\&Dintensity_{ij,t}$	the ratio of investment in research and development compared to the value-added by affiliates of U.S.-based MNEs in industry i of country j in year t (two measures: R&D expenditure as a share of total sales; R&D expenditure as a s share of value-added)
$local\_R\&Dintensity_{ij,t}$ (+)	the ratio of investment in research and development compared to the value-added by business enterprises in industry i of country j in year t
$salesratio_{ij,t}$ (+)	the ratio of sales in industry i of country j compared to the total sales in industry i of the world.
$distance_j$ (- or +)	great-circle distance between the capital city of the given country i to Washington DC
$investmentposition_{ij,t}$ (- or +)	the U.S. direct investment position abroad on a historical-cost basis in industry i of country j in year t (dollars)
$insquality_{j,t}$ (+)	legal structure and property rights of county j in year t overall insitutional quality of county j in year t
$researchers_{j,t}$ (+)	number of researchers in R&D per thousand population

Table 5-6 Summary data on variables used in the regression analysis

	Maximum	Minimum	Mean	Standard Deviation
local_R&Dintensity	1.26	0.000093	0.07	0.11
salesratio	0.300	0	0.030	0.043
researchers	80	0.22	2.7	1.6
insquality	9.6	3.6	7.18	1.37
investmentposition	20640	-3298	1210.27	2292.1
distance	15936	743	7620.56	3237.18
MNER&Dintensity (R&D expenditure as a share of total sales)	0.17	0	0.011	0.016
MNER&Dintensity (R&D expenditure as a share of value-added)	1.5	-0.096	0.044	0.073

Source: Author's own calculation based on data from Bureau of Economic Analysis, the Department of Commerce.

Table 5-7 Ordinary Least Squares estimation

(R&D intensity defined as R&D expenditure as a share of value-added)

Regressors	Coeff.	S.e.	p-value
Local R&D intensity (local_R&Dintensity)	0.085**	0.034	0.012
Market share (salesratio)	0.48***	0.11	0
Density of researchers (researchers)	0.10***	0.033	0.001
Geographic distance (distance)	3.2E-06**	1.5E-06	0.026
FDI stock (investmentposition)	2.3E-06	1.6E-06	0.161
Institutional quality (overall institutional quality measure)	-0.0031	4.0E-03	0.430
Nubmber of Observations		811	

Source: Author's own calculation.

Table 5-8 Determinants of R&D intensity of U.S.-based MNEs in overseas manufacturing sectors

(R&D intensity defined as R&D expenditure as a share of value-added)

Regressors	Coeff.	S.e.	p-value
Initial R&D intensity (MNER&Dintensity)	0.59***	0.1	0.000
Local R&D intensity (local_R&Dintensity)	0.073**	0.037	0.048
Market share (salesratio)	0.93**	0.44	0.036
Density of researchers (researchers)	0.011***	0.0038	0.004
Geographic distance (distance)	2.30E-06	2.00E-06	0.251
FDI stock (investmentposition)	-3.45E-06*	2.94E-07	0.168
Institutional quality (measure of legal protection)	-0.015*	7.80E-03	0.055
AR(2) test (p-value)		0.535	
J-test (p-value)		0.363	
Nubmber of Observations		744	

Note: S.e. denotes heteroskedasticity-robust error. AR(2) is a test of second-order residual serial correlation. J-test is the Hansen overidentification test. Time dummies are included to capture period specific effect but are not reported. \
Source: Author's own calculation.

Table 5-9 Determinants of R&D intensity of U.S.-based MNEs in overseas manufacturing sectors

(R&D intensity defined as R&D expenditure as a share of value-added)

Regressors	Coeff.	S.e.	p-value
Initial R&D intensity (MNER&Dintensity)	0.59***	0.090	0.000
Local R&D intensity (local_R&Dintensity)	0.069**	0.03	0.021
Market share (salesratio)	1.17**	0.51	0.021
Density of researchers (researchers)	0.009***	0.0025	0.000
Geographic distance (distance)	3.20E-06	2.01E-06	0.108
FDI stock (investmentposition)	-3.41E-06**	2.53E-07	0.178
Institutional quality (overall institutional quality measure)	-0.043**	1.90E-02	0.026
AR(2) test (p-value)		0.445	
J-test (p-value)		0.702	
Nubmber of Observations		744	

Note: S.e. denotes heteroskedasticity-robust error. AR(2) is a test of second-order residual serial correlation. J-test is the Hansen overidentification test.
Time dummies are included to capture period specific effect but are not reported.
Source: Author's own calculation.

Table 5-10 Determinants of R&D intensity of U.S.-based MNEs in overseas manufacturing sectors

(R&D intensity defined as R&D expenditure as a share of total sales)

Regressors	Coeff.	S.e.	p-value
Initial R&D intensity (MNER&Dintensity)	0.63***	0.08	0.000
Local R&D intensity (local_R&Dintensity)	0.011**	0.0052	0.029
Market share (salesratio)	0.098**	0.042	0.019
Density of researchers (researchers)	0.0012***	0.00039	0.003
Geographic distance (distance)	3.09E-07	2.10E-07	0.142
FDI stock (investmentposition)	-0.607*	2.94E-07	0.039
Institutional quality (measure of legal protection)	-0.0013	8.90E-04	0.148
AR(2) test (p-value)		0.846	
J-test (p-value)		0.985	
Nubmber of Observations		737	

Note: S.e. denotes heteroskedasticity-robust error. AR(2) is a test of second-order residual serial correlation. J-test is the Hansen overidentification test. Time dummies are included to capture period specific effect but are not reported.
Source: Author's own calculation.

Table 5-11 Determinants of R&D intensity of U.S.-based MNEs in overseas manufacturing sectors

(R&D intensity defined as R&D expenditure as a share of total sales)

Regressors	Coeff.	S.e.	p-value
Initial R&D intensity (MNER&Dintensity)	0.62***	0.077	0.000
Local R&D intensity (local_R&Dintensity)	0.010**	0.0051	0.043
Market share (salesratio)	0.099**	0.042	0.019
Density of researchers (researchers)	0.0010***	0.00033	0.002
Geographic distance (distance)	2.65E-07	1.77E-07	0.135
FDI stock (investmentposition)	-0.593*	3.00E-07	0.048
Institutional quality (overall institutional quality measure)	-0.0029	1.80E-03	0.116
AR(2) test (p-value)		0.864	
J-test (p-value)		0.984	
Nubmber of Observations		737	

Note: S.e. denotes heteroskedasticity-robust error. AR(2) is a test of second-order residual serial correlation. J-test is the Hansen overidentification test. Time dummies are included to capture period specific effect but are not reported.
Source: Author's own calculation

Table 5-12 Random effects Tobit estimation

(R&D intensity defined as R&D expenditure as a share of value-added)

Regressors	Coeff.	S.e.	p-value
Local R&D intensity (local_R&Dintensity)	0.072*	0.04	0.075
Market share (salesratio)	0.48***	0.11	0
Density of researchers (researchers)	0.011***	0.0039	0.004
Geographic distance (distance)	3.46E-06**	1.72E-06	0.045
FDI stock (investmentposition)	1.09E-06	1.79E-06	0.542
Institutional quality (overall institutional quality measure)	-0.0034	4.60E-03	0.465
Left-censorted observations		86	
Uncensored observations		725	
Nubmber of Observations		811	

Source: Author's own calculation.

Chapter 6: Task sharing and changing production structure

6.1 Introduction and background

One of the major recent trends in global manufacturing is "trade in tasks" or the "global value chain" or "production fragmentation" (Grossman and Rossi-Hansberg, 2006; Baldwin and Robert-Nicoud, 2010; Bayoumi et al., 2013). These terms all refer to the fragmentation of production of a final output into geographically dispersed task-based production, which is enabled by the reduction in logistics costs and both tariff and non-tariff barriers to trade. Consequently, trade has become even more important for manufacturing because not only are manufactured final goods traded, intermediate goods embodied with production tasks are increasingly traded as well.

Against such a background, it may no longer be appropriate to think of technological progress as a self-contained process that happens within a certain industry of a country. Technological progress can begin from specialization in certain production tasks instead of requiring the knowledge for the entire bundle of tasks that constitute the final output. Countries that are seemingly engaged in the same industries may in fact perform very different production tasks. Therefore, if one is interested in a country's technological capability and position in the global value chain, it is not enough to just look at measures such as high-tech industry shares or high-tech export shares unless highly disaggregated product-level or industry-level data are available. To reflect the new reality, this study looked at shares of compensation for various inputs, which are closely related to a country's major types of production activities and production structure. The information about major types of production activities and production structure will then reflect a country's technological capability and position in the global value chain.

In the empirical part of this study, data from the World Input and Output Database are used to obtain the shares of compensation for various inputs in 40 countries over the period 1995 to 2008. I classify these 40 countries into four groups according to their respective patterns of shares of compensation for inputs. Interestingly, one group of countries identified are developed countries that continue to experience increasing shares of compensation to capital and increasing shares of compensation to high-skill labour. The reason for this phenomenon may be that these countries have grown into suppliers of high-tech and capital-intensive intermediate goods in global value chains. This finding is consistent with the finding in the Industrial Development Report 2009

(UNIDO, 2009). The report argues that although the popular picture of trade in tasks is one of developed country firms outsourcing intermediate inputs from developing country suppliers, this prototype is not a precise one. Instead, the level and growth of outsourcing are found to be lowest in OECD countries according to the measure used in the report. The finding in this study provides a potential explanation for the UNIDO (2009) finding in that *net* outsourcing activities may not be significant in some OECD countries because the world in fact outsources the production of high-tech intermediate goods to a number of OECD countries.

In order to interpret the empirical findings, I adapt a theoretical model from Acemoglu and Autor (2011). This adapted model can capture the changing shares of compensation for various inputs when a country's position along the value chain changes. It provides the theoretical foundation for using the shares of compensation for various inputs to examine a country's changing position in the global value chain. Although this study does not discuss what factors are driving changing positions in the global value chain and how a changing position in the global value chain impacts on growth performance, it provides an analytical framework for capturing the changing positions of countries in the global value chain. This provides the groundwork for future analyses where I intend to probe how movements along the global value chain take place and how these movements affect economic growth.

The chapter proceeds as follows. Section 6.2 presents some empirical findings about the shares of compensation to various inputs and the classification of country groups according to countries' distinctive performances in terms of production structures. Section 6.3 introduces a theoretical model for understanding the link between a country's shares of compensation to various inputs and its position in the global value chain. The link enables us to probe into the changing positions of countries in the global value chain through the empirical observations made in Section 6.2. Section 6.4 concludes and anticipates future research directions.

6.2 Empirical evidence on countries' changing production structure

In order to measure countries' production structure, I focus on the shares of compensation to various inputs. The data are drawn from the World Input-Output Database (WIOD), which contains the socio-economic accounts for 40 major countries taking up around 80% of the global output value. In these accounts, data on hours worked by and compensation for three types of labour (high-skill, medium-skill and low-skill) and compensation for capital inputs and capital stock are reported. Since capital compensation is derived from gross value added minus labour compensation, capital compensation is thus the remuneration for all kinds of capital (such as R&D, software, database development, branding and organizational capital), mineral resources, land and financial capital (Timmer et al., 2012).

While the socio-economic accounts contain information for 35 industries, we focus on manufacturing industries that are intensive in global production sharing: "Machinery, NEC" (NACE code: 29), "Electrical and optical equipment" (NACE code: 30) and "Transport equipment" (NACE code: 31) in this study. This choice is made because this study is particularly interested in the impact of global production sharing on the production structure of industries in various countries. Although the great unbundling of production is prevalent and deepening (Baldwin 2011), it does not mean that all industries actively participate in it. It is therefore important that industries that are intensive in global production sharing are examined. Athukorala (2010) identifies the following product categories that are intensive in production sharing. They include office machines and automatic data processing (SITC 75), telecommunication and sound recording equipment (SITC 76), electrical machinery (SITC 77), road vehicles (SITC 78), professional and scientific equipment (SITC 87) and photographic apparatus (SITC 88). Since the data used in this study are based on the International Standard Industrial Classification Revision 3 (ISIC rev.3) instead of SITC, I choose the two-digit industries in ISIC rev. 3 that roughly correspond to the industries identified in Athukorala (2010) as the focus of this study.

I examine the compensation for capital, high-skill labour, medium-skill labour and low-skill labour as four respective shares in the value added of the three industries across 40 countries during 1995-2008. Since the financial crisis in 2009 may have a sudden and unusual impact on the factor income distribution, data in 2009 are excluded despite their availability. After careful classification, it is found that countries can be categorized into four types according to their distinctive patterns of capital compensation and labour compensation as shares of total value-added in three industries intensive in global production sharing. The results are presented as follows and in Table 6-1 as well:

Group 1:

Australia, the United States, Japan, Germany, Korea, Taiwan, Italy, Denmark, Austria, Ireland, Luxembourg

Share of capital compensation increased. Share of compensation to low-skill labour decreased. Share of compensation to medium-skill labour either increased or decreased. Share of compensation to high-skill labour increased.

Group 2:

Sweden, Britain, Greece, Canada, Finland, Romania, Czech Republic, France, Netherlands and Belgium

Share of capital compensation decreased. Share of compensation to low-skill labour decreased. Share of compensation to medium-skill labour either increased or decreased. Share of compensation to high-skill labour increased.

Group 3:

China, Mexico, India, Indonesia, Hungary, Russia, Slovakia, Slovenia, Portugal, Poland

Share of capital compensation increased. Share of compensation to low-skill labour decreased. Share of compensation to medium-skill labour slightly decreased or was stable. Share of compensation to high-skill labour slightly increased or was stable or decreased.

Group 4:

Brazil, Turkey, Cyprus, Lithuania, Estonia, Latvia, Spain

These countries' patterns of production structures are not clear and no common trends could be extracted.

To summarize the above empirical findings about the shares of compensation to various inputs in the three industries across 40 countries, I make the following hypothesis to link countries' positions in the global value chain with countries' production structures: during the period 1995-2009, the 40 countries can be roughly classified into four groups.

The first group is composed of countries that are developed countries and may have increasingly specialized in the part of production that is of high-technology content and have grown into suppliers of these high-tech intermediate inputs to other countries. In terms of high-tech intermediate goods, the relationship between these countries and other countries can be likened to one between a hub and its spokes. While this small group of countries is at a high stage of development, they continue to maintain a major manufacturing base and a role of technology leadership in high-tech manufacturing activities. Hence, we can see from their factor income distributions that capital compensation in these countries and especially in the high-tech industries of these countries rose during 1995-2009.

The second group of countries is composed of developed countries that have experienced moving production offshore for high-tech intermediate googds. Capital compensation in these developed countries decreased significantly and persistently, which is in stark contrast to the performance of capital compensation in countries in Group 1. Compensation to high-skill labour in countries in the second group of countries rose sharply. All these aspects suggest that these countries may be moving more and more towards complex production activities that rely mainly on human capital such as product design and R&D and away from the physical production of products. The production offshoring of high-tech goods is more intense than the production offshoring of low-tech goods in these countries.

The third group of countries is composed of developing countries that have been experiencing industrialization. Capital compensation in these countries rose rapidly and persistently. Despite their industrialization and catch-up, these countries are still technology followers. They rely more on foreign sources for high-tech intermediate inputs than for low-tech intermediate inputs and this reflects their comparative disadvantage in high-tech intermediate goods. The compensation to high-skill labour in these economies grew slowly or stagnated and this is consistent with a production structure that requires less input from high-skill labour and is therefore less technology intensive. In the fourth group of countries, the patterns of factor income distribution are less clear and cannot be easily identified. Correspondingly, it implies that the mechanisms that drive evolution of factor income distributions in these countries are more complex and a straightforward explanation may be unlikely.

With these hypotheses in mind, we will move to the next section where a theoretical model describing countries' engagement in global production sharing will be adopted to examine whether the relationship between countries' positions in the global value chain and countries' production structures can be established.

6.3 A simple theoretical model adapted from Acemoglu and Autor (2011)

In this section, I present a simple theoretical model to explain how countries' engagement and positions in the global value chain is related with countries' production structures. With this model, we will be able to understand the empirical patterns of countries' production structures in light of it being driven by the evolving positions of countries in the global value chain. This model is an extension of the Ricardian Model of the labour market developed in Acemoglu and Autor (2011). The major innovation of my extension is to change the production function of each task service from being a linear combination of various types of labour and capital inputs to being a linear combination of Leontief production functions.

Although the adaptation is a small step from the original model in Acemoglu and Autor (2011), the implication of taking this step is significant. The motivation for making this change is to enable a simultaneous examination of the patterns of shares of compensation to three types of labour and capital when countries' positions in the global value chain change. In contrast, in Acemoglu and Autor (2011), the aim is to explain the evolution of labour market outcomes in the U.S. and the advanced European countries. Their study carefully examines the relationship between wages and factor-augmenting technological changes, the implications of the adoption of human-replacing machines in production, and the influences from production offshoring to relative wages and employment in tasks of various degrees of complexity.

In Acemoglu and Autor (2011), due to the fact that labour inputs and capital input are separate in the production function, each task service is produced solely by labour or solely by capital in equilibrium. Thus the role of capital in their original model is one that reflects the substitution of machines for routine tasks that used to be performed by labour. When production offshoring is discussed in their model, not much attention is given to capital since the model cannot examine the changing capital and labour shares at the same time. Therefore, if one hopes to provide a more satisfactory explanation for some noteworthy patterns of the shares of compensation to capital and the three types of labour shown in the next section, it is necessary to alter the production function to allow for this consideration.

The Acemoglu and Autor (2011) model features the separate roles of "tasks" and "skills" and this is a significant deviation from the canonical models (Autor et al., 1998, 2008). In the canonical models, the mapping between skills and tasks is one-to-one, that is, high- (medium or low-) skill workers will definitely perform tasks of high (medium or low) complexity. In the Acemoglu and Autor (2011) model, skills are defined as workers' endowment or inner capabilities of performing various tasks. Tasks are defined as units of work activity that compose the production process of the final product. Each task can be performed by high-, medium- or low- skill workers or by machines, but the comparative advantages of skill groups differ across tasks. The structure of comparative advantage determines by whom (high-, medium- or low- skill labours) each task is performed. In other words, skills are applied in production after they are allocated to various tasks, while in the canonical models, the mapping between skills and tasks are one-to-one and skills directly produce output.

If one thinks more carefully about the relationship between skills and tasks, it is reasonable to argue that workers of different skill levels have capabilities to work with various types of capital. These skills are then applied to the production of various tasks. For example, low-skill labour works with machines such as those found on assembly lines; medium-skill labour works with machine tools; and high-skill labour mainly relies on their knowledge and works on product design, product quality improvement and assessing market needs. Therefore, in my adapted model, the production function of each task service has three components. The first component is a Leontief production function that is used to describe the complementary relationship between low-skill labour and the certain types of machines this labour works with. This set of machines include, for example, manufacturing equipment and facilities on the assembly line. The second component is another Leontief production function that is used to describe the complementary relationship between medium-skill labour and the certain types of machines this labour works with. This set of machines is more complex and the use of them is more difficult to master. These machines include, for instance, machine tools and Information and Communications Technology (ICT). The third component is a linear term of high-skill labour. The case of high-skill labour is different from those of medium-skill and low-skill labours since the main skills of high-skill labour lie not in the ability to work with machines but in the ability to use knowledge to generate process and product innovation. Therefore, high-skill labour enters the production function as a linear term. Compared with the original model in Acemoglu and Autor (2011) in which all three types of labour and capital enter as linear terms into the production function of each task service, the approach adopted in this study is clearer about what "skills" really are and allows for an examination of the influence of global production sharing on income shares of different types of labours and capital simultaneously.

Assume that the final good in an industry is produced by the combination of a continuum of tasks represented by the unit interval [0, 1]. That is, the production of the final good is regarded as a value chain that begins from 0 and ends at 1. Along the value chain, the tasks can be ranked by their complexity, with 0 denoting the least complex task and 1 denoting the most complex task and the higher the i index, the more complex the task is. For example, the least complex task in the production chain of the final output in an industry may be to assemble components, while the most complex task may be to draw the blueprint of the product and to improve the product design for new market needs. In between are production activities such as the production of core intermediate inputs or specialized inputs.

$$Y = exp[\int_0^1 lny(i)di] \tag{6.1}$$

where Y denotes the final good and $y(i)$ denotes the production level of task i.

Each task has the following production function:

$$y(i) = \min[A_{m_1}\alpha_{m_1}(i)m_1(i),\ \alpha_{m_1}(i)\, B_{k_1}\, k_1(i)] + \min[A_{m_2}\alpha_{m_2}(i)m_2(i),\ \alpha_{m_2}(i)\, B_{k_2}\, k_2(i)] + A_h\alpha_h(i)h(i) \tag{6.2}$$

where $m_1(i)$ represents low-skill labour in the economy, $m_2(i)$ represents medium-skill labour in the economy and $h(i)$ represents high-skill labour in the economy. $k_1(i)$ refers to machines/capital that are used by low-skill labour and $k_2(i)$ refers to machines/capital that are used by medium-skill labour. The A terms represent factor-augmenting technology for labour of various skills and the B terms represent factor-augmenting technology for various machines.

As discussed above, there exist three technologies that could potentially produce each task service. These three technologies reflect the endowment or capabilities of labour of different skill levels. The first technology is captured by a Leontief production function $\min[A_{m_1}\alpha_{m_1}(i)m_1(i), B_{k_1}\alpha_{m_1}(i)k_1(i)]$ and reflects the capability of low-skill workers to use manufacturing equipment and facilities on the assembly line to produce output. The second technology is captured by a Leontief production function $\min[A_{m_2}\alpha_{m_2}(i)m_2(i),\ B_{k_2}\alpha_{m_2}(i)k_2(i)]$ and reflects the capability of medium-skill workers to work with more complex machines such as machine tools and ICT equipment to produce output. The third technology is a linear production function $A_H\alpha_H(i)H(i)$, which reflects the capability of high-skill workers to use their knowledge to find out market needs, conduct innovation and streamline the production process.

We follow Acemoglu and Autor (2011) in making the following assumption:

Assumption 1: $\alpha_{m_1}(i)/\alpha_{m_2}(i)$ and $\alpha_{m_2}(i)/\alpha_h(i)$ are continuously differentiable and strictly decreasing. That is, as the task becomes more complex, the productivity of low-skill (middle-skill) labour relative to that of medium-skill (high-skill) labour falls.

$\alpha_{m_1}(i)$, $\alpha_{m_2}(i)$ and $\alpha_h(i)$ are the task productivity schedules that describe the productivity of low-, medium- and high-skill workers when they are assigned to different tasks. The task productivity schedules described in Assumption 1 reflect the comparative advantages of workers with different skill levels in tasks of various degrees of complexity. While the production function (6.2) suggests that each task can be performed by low-, medium- or high-skill workers, the task productivity schedule describes how various types of workers and the machines they specialize in should be allocated to various tasks according to the workers' respective comparative advantages in undertaking each task. High-skill workers have a comparative advantage in the most complex tasks, low-skill workers have a comparative advantage in the least complex tasks and medium-skill workers have a comparative advantage in tasks of medium complexity. As seen from Eq. 6.2, it is also assumed that $k_1(i)$ and $k_2(i)$ have the same task productivity schedules, $m_1(i)$ and $m_2(i)$ respectively. Since a low-skill worker's endowment lies in the ability to work with manufacturing equipment such as assembly lines and a medium-skill worker's endowment lies in the ability to work with more complex machines such as machine tools and ICT equipments, it is reasonable that $k_1(i)$ $(k_2(i))$ and $m_1(i)$ $(m_2(i))$ share the task productivity schedules.

Factor market clearing conditions:

$\int_0^1 m_1(i)di \leq M_1$, $\int_0^1 m_2(i)\, di \leq M_2$, $\int_0^1 k_1(i)di \leq K_1$, $\int_0^1 k_2(i)\, di \leq K_2$,

$\int_0^1 h(i)\, di \leq H$. (6.3)

Where M_1, M_2 and H are respectively the total numbers of low-, medium- and high-skill labours in a country. K_1 and K_2 are respectively the total amount of capital associated with low- and medium-skill labours in a country. M_1, M_2, H, K_1 and K_2 are all constants.

Initial equilibrium:

Lemma 1: In any equilibrium, there exist I_L and I_H such that $0 < I_L < I_H < 1$ and for any $i < I_L$, $m_2(i) = k_2(i) = h(i) = 0$, for any $i \in (I_L, I_H)$, $m_1(i) = k_1(i) = h(i) = 0$, and for any $i > I_H$, $m_1(i) = k_1(i) = m_2(i) = k_2(i) = 0$.

The proof of this lemma is straightforward:

Due to the law of one price for the same factor in competitive equilibrium, all task performed by low-skill workers (medium-skill workers, high-skill workers) must provide them the same wage rate, $w_{m_1}(w_{m_2}, w_h)$.

The unit cost of task service i when the Leontief technology with low-skill labour is used is:

$$C_{m_1}(i) = \frac{w_{m_1}}{A_{m_1} * \alpha_{m_1}(i)} + \frac{r_{k_1}}{B_{k_1} * \alpha_{m_1}(i)} \quad (6.4)$$

where $C_{m_1}(i)$ is the unit cost, w_{m_1} is the wage rate of low-skill workers, r_{k_1} is the price of equipment to be used together with low-skill workers in production.

The unit cost of task service i when the Leontief technology with medium-skill labour is used is:

$$C_{m_2}(i) = \frac{w_{m_2}}{A_{m_2} * \alpha_{m_2}(i)} + \frac{r_{k_2}}{B_{k_2} * \alpha_{m_2}(i)} \quad (6.5)$$

where $C_{m_2}(i)$ is the unit cost, w_{m_2} is the wage rate of medium-skill labour, r_{k_2} is the price of equipment to be used together with medium-skill labour in production.

The unit cost when high-skill labour is used is:

$$C_h(i) = \frac{w_h}{A_h * \alpha_h(i)} \tag{6.6}$$

where $C_h(i)$ is the unit cost, w_h is the wage rate of high-skill labour.

The no arbitrage condition implies that given the prices of three types of labour, w_{m_1}, w_{m_2} and w_h and the prices of two types of capital, r_{k_1} and r_{k_2}, the costs of producing a unit of task service I_L using either the Leontief technology with low-skill labour or the Leontief technology with medium-skill labour should be the same. Due to the fact that $\alpha_{m_1}(i)/\alpha_{m_2}(i)$ is decreasing in i, it will cost strictly less to perform task $i > I_L$ using medium-skill workers than with low-skill workers. Formally:

$$C_{m_1}(I_L) = C_{m_2}(I_L)$$

$$\frac{w_{m_1}}{A_{m_1} * \alpha_{m_1}(I_L)} + \frac{r_{k_1}}{B_{k_1} * \alpha_{m_1}(I_L)} = \frac{w_{m_2}}{A_{m_2} * \alpha_{m_2}(I_L)} + \frac{r_{k_2}}{B_{k_2} * \alpha_{m_2}(I_L)}$$

Since $\alpha_{m_1}(i)/\alpha_{m_2}(i)$ is decreasing in i, when $i > I_L$,

$$\frac{w_{m_1}}{A_{m_1} * \alpha_{m_1}(i)} + \frac{r_{k_1}}{B_{k_1} * \alpha_{m_1}(i)} > \frac{w_{m_2}}{A_{m_2} * \alpha_{m_2}(i)} + \frac{r_{k_2}}{B_{k_2} * \alpha_{m_2}(i)}$$

Therefore $C_{m_1}(i) > C_{m_2}(i)$.

The same argument applies to the comparison of unit production costs of task services above the threshold I_H by medium- and high-skill workers.

In equilibrium, the tasks on the interval [0, 1] will be partitioned into three sets. The least complex set is produced by the Leontief production technology with low-skill workers. The medium complex set is produced by the Leontief production technology with medium-skill workers. The most complex set is produced by high-skill workers.

Let $p(i)$ denote the price of services of task i. The price of the final good is chosen as numeraire and we therefore have:

$$\exp[\int_0^1 lnp(i)di] = 1 \tag{6.7}$$

Under competitive equilibrium, when $i < I_L$, $p(i) = C_{m_1}(i) = \frac{w_{m_1}}{A_{m_1} * \alpha_{m_1}(i)} + \frac{r_{k_1}}{\beta_{k_1} * \alpha_{m_1}(i)}$.

Then $p(i) * \alpha_{m_1}(i) = \frac{w_{m_1}}{A_{m_1}} + \frac{r_{k_1}}{B_{k_1}}$ for $\forall i \in [0, I_L]$. (6.8)

Hence for $\forall i, i' \in [0, I_L]$, $p(i) * \alpha_{m_1}(i) = p(i') * \alpha_{m_1}(i') \equiv P_{m_1}$. (6.9)

Similarly, we have for $\forall i, i' \in [I_L, I_H]$, $p(i) * \alpha_{m_2}(i) = p(i') * \alpha_{m_2}(i') \equiv P_{m_2}$ (6.10)

For $\forall i, i' \in [I_H, 1]$, $p(i) * \alpha_h(i) = p(i') * \alpha_h(i') \equiv P_h$. (6.11)

The Cobb-Douglas technology (the unitary elasticity of substitution between tasks) in (6.1) implies equal expenditure across all tasks: $p(i) * y(i) = p(i') * y(i')$ for any i and i'.

Since under competitive equilibrium $\int_0^1 p(i)y(i) = P * Y$ and $\text{P} \equiv 1$, we have

$p(i)y(i) = Y$, $\forall i \in [0.1]$ (6.12)

For $\forall\, i, i' < I_L$, $p(i) * A_{m_1} * \alpha_{m_1}(i) * m_1(i) = p(i') * A_{m_1} * \alpha_{m_1}(i') * m_1(i)$.

Hence for $\forall\, i, i' < I_L$, $m_1(i) = m_1(i')$.

Thus we have $m_1(i) = \frac{M_1}{I_L}$ $\forall\, i \in [0, I_L]$. (6.13)

By the same logic, $m_2(i) = \frac{M_2}{I_H - I_L}$ $\forall\, i \in [I_L, I_H]$. (6.14)

$h(i) = \frac{H}{1 - I_H}$ for $\forall\, i \in [I_H, 1]$. (6.15)

Also, we know for $I_L < i < I_H < i'$, $\text{p}(i) * y(i) = p(i') * y(i')$. Then

$p(i) * A_{m_1} * \alpha_{m_1}(i) * m_1(i) = p(i') * A_{m_2} * \alpha_{m_2}(i') * m_2(i)$.

Hence, $\frac{P_{m_1} * A_{m_1} * M_1}{I_L} = \frac{P_{m_2} * A_{m_2} * M_2}{I_H - I_L}$.

Then $\frac{P_{m_2}}{P_{m_1}} = (\frac{A_{m_2} M_2}{I_H - I_L})^{-1} (\frac{A_{m_1} M_1}{I_L})$. (6.16)

Similarly, $\frac{P_h}{P_{m_2}} = (\frac{A_h H}{1 - I_H})^{-1} (\frac{A_{m_2} M_2}{I_H - I_L})$. (6.17)

The no arbitrage condition on the two threshold values I_L and I_H implies that the unit costs of production by different types of labour should be the same on the threshold:

$$C_{m_1}(I_L) = C_{m_2}(I_L)$$

and

$$C_{m_2}(I_H) = C_h(I_H)$$

Therefore we have $\frac{w_{m1}}{A_{m_1} * \alpha_{m_1}(I_L)} + \frac{r_{k_1}}{B_{k_1} * \alpha_{m_1}(I_L)} = \frac{w_{m2}}{A_{m_2} * \alpha_{m_2}(I_L)} + \frac{r_{k_2}}{B_{k_2} * \alpha_{m_2}(I_L)}$.

$$\frac{\alpha_{m_2}(I_L)}{\alpha_{m_1}(I_L)} = \frac{\frac{w_{m_2}}{A_{m_2}} + \frac{r_{k_2}}{B_{k_2}}}{\frac{w_{m_1}}{A_{m_1}} + \frac{r_{k_1}}{B_{k_1}}} \quad (6.18)$$

That is, the relative productivity of medium-skill to low-skill labour is equal to the relative factor payments of medium-skill to low-skill labour and associated capital adjusted by their respective factor augment technology parameters.

Eq. 6.17 together with Eq. 6.8, implies that $\frac{\alpha_{m_2}(I_L)}{\alpha_{m_1}(I_L)} = \frac{P_{m_2}}{P_{m_1}}$ (6.19)

And because we have Eq. 6.16, then $\frac{\alpha_{m_2}(I_L)}{\alpha_{m_1}(I_L)} = (\frac{A_{m_2} M_2}{I_H - I_L})^{-1} (\frac{A_{m_1} M_1}{I_L})$ (6.20)

Or $\frac{A_{m_2} \alpha_{m_2}(I_L) M_2}{I_H - I_L} = \frac{A_{m_1} \alpha_{m_1}(I_L) M_1}{I_L}$ (6.21)

Analogously, we have $\frac{\alpha_H(I_H)}{\alpha_{m_2}(I_H)} = \frac{\frac{w_h}{A_h}}{\frac{w_{m_2}}{A_{m_2}} + \frac{r_{k_2}}{B_{k_2}}}$ (6.22)

and $\frac{A_{m_2} \alpha_{m_2}(I_H) M_2}{I_H - I_L} = \frac{A_h \alpha_h(I_H) H}{1 - I_H}$ (6.23)

Assumption 2: The output of the Leontief production functions are allocated between the labour input and the capital input. The share allocated to labour input is s and the share allocated to capital input is $(1 - \text{s})$.

For each unit of output from the Leontief production function, $\min[A_{m_1} \alpha_{m_1}(i) m_1(i), B_{k_1} \alpha_{m_1}(i) k_1(i)]$, a proportion s_1 is the compensation to the corresponding labour input. Hence $w_{m_1} = \frac{s * p(i) * 1}{\frac{1}{A_{m_1} * \alpha_{m_1}(i)}} = s_1 * p(i) * A_{m_1} * \alpha_{m_1}(i)$ and

$$r_{k_1} = \frac{(1-s) * p(i) * 1}{\frac{1}{B_{k_1} * \alpha_{m_1}(i)}} = (1 - s_1) * p(i) * B_{k_1} * \alpha_{m_1}(i)$$

Thus $\frac{w_{m_1}}{r_{k_1}} = \frac{s_1 * A_{m_1}}{(1-s_1)B_{k_1}}$ (6.24)

Also, $\frac{w_{m_2}}{r_{k_2}} = \frac{s_2 * A_{m_2}}{(1-s_2)B_{k_2}}$ (6.25)

That is to say, the ratio between the wage rate and the capital price within the same Leontief production function is constant.

Proposition 1: There exists a unique equilibrium summarized by $(I_L, I_H, P_L, P_M, P_H, w_L, w_M, w_H)$ given by Eqs. 6.16, 6.17, 6.19, 6.20, 6.21, 6.22, 6.23 and 6.24.

With the theoretical model specified above, I attempt an explanation for the empirical observations made in Section 6.2.

Based on the above theoretical model, I can now examine the relationship between a country's position in the global value chain and the country's production structure as captured by the shares of compensation to various inputs. In Section 6.2, we have identified three groups of countries each of which has a distinctive trend in share of compensation to various inputs and a group of countries with no clear trend. For the three types of countries, I have made hypotheses about how these countries' positions in the global value chains have changed and how this impacted on the observed production structure. Now I will resort to the theoretical model to examine whether the link between the position in the global chain and the production structure indeed holds as suggested by the hypotheses made in Section 6.2. When the results depend on certain conditions, I will also spell out the conditions under which the hypotheses will hold.

Type 1 country:

A country of the first type offshores the production of the least complex tasks in its economy but at the same time increasingly specializes in more complex tasks in its economy such as the production of high-tech intermediate goods as well as the most complex jobs such as product innovation and design. As shown in Section 6.2, countries of this type include Japan, Germany, Korea, Taiwan and the United States.

In order to see how the production structure of this type of country changes in response to their changing position in the global value chain, we conduct the following analysis.

We take logs in Eqs. 6.19 and 6.20:

$$lnA_{m_2-} - lnA_h + N_H(I_H) + lnM_2 - lnH - \ln(I_H - I_L) + \ln(1 - I_H) = 0$$

$$lnA_{m_1-} - lnA_{m_2} + B_L(I_L) + lnM_1 - lnM_2 + \ln(I_H - I_L) - \ln(I_L) = 0$$

where $B_H(I) \equiv ln\alpha_{m_2}(I) - ln\alpha_{m_1}(I)$ and $B_L(I) \equiv ln\alpha_{m_1}(I) - ln\alpha_{m_2}(I)$, both of which are strictly decreasing due to Assumption 1.

Now consider the impact of production offshoring of the least complex tasks. Suppose tasks in the range $[I', I'']\complement [0, I_L]$ are now offshored. We begin the analysis with $[I', I''] = \emptyset$ and then the set of tasks offshored expands to an interval of size ε, where ε is small.

Under this situation, we have

$$lnA_{m_2-} - lnA_h + B_H(I_H) + lnM_2 - lnH - \ln(I_H - I_L) + \ln(1 - I_H) = 0 \qquad (6.26)$$

$$lnA_{m_1-} - lnA_{m_2} + \beta_L(I_L) + lnM_1 - lnM_2 + \ln(I_H - I_L) - \ln(I_L - \varepsilon) = 0 \qquad (6.27)$$

Total differentiation of Eq. 6.26 and Eq. 6.27, we obtain:

$$\begin{pmatrix} \beta_H'(I_H) - \frac{1}{I_H - I_L} - \frac{1}{1 - I_H} & \frac{1}{I_H - I_L} \\ \frac{1}{I_H - I_L} & \beta_L'(I_L) - \frac{1}{I_H - I_L} - \frac{1}{I_L} \end{pmatrix} \begin{pmatrix} dI_H \\ dI_L \end{pmatrix} = \begin{pmatrix} 0 \\ -\frac{1}{I_L} \end{pmatrix} d\varepsilon$$

Hence,

$$\frac{dI_H}{d\varepsilon} = \frac{1}{I_H - I_L} * \frac{1}{\Delta} * \frac{1}{I_L} > 0$$

$$\frac{dI_L}{d\varepsilon} = -(\beta_H'(I_H) - \frac{1}{I_H - I_L} - \frac{1}{1 - I_H}) * \frac{1}{\Delta} * \frac{1}{I_L} > 0$$

$$\frac{d(I_H - I_L)}{d\varepsilon} = \left(\beta_H'(I_H) - \frac{1}{1 - I_H}\right) * \frac{1}{\Delta} * \frac{1}{I_L} < 0$$

where Δ is the determinant of the matrix and is positive.

Therefore, when the least complex tasks are offshored, I_L and I_H increase while $(I_H - I_L)$ decreases. Under Assumption 1, $\frac{\alpha_{m_2}(I_L)}{\alpha_{m_1}(I_L)}$ and $\frac{\alpha_H(I_H)}{\alpha_{m_2}(I_H)}$ will both increase.

According to Eqs 6.18 and 6.22, $\frac{\frac{w_{m_2}}{A_{m_2}}+\frac{r_{k_2}}{B_{k_2}}}{\frac{w_{m_1}}{A_{m_1}}+\frac{r_{k_1}}{B_{k_1}}}$ and $\frac{\frac{w_h}{A_h}}{\frac{w_{m_2}}{A_{m_2}}+\frac{r_{k_2}}{B_{k_2}}}$ will also increase. It is assumed that the ratio between the wage rate and the capital price within the same Leontief production function is constant (Eqs. 6.24 and 6.25). Also, the numbers of three types of workers (M_1, M_2 and H) and the amount of two types of capital (K_1 and K_2) are assumed to fixed[37]. Hence, the share of compensation to high-skill workers will increase. The share of compensation to medium-skill workers may increase or decrease. The share of compensation to low skill workers will decrease. The share of compensation to capital will increase (decrease) when $\frac{s_2 * A_{m_2}}{(1-s_2)B_{k_2}}$ is not very large (large enough), which is likely to hold when the relative productivity of labour to capital $\frac{A}{B}$ is not very large (large enough) in the production technology used by medium-skill labours. The derivations of these findings are available in Appendix 6.

Type 2 country:

A country of the second type is experiencing offshoring of tasks of medium-complexity. This could be a developed country that experiences production offshoring in high-tech intermediate goods. Capital compensation in these developed countries decreases significantly and persistently, while compensation to high-skill workers rises sharply. All these aspects suggest that this country may be moving more and more towards product design and R&D activities and away from the physical production of high-tech intermediate goods. We have seen in Section 6.2 that countries of this type include Britain, Sweden, Brazil, Greece, Canada, Finland, Netherlands and Denmark.

Again we perform an analysis in order to see how the production structure of this type of country changes.

Tasks offshored expands to an interval of size ε from 0, where ε is small.

[37] The responses of human capital investment and physical capital investment are not considered in this chapter. In the future, we could try to model these responses to gain more understanding of the impact from global production sharing on a country's economic structure.

Under this situation, we have

$$lnA_{m_2-} - lnA_h + \beta_H(I_H) + lnM_2 - lnH - \ln(I_H - I_L - \varepsilon) + \ln(1 - I_H) = 0 \quad (6.28)$$

$$lnA_{m_1-} - lnA_{m_2} + \beta_L(I_L) + lnM_1 - lnM_2 + \ln(I_H - I_L - \varepsilon) - \ln(I_L) = 0 \quad (6.29)$$

Then

$$\begin{pmatrix} \beta_H'(I_H) - \frac{1}{I_H - I_L} - \frac{1}{1 - I_H} & \frac{1}{I_H - I_L} \\ \frac{1}{I_H - I_L} & \beta_L'(I_L) - \frac{1}{I_H - I_L} - \frac{1}{I_L} \end{pmatrix} \begin{pmatrix} dI_H \\ dI_L \end{pmatrix} = \begin{pmatrix} -\frac{1}{I_H - I_L} \\ \frac{1}{I_H - I_L} \end{pmatrix} d\varepsilon$$

$$\frac{dI_H}{d\varepsilon} = \frac{1}{I_H - I_L} * \frac{1}{\Delta} * [\beta_L'(I_L) + \frac{1}{I_L}] > 0$$

$$\frac{dI_L}{d\varepsilon} = \frac{1}{I_H - I_L} * \frac{1}{\Delta} * \left[\beta_H'(I_H) + \frac{1}{1 - I_H}\right] < 0$$

$$\frac{d(I_H - I_L)}{d\varepsilon} = \frac{1}{I_H - I_L} * \frac{1}{\Delta} * \left[-\beta_L'(I_L) - \beta_H'(I_H) + \frac{1}{1 - I_H} + \frac{1}{I_L}\right] > 0$$

Therefore, when the medium complex tasks are offshored, I_L decreases and I_H increases while $(I_H - I_L)$ increases. Under Assumption 1, $\frac{\alpha_{m_2}(I_L)}{\alpha_{m_1}(I_L)}$ will decrease and $\frac{\alpha_H(I_H)}{\alpha_{m_2}(I_H)}$ will increase. According to Eqs. 6.18 and 6.22, $\frac{\frac{w_{m_1}}{A_{m_1}} + \frac{r_{k_1}}{B_{k_1}}}{\frac{w_{m_2}}{A_{m_2}} + \frac{r_{k_2}}{B_{k_2}}}$ and $\frac{\frac{w_h}{A_h}}{\frac{w_{m_2}}{A_{m_2}} + \frac{r_{k_2}}{B_{k_2}}}$ will increase. The share of compensation to medium-skill workers will decrease. The share of compensation to low-skill labour will decrease if $\frac{w_h}{w_{m_1}}$ grows large enough. The share of compensation to high-skill workers will increase if $\frac{w_h}{w_{m_1}}$ grows large enough. The share of compensation to capital will decrease (increase) when $\frac{s_1 * A_{m_1}}{(1-s_1)B_{k_1}}$ is large enough (not very large), which is likely to hold when the relative productivity of labour to capital $\frac{A}{B}$ is large enough (not very large) in the production technology used by low-skill labours.

Type 3 country:

Countries of this type are developing countries where tasks of medium complexity are increased. This could be a country that are experiencing industrialization. Capital compensation in these countries rises rapidly and persistently. These countries become increasingly important producers of the offshored simple tasks from Type 1 countries. Although these tasks such as assembly are the least complex ones in Type 1 countries, they are of medium complexity in Type 3 countries. The reason is that these tasks require more complex technologies and are more capital intensive compared with agricultural activities in Type 3 countries. As shown in Section 6.2, this third type covers China, Indonesia, Slovenia, Russia, Portugal, Mexico, India, Bulgaria, Slovakia, Poland and Hungary.

What happens to production structures in these countries can be analyzed as follows:

These countries begin to produce more and more tasks in the range $[I_L, I_H]$. This range, say, expands by an interval of size ε, where ε is small.

$$lnA_{m_2-} - lnA_h + \beta_H(I_H) + lnM_2 - lnH - \ln(I_H - I_L + \varepsilon) + \ln(1 - I_H) = 0 \quad (6.30)$$

$$lnA_{m_1-} - lnA_{m_2} + \beta_L(I_L) + lnM_1 - lnM_2 + \ln(I_H - I_L + \varepsilon) - \ln(I_L) = 0 \quad (6.31)$$

Then

$$\begin{pmatrix} \beta_H'(I_H) - \frac{1}{I_H - I_L} - \frac{1}{1 - I_H} & \frac{1}{I_H - I_L} \\ \frac{1}{I_H - I_L} & \beta_L'(I_L) - \frac{1}{I_H - I_L} - \frac{1}{I_L} \end{pmatrix} \begin{pmatrix} dI_H \\ dI_L \end{pmatrix} = \begin{pmatrix} \frac{1}{I_H - I_L} \\ -\frac{1}{I_H - I_L} \end{pmatrix} d\varepsilon$$

$$\frac{dI_H}{d\varepsilon} = -\frac{1}{I_H - I_L} * \frac{1}{\Delta} * \left[\beta_L'(I_L) + \frac{1}{I_L}\right] < 0$$

$$\frac{dI_L}{d\varepsilon} = -\frac{1}{I_H - I_L} * \frac{1}{\Delta} * \left[I_H'(I_H) + \frac{1}{1 - I_H}\right] > 0$$

$$\frac{d(I_H - I_L)}{d\varepsilon} = -\frac{1}{I_H - I_L} * \frac{1}{\Delta} * \left[-\beta_L'(I_L) - \beta_H'(I_H) + \frac{1}{1 - I_H} + \frac{1}{I_L}\right] < 0$$

Therefore, when the opportunities to perform medium complex tasks expand, I_L increases and I_H decreases while $(I_H - I_L)$ decreases. Under Assumption 1, $\frac{\alpha_{m_2}(I_L)}{\alpha_{m_1}(I_L)}$ will increase and $\frac{\alpha_H(I_H)}{\alpha_{m_2}(I_H)}$ will decrease. According to Eqs, 6.18 and 6.22, $\frac{\frac{w_{m_2}}{A_{m_2}} + \frac{r_{k_2}}{B_{k_2}}}{\frac{w_{m_1}}{A_{m_1}} + \frac{r_{k_1}}{B_{k_1}}}$ will increase and $\frac{\frac{w_h}{A_h}}{\frac{w_{m_2}}{A_{m_2}}+\frac{r_{k_2}}{\beta_{k_2}}}$ will decrease. The share of compensation to medium-skill workers will increase. The share of compensation to low-skill workers will decrease if $\frac{w_h}{w_{m_1}}$ is not decreased significantly. The share of compensation to high-skill workers will increase if $\frac{w_h}{w_{m_1}}$ grows large enough. The share of compensation to capital will decrease when. The share of compensation to capital will increase (decrease) when $\frac{s_2 * A_{m_2}}{(1-s_2)B_{k_2}}$ is not very large (large enough), which is likely to hold when the relative productivity of labour to capital $\frac{A}{B}$ is not very large (large enough) in the production technology used by medium-skill labours.

6.4 Conclusion

Production is increasingly organised in the form of global value chains in which production tasks fragment across borders. Since countries that produce seemingly similar products could in fact perform different production tasks, it is difficult to precisely gauge a country's performance in technological progress unless we have highly disaggregated product-level or industry-level data. Therefore, instead of looking directly at the industry structure or output structure of a country, I focus on the shares of compensation for various inputs into production, which provides information about the types of production activities a country is engaged in. This initial effort to assess the changing positions of countries in the global value chain is the first step towards understanding technological progress in a world featuring global production networks. Further works could be done to assess the validity of the assumptions made in this chapter.

Based on data from the WIOD Database and a theoretical model adapted from Acemoglu and Autor (2011), this study sheds new light on the patterns of global production sharing and provided a typology about the evolution of countries' positions in the global value chain as detailed in Sections 6.2 and 6.3. In the future, we could extend the framework to consider issues such as the implications of various paths along the global value chain for growth performance and the factors that determine which path a country will follow.

To anticipate future research on the implication of global production sharing for long-term economic growth, we need to address the fundamental question: what is the implication of the current global pattern of trade in tasks for a country's ability and potential to achieve technological progress? In other words, to what extent will a country's current position in the global value chain influence its future position? On the one hand, the barriers of entry to a vigorous process of technological catch-up could be lower in a trade-in-task regime. It could be a daunting challenge to master all the knowledge about the vertical process that begins from raw materials and ends at the final product. In contrast, it may be easier to adopt the production technologies and learn the knowledge required for a small number of production tasks and rely on the economies of scale provided by exporting to the global market to achieve technological catch-up. In the long run, these production tasks could then become the stepping stones towards more sophisticated and technological-demanding production tasks, thus initiating a dynamic and sustainable process of technological catch-up.

On the other hand, however, there is also the risk that task-based production encourages countries to specialize in a narrower range of industrial production. Consequently, poor countries' specializations in low-technology, unsophisticated industrial processes tend to be reinforced (UNIDO, 2009). Since the product space that a country experiences can be a path-dependent and a low-technology industrial process provides less room and dynamism for technological progress, a country that resorts to task-based production for technological catch-up may end up being trapped in a low-technology production structure. This point links back to Chapter 4 where it was found that participation in processing trade is not beneficial for firm-level R&D investment growth. The intertwining relationship between global production sharing and technological progress is a complex and interesting topic that is well worth further research. This study is a small yet much-needed step in this line of research by starting to think about measuring countries' technological capability in the context of global production sharing.

Table 6-1 Changing production structures of countries in industries that are intensive in global production sharing

Type 1 countries: K ↑, High-skill↑, Medium-skill? Low-skill↓

type	country	capital share			high-skill labour share			medium-skill labour share			low-skill labour share		
		1995	2008	2008>1995?	1995	2008	2008>1995?	1995	2008	2008>1995?	1995	2008	2008>1995?
1	Australia	0.21	0.21	1	0.10	0.14	1	0.33	0.37	1	0.36	0.28	0
1	the U.S.	0.31	0.32	1	0.24	0.33	1	0.41	0.32	0	0.05	0.03	0
1	Japan	0.35	0.45	1	0.16	0.16	1	0.37	0.33	0	0.12	0.05	0
1	Germany	0.16	0.24	1	0.23	0.27	1	0.49	0.42	0	0.12	0.07	0
1	Korea	0.28	0.32	1	0.21	0.31	1	0.37	0.33	0	0.14	0.04	0
1	Taiwan	0.30	0.39	1	0.18	0.20	1	0.20	0.20	1	0.42	0.27	0
1	Italy	0.04	0.14	1	0.07	0.12	1	0.31	0.47	1	0.62	0.41	0
1	Denmark	0.23	0.28	1	0.15	0.20	1	0.44	0.36	0	0.18	0.17	0
1	Austria	0.28	0.36	1	0.09	0.12	1	0.51	0.44	0	0.12	0.08	0
1	Ireland	0.38	0.45	1	0.11	0.24	1	0.47	0.42	0	0.36	0.21	0
1	Luxembourg	0.24	0.37	1	0.13	0.16	1	0.25	0.28	1	0.38	0.19	0
11 countries in total													

Type 2 countries: K ↓, High-skill ↑, Medium-skill? Low-skill ↓

type	country	capital share			high-skill labour share			medium-skill labour share			low-skill labour share		
		1995	2008	2008>1995?	1995	2008	2008>1995?	1995	2008	2008>1995?	1995	2008	2008>1995?
2	Swden	0.33	0.24	0	0.09	0.15	1	0.39	0.47	1	0.19	0.14	0
2	Britain	0.28	0.10	0	0.26	0.39	1	0.30	0.15	0	0.24	0.17	0
2	Greence	0.48	0.27	0	0.11	0.13	1	0.22	0.29	1	0.48	0.27	0
2	Canada	0.38	0.25	0	0.10	0.23	1	0.48	0.51	1	0.03	0.01	0
2	Finland	0.21	0.10	0	0.16	0.24	1	0.36	0.30	0	0.21	0.10	0
2	Romania	0.41	0.25	0	0.05	0.07	1	0.10	0.11	1	0.52	0.45	0
2	Czech	0.43	0.34	0	0.06	0.10	1	0.46	0.52	1	0.05	0.04	0
2	France	0.26	0.19	0	0.19	0.29	1	0.32	0.35	1	0.24	0.16	0
2	Netherlands	0.23	0.22	0	0.13	0.23	1	0.36	0.34	0	0.28	0.22	0
4	Belgium	0.24	0.23	0	0.11	0.15	1	0.32	0.45	1	0.33	0.17	0
10 countries in total													

Note: 1. Data for Bulgaria and Malta are problematic and omitted here since negative values of shares are obtained.
2. The symbols "↑" and "↓" indicate respectively that the value of the variable is larger and smaller in 2008 than that in 1995. The symbol "~" indicates that the change is very small. The symbol "?" indicates that the direction of change is uncertain.
Source: Author's own calculation using data from the World Input-Output Database (WIOD).

Appendix 6 Derivations of the patterns of shares of income to various labours and capital in three types of countries

Based on Eqs. 6.24 and 6.25, define $q_1 \equiv \frac{w_{m_1}}{r_{k_1}} = \frac{s_1 * A_{m_1}}{(1-s_1)B_{k_1}}$ and $q_2 \equiv \frac{w_{m_2}}{r_{k_2}} = \frac{s_2 * A_{m_2}}{(1-s_2)B_{k_2}}$. That is to say, q_1 and q_2 are equal to the ratio between the wage rate and the capital price for low-skill and medium-skill labours and their associated capitals respectively.

According to Eqs. 6.24 and 6.25, $\frac{w_{m_1}}{r_{k_1}} = \frac{s_1 * A_{m_1}}{(1-s_1)B_{k_1}}$ and $\frac{w_{m_2}}{r_{k_2}} = \frac{s_2 * A_{m_2}}{(1-s_2)B_{k_2}}$.

Hence, $w_{m_1} = q_1 * r_{k_1}$ (6.32) and, $w_{m_2} = q_2 * r_{k_2}$ (6.33)

Further, $$\frac{\frac{w_{m_2}}{A_{m_2}}+\frac{r_{k_2}}{B_{k_2}}}{\frac{w_{m_1}}{A_{m_1}}+\frac{r_{k_1}}{B_{k_1}}} = \frac{(\frac{q_2}{A_{m_2}}+\frac{1}{B_{k_2}})r_{k_2}}{(\frac{q_1}{A_{m_1}}+\frac{1}{B_{k_1}})r_{k_1}} = \frac{\frac{q_2}{A_{m_2}}+\frac{1}{B_{k_2}}}{\frac{q_1}{A_{m_1}}+\frac{1}{B_{k_1}}} * \frac{r_{k_2}}{r_{k_1}} \quad (6.34)$$

and $$\frac{\frac{w_h}{A_h}}{\frac{w_{m_2}}{A_{m_2}}+\frac{r_{k_2}}{B_{k_2}}} = \frac{\frac{1}{A_h}}{\frac{w_{m_2}}{A_{m_2}}+\frac{1}{B_{k_2}}} * \frac{w_h}{r_{k_2}} \quad (6.35)$$

The share of compensation to low-skill labour is:

$$\frac{w_{m_1}*M_1}{w_h*H+w_{m_1}*M_1+w_{m_2}*M_2+r_{k_1}*K_1+r_{k_2}*K_2} = \frac{M_1}{\frac{w_h}{w_{m_1}}H+M_1+\frac{w_{m_2}}{w_{m_1}}M_2+\frac{1}{q_1}K_1+\frac{r_{k_2}}{w_{m_1}}K_2} \quad (6.36)$$

The share of compensation to medium-skill labour is:

$$\frac{w_{m_2}*M_2}{w_h*H+w_{m_1}*M_1+w_{m_2}*M_2+r_{k_1}*K_1+r_{k_2}*K_2} = \frac{M_2}{\frac{w_h}{w_{m_2}}H+M_2+\frac{w_{m_1}}{w_{m_2}}M_1+\frac{r_{k_1}}{w_{m_2}}K_1+\frac{1}{q_2}K_2} \quad (6.37)$$

The share of compensation to high-skill labour is:

$$\frac{w_h*H}{w_h*H+w_{m_1}*M_1+w_{m_2}*M_2+r_{k_1}*K_1+r_{k_2}*K_2} = \frac{H}{H+\frac{w_{m_1}}{w_h}*M_1+\frac{w_{m_2}}{w_h}M_2+\frac{r_{k_1}}{w_h}K_1+\frac{r_{k_2}}{w_h}K_2} \quad (6.38)$$

The share of compensation to capital is:

$$\frac{r_{k_1}*K_1+r_{k_2}*K_2}{w_h*H+w_{m_1}*M_1+w_{m_2}*M_2+r_{k_1}*K_1+r_{k_2}*K_2} = \frac{\frac{r_{k_1}}{r_{k_2}}K_1+K_2}{\frac{w_h}{r_{k_2}}H+\frac{w_{m_1}}{r_{k_2}}M_1+\frac{w_{m_2}}{r_{k_2}}M_2+\frac{r_{k_1}}{r_{k_2}}K_1+K_2} =$$

$$\frac{\frac{r_{k_1}}{r_{k_2}}K_1+K_2}{(\frac{w_h}{r_{k_2}}H+\frac{w_{m_1}}{r_{k_2}}M_1)+(q_2M_2+\frac{r_{k_1}}{r_{k_2}}K_1+K_2)} \quad (6.39)$$

Or equivalently,

$$\frac{r_{k_1}*K_1+r_{k_2}*K_2}{w_h*H+w_{m_1}*M_1+w_{m_2}*M_2+r_{k_1}*K_1+r_{k_2}*K_2}=\frac{K_1+\frac{r_{k_2}}{r_{k_1}}K_2}{\frac{w_h}{r_{k_1}}H+\frac{w_{m_1}}{r_{k_1}}M_1+\frac{w_{m_2}}{r_{k_1}}M_2+K_1+\frac{r_{k_2}}{r_{k_1}}K_2}=$$

$$\frac{K_1+\frac{r_{k_2}}{r_{k_1}}K_2}{\frac{w_h}{r_{k_1}}H+\frac{w_{m_2}}{r_{k_1}}M_2+(q_1M_1+K_1+\frac{r_{k_2}}{r_{k_1}}K_2)} \tag{6.40}$$

Type 1 country:

We have found that $\frac{\frac{w_{m_2}}{A_{m_2}}+\frac{r_{k_2}}{B_{k_2}}}{\frac{w_{m_1}}{A_{m_1}}+\frac{r_{k_1}}{B_{k_1}}}$ and $\frac{\frac{w_h}{A_h}}{\frac{w_{m_2}}{A_{m_2}}+\frac{r_{k_2}}{B_{k_2}}}$ will both increase when the least complex tasks are offshored (ie, ε is removed from the range of tasks performed by low-skill labour I_L in Eqs. 6.27 and 6.27). According to Eqs. 6.34 and 6.35, $\frac{r_{k_2}}{r_{k_1}}$ and $\frac{w_h}{r_{k_2}}$ increase. Furthermore, from Eqs. 6.32 and 6.33, we have $\frac{r_{k_2}}{r_{k_1}}=\frac{\frac{w_{m_2}}{q_2}}{\frac{w_{m_1}}{q_1}}=\frac{q_1}{q_2}\frac{w_{m_2}}{w_{m_1}}$ Hence, $\frac{w_{m_2}}{w_{m_1}}$ will increase. Since $\frac{w_h}{w_{m_2}}=\frac{w_h}{q_2*r_{k_2}}=\frac{1}{q_2}\frac{w_h}{r_{k_2}}$, $\frac{w_h}{w_{m_2}}$ will increase. Since $\frac{w_h}{r_{k_1}}=\frac{w_h}{r_{k_2}}*\frac{r_{k_2}}{r_{k_1}}$, $\frac{w_h}{r_{k_1}}$ will increase. Similarly, $\frac{w_h}{w_{m_1}}$ and $\frac{r_{k_1}}{w_{m_2}}$ increase while $\frac{r_{k_1}}{w_{m_2}}$ decreases.

For the share of compensation to low-skill labour: $\frac{w_h}{w_{m_1}}$, $\frac{w_{m_2}}{w_{m_1}}$ and $\frac{r_{k_2}}{w_{m_1}}$increase. Therefore, from Eq. 6.36, we obtain the result that the share of compensation to low-skill labour will decrease.

For the share of compensation to medium-skill labour: $\frac{w_{m_1}}{w_{m_2}}$ and $\frac{r_{k_1}}{w_{m_2}}$ decrease, but $\frac{w_h}{w_{m_2}}$ increases. Therefore, from Eq. 6.37, we obtain the result that the direction of change of the share of compensation to medium-skill labour is not definite.

For the share of compensation to high-skill labour: $\frac{w_{m_1}}{w_h}$, $\frac{w_{m_2}}{w_h}$, $\frac{r_{k_1}}{w_h}$ and $\frac{r_{k_2}}{w_h}$ all decrease. Therefore, from Eq. 6.38, we obtain the result that the share of compensation to high-skill labour will increase.

For the share of compensation to capital: both $\frac{r_{k_2}}{r_{k_1}}$ and $\frac{w_h}{r_{k_1}}$ increase. Also, $\frac{w_{m_2}}{r_{k_1}}=\frac{w_{m_2}}{r_{k_2}}\frac{r_{k_2}}{r_{k_1}}=q_2*\frac{r_{k_2}}{r_{k_1}}$. We know that for the expression $\frac{K_1+\frac{r_{k_2}}{r_{k_1}}K_2}{q_1M_1+K_1+\frac{r_{k_2}}{r_{k_1}}K_2}$, when $\frac{r_{k_2}}{r_{k_1}}$ increases, this expression will increase. However, the final expression in Eq. 6.40 is different from the above expression in that the dominator in Eq. 6.40 also includes another two terms $\frac{w_h}{r_{k_1}}H$ and $\frac{w_{m_2}}{r_{k_1}}M_2$. If q_2 is very large, then $\frac{w_{m_2}}{r_{k_1}}$ will increase significantly, which could make the final expression in Eq. 6.40 decrease. Therefore, we obtain the conclusion that the share of compensation to capital will increase (decrease) when $\frac{s_2 * A_{m_2}}{(1-s_2)B_{k_2}}$ is not very large (large enough), which is likely to hold when the relative productivity of labour to capital $\frac{A}{B}$ is not very large (large enough) in the production technology used by medium-skill labour.

Type 2 country:

We have found that both $\frac{\frac{w_{m_1}}{A_{m_1}}+\frac{r_{k_1}}{B_{k_1}}}{\frac{w_{m_2}}{A_{m_2}}+\frac{r_{k_2}}{B_{k_2}}}$ and $\frac{\frac{w_h}{A_h}}{\frac{w_{m_2}}{A_{m_2}}+\frac{r_{k_2}}{B_{k_2}}}$ increase when tasks performed by medium-skill labour are offshored (ie, ε is taken from the range of tasks performed by medium-skill labour $(I_H - I_L)$ in Eqs. 6.28 and 6.29. According to Eqs. 6.34 and 6.35, $\frac{r_{k_1}}{r_{k_2}}$ and $\frac{w_h}{r_{k_2}}$ increase. Furthermore, $\frac{w_h}{r_{k_2}}$, $\frac{r_{k_1}}{w_{m_2}}$ and $\frac{w_h}{w_{m_2}}$ all increase.

For the share of compensation to low-skill labour: $\frac{w_{m_2}}{w_{m_1}}$ and $\frac{r_{k_2}}{w_{m_1}}$ both decrease. Since $\frac{w_h}{w_{m_1}} = \frac{w_h}{w_{m_2}} * \frac{w_{m_2}}{w_{m_1}}$, $\frac{w_h}{w_{m_1}}$ may increase or decrease. Therefore, from Eq. 6.36, we obtain the result that the direction of change of the share of compensation to low-skill labour is not definitive. The share of compensation to low-skill labour will decrease if $\frac{w_h}{w_{m_1}}$ grows large enough.

For the share of compensation to medium-skill labour: $\frac{w_h}{w_2}$, $\frac{w_{m_1}}{w_{m_2}}$ and $\frac{r_{k_1}}{w_{m_2}}$ all decrease. Therefore, from Eq. 6.37, we obtain the result that he share of compensation to medium-skill labour will decrease.

For the share of compensation to high-skill labour: $\frac{w_{m_2}}{w_h}$ and $\frac{r_{k_2}}{w_h}$ both decrease. $\frac{w_{m_1}}{w_h} = \frac{q_1 * r_{k_1}}{w_h}$. $\frac{r_{k_1}}{w_h} = \frac{r_{k_1}}{r_{k_2}} * \frac{r_{k_2}}{w_h}$. Therefore, the directions of the changes of $\frac{r_{k_1}}{w_h}$ and $\frac{w_{m_1}}{w_h}$ are not definitive. Therefore, from Eq. 6.37, we obtain the result that the direction of change of the share of compensation to high-skill labour is not definitive. The share of compensation to high-skill workers will increase if $\frac{w_h}{w_{m_1}}$ grows large enough.

For the share of compensation to capital: $\frac{r_{k_1}}{r_{k_2}}$ and $\frac{w_h}{r_{k_2}}$ increase. $\frac{w_{m_1}}{r_{k_2}} = \frac{w_{m_1}}{r_{k_1}}\frac{r_{k_1}}{r_{k_2}} = q_1 * \frac{r_{k_1}}{r_{k_2}}$. We know that for the expression $\frac{K_2+\frac{r_{k_1}}{r_{k_2}}K_1}{q_2M_2+K_2+\frac{r_{k_1}}{r_{k_2}}K_2}$, when $\frac{r_{k_1}}{r_{k_2}}$ increases, this expression will increase. However, the final expression in Eq. 6.39 is different from the above expression in that the dominator in Eq. 6.39 also includes another two terms $\frac{w_h}{r_{k_2}}H$ and $\frac{w_{m_1}}{r_{k_2}}M_1$. If q_1 is very large, then $\frac{w_{m_1}}{r_{k_2}}$ will increase significantly, which could make the final expression in Eq. 6.39 decrease. Therefore, we obtain the conclusion that the share of compensation to capital will decrease (increase) when $\frac{s_1 * A_{m_1}}{(1-s_1)B_{k_1}}$ is large enough (not very large), which is likely to hold when the relative productivity of labour to capital, as determined by their relative factor-augmenting coefficients $\frac{A}{B}$, is large enough (not very large) in the production technology used by low-skill labour.

Type 3 country:

We have found that $\frac{\frac{w_{m_2}}{A_{m_2}}+\frac{r_{k_2}}{B_{k_2}}}{\frac{w_{m_1}}{A_{m_1}}+\frac{r_{k_1}}{B_{k_1}}}$ increases and $\frac{\frac{w_h}{A_h}}{\frac{w_{m_2}}{A_{m_2}}+\frac{r_{k_2}}{\beta_{k_2}}}$ decreases as countries are experiencing increases in the range of tasks performed by medium-skill labour (ie, ε is added to $(I_H - I_L)$ in Eqs. 6.30 and 6.31). According to Eqs. 6.34 and 6.35, $\frac{r_{k_2}}{r_{k_1}}$ will increase and $\frac{w_h}{r_{k_2}}$ will decrease. Furthermore, $\frac{w_{m_2}}{w_{m_1}}$, $\frac{r_{k_2}}{w_{m_1}}$, $\frac{w_{m_2}}{w_h}$ and $\frac{w_{m_2}}{r_{k_1}}$ all increase.

For the share of compensation to low-skill labour: $\frac{w_{m_2}}{w_{m_1}}$ and $\frac{r_{k_2}}{w_{m_1}}$ both increase. Since $\frac{w_h}{w_{m_1}} = \frac{w_h}{w_{m_2}} * \frac{w_{m_2}}{w_{m_1}}$, $\frac{w_h}{w_{m_1}}$ may increase or decrease. Therefore, from Eq. 6.36, we obtain the result that the direction of change of the share of compensation to low-skill labour is not definitive. The share of compensation to low-skill workers will decrease if $\frac{w_h}{w_{m_1}}$ is not decreased significantly.

For the share of compensation to medium-skill labour: $\frac{w_h}{w_2}$, $\frac{w_{m_1}}{w_{m_2}}$ and $\frac{r_{k_1}}{w_{m_2}}$ all decrease. Therefore, from Eq. 6.37, we obtain the result that he share of compensation to medium-skill labour will increase.

For the share of compensation to high-skill labour: $\frac{w_{m_2}}{w_h}$ and $\frac{r_{k_2}}{w_h}$ both increase.

$\frac{w_{m_1}}{w_h} = \frac{q_1 * r_{k_1}}{w_h}$. $\frac{r_{k_1}}{w_h} = \frac{r_{k_1}}{r_{k_2}} * \frac{r_{k_2}}{w_h}$. Therefore, the directions of the changes of $\frac{r_{k_1}}{w_h}$ and $\frac{w_{m_1}}{w_h}$ are not definitive. Therefore, from Eq. 6.37, we obtain the result that the direction of change of the share of compensation to high-skill labour is not definitive. The share of compensation to high-skill workers will increase if $\frac{w_h}{w_{m_1}}$ grows large enough.

For the share of compensation to capital: both $\frac{r_{k_2}}{r_{k_1}}$ increases and $\frac{w_h}{r_{k_1}}$ decreases.

$\frac{w_{m_2}}{r_{k_1}} = \frac{w_{m_2}}{r_{k_2}} \frac{r_{k_2}}{r_{k_1}} = q_2 * \frac{r_{k_2}}{r_{k_1}}$. We know that for the expression $\frac{K_1 + \frac{r_{k_2}}{r_{k_1}} K_2}{q_1 M_1 + K_1 + \frac{r_{k_2}}{r_{k_1}} K_2}$, when $\frac{r_{k_2}}{r_{k_1}}$ increases, this expression will increase. However, the final expression in Eq. 6.40 is different from the above expression in that the dominator in Eq. 6.40 also includes another two terms $\frac{w_h}{r_{k_1}} H$ and $\frac{w_{m_2}}{r_{k_1}} M_2$. If q_2 is very large, then $\frac{w_{m_2}}{r_{k_1}}$ will increase significantly, which could make the final expression in Eq. 6.40 decrease. Therefore, we obtain the conclusion that the share of compensation to capital will increase (decrease) when $\frac{s_2 * A_{m_2}}{(1-s_2) B_{k_2}}$ is not very large (large enough), which is likely to hold when the relative productivity of labour to capital $\frac{A}{B}$ is not very large (large enough) in the production technology used by medium-skill labour.

Chapter 7: Conclusions and policy implications

7.1 Contributions and policy implications

Technological progress is the fundamental source of long-term economic growth and is important for countries at all stages of development. While most developed countries have established systems where institutions and markets are generally conducive to the generation and spread of innovative ideas and new technologies, many developing countries are still struggling in their quest for the pathways towards continuous technological catch-up and development of innovative capabilities. The thesis aims to inform this quest by identifying the critical ingredients of a well-functioning system for incessant technological catch-up and innovation. While the thesis is not limited to the issue of technological progress in developing countries, one major context is the technological progress of countries that are aiming to pursue continuous technological catch-up towards countries on the world technology frontier and to ultimately transition towards innovative economies themselves. For China and a number of other countries that are approaching or have already reached middle –income status, this study makes a timely contribution to policy makings by providing an up-to-date review and empirical demonstration of the channels and mechanisms through which industrial upgrading and technological catch-up take place.

The thesis has identified several economic mechanisms and channels that impact on technological catch-up and innovation. These include: institutional quality and the productive use of human capital; institutional quality and the R&D investment of firms and thus the innovativeness of firms; global production sharing and the types of production activities firms perform, and the consequent room for technological learning, and influence from industrial policies on technological catch-up. In doing so, the thesis has contributed to the study of economic development, the economics of innovation and global patterns of growth. While the thesis has clearly not exhausted the ways that technological progress takes place in countries within the world technological frontier, it has drawn attention to several key channels and mechanisms, which enables the formulation of practical policies accordingly.

Each chapter of the thesis contained detailed and comprehensive conclusions and policy implications. Here, I will draw upon all chapters and make a summary of the key findings and policy suggestions.

Institutional quality is critical for nurturing industrial upgrading and innovation.

The results of the thesis suggest that institutional quality significantly influences the productive use of human capital and firms' investment in R&D, thus impacting on country- and firm-level performance in industrial upgrading (Chapter 2) and innovation (Chapter 3). In Chapter 2, it was found that the size of the marginal impact from increased tertiary human capital on industrial upgrading is conditional on the institutional quality of the economy. Both overall institutional quality and its four components (size of government, access to sound money, freedom to trade and market regulations) are complementary to human capital in enhancing industrial upgrading. When opportunities to profit from technological upgrading arise, sound domestic institutions can channel human capital to exploit these potential opportunities and thus promote economic growth. In Chapter 3, determinants of firm-level R&D investment have been identified. Among these determinants, higher institutional quality of the province where a firm is located has been found to significantly enhance firms' probability of doing R&D, which is a critical input to innovation.

Besides its direct impact on firm-level R&D activities, institutional quality may also have indirect effects on firm-level R&D activities through a firm's business strategy and the trade regime a firm is consequently engaged in. When the degree of property rights protection or that of intellectual property rights protection is low, the incentives to invest in R&D and upgrade production technologies will be deficient and firms may be locked in labour-intensive and low-tech processing trade activities in the long run (Chapter 4). The key to breaking this vicious cycle is to improve the institutional quality of the economic environment that firms operate in and thus enhance firms' incentives to do product and process innovations and climb up the value chain.

These findings about the importance of institutional quality for industrial upgrading, firm-level R&D investment and business strategy are particularly relevant to countries that need to move beyond the stages of industrialization and development characterized by comparative advantage in low-tech and labour-intensive products. While institutional quality may not exert a first-moment impact on growth performance during the early stages of development, it is clearly a core determinant as a country converges towards the world technology frontier and increasingly relies on innovation and mastery of complex technologies for growth. It is helpful to realize that policy strategies directed towards boosting human capital and R&D investment should be in conjunction with, rather than precede, policies promoting better institutions, because higher institutional quality will provide an economic environment that delivers greater benefits from these inputs.

Human capital stock is essential for technological catch-up and industrial upgrading

The study supports the argument that one of the key factors that drives technological catch-up and industrial upgrading is the human capital stock of an economy. Investing in tertiary education and nurturing researchers should be a prime concern of policymakers. There is empirical evidence from cross-country analyses that shows that increases of the tertiary human capital stock promotes the growth of high-tech industries relative to that of medium- or low-tech industries and thus induces inter-sectoral industrial upgrading (Chapter 2). Firm-level analyses show that the R&D intensity of a firm is positively associated with the average wage of employees, which reflects the human capital and skill level of the employees (Chapters 3 and 4). Therefore, firms that commit a larger share of resources to R&D investment require more skilled workers. When setting up R&D centres and investing in R&D activities overseas, multinational enterprises are drawn to countries with high shares of researchers in total populations (Chapter 5). Therefore, the number of researchers is positively associated with the chance that an economy benefits from multinational enterprises' R&D activities.

The effect of industrial policies and trade policies

This study finds that, while industrial policies and trade policies could promote the development of manufacturing and trade activities, these policies may influence an economy's potential of technological catch-up and industrial upgrading as well. In Chapter 4, it is found that the larger the extent of engagement in processing trade, the lower a firm's R&D intensity. It is worth noticing that the current policy setting in China contains a variety of industrial and trade policies that promote processing trade. For example, various free-trade zones—such as special economic zones, economic and technological development zones, high-technology industrial development zones and export-processing zones— have been established, where processing firms enjoy privileges such as freedom from duties and minimal administrative restrictions. Furthermore, processing assembly is a 100% duty free; processing using imported inputs enjoys 100% duty rebate.

While participation in global production sharing has allowed for the rapid expansion and diversification of China's manufacturing export capacities at a stage of development featuring low labour costs, the findings in Chapter 4 suggests that heavy reliance on processing trade may have a negative impact on the rise of innovation capacity as China tries to enter a new stage of development emphasizing technological competitiveness in the global market. It is important that policymakers are informed of this point when formulating industrial and trade policies.

It is also important to note that the ways in which technological catch-up and industrial upgrading take place change as trade and investment activities are increasingly associated with global production sharing (Chapter 6). It may no longer be proper to think of technological progress as a self-contained process that happens within a certain industry of a certain country. The recent development is that technological progress can begin from specialization in certain production tasks instead of requiring the knowledge for the entire bundle of tasks that constitute the final output. Therefore, when making policies aimed at enhancing countries' technological performance, governments need to accommodate this change and design policies that suit the new global trend.

R&D is important for developing countries as well.

Although R&D activities are often regarded as being exclusive to developed countries on the world technology frontier and developing countries can rely only on technology imitation and adoption for technological progress, this view neglects the importance of R&D in digesting the imitated and adopted technologies and in attracting R&D investment from foreign firms. The empirical findings in Chapter 5 suggest that the technology-seeking motive is important since higher growth of R&D intensity in the relevant industry of the host country induces a higher level of R&D intensity of MNEs. R&D investment by multinational enterprises is drawn towards countries that have high domestic R&D investment and thus host valuable knowledge and technologies. As more and more overseas R&D investment comes to a country, the country's attractiveness as a destination of R&D investment will become even higher. Hence, if a government could pay special attention to encouraging R&D investment by various agents such as the higher education sector, research institutes and business enterprises, the country will gain access to a larger amount of international R&D resource and enjoy the potential technological spill-overs on a larger scale. Therefore, developing countries need to invest in domestic R&D and leverage it for R&D investment by multinational enterprises. In this virtuous cycle, R&D intensifications by domestic and foreign firms are complementary to each other.

Beyond these major findings and their policy implications, in the thesis, I have also carefully constructed several unique datasets that will be valuable for future research on related topics. The cross-country industry-level dataset for assessing the impact of human capital and institutional quality on inter-sectoral industrial upgrading is unique; it is the first time that the data of cross-country industry-level R&D investment by U.S.-based multinational enterprises and the data of industry-level R&D investment in 23 countries have been merged in order to better reflect the technological seeking motive of multinational enterprises; the large sample of a firm-level production panel dataset and the careful merging of this dataset with a large-scale product-level customs dataset are both of considerable value to future firm-level studies on trade and innovation.

Besides the contributions in terms of datasets, the thesis also uses advanced econometric methods to tackle various research questions and data characteristics. The GMM estimators adopted in Chapters 2 and 5 can tackle the dynamic structure caused by the inclusion of the lagged dependent variable on the right hand side of the estimation equation, which cannot be addressed by an OLS estimator or a fixed-effect estimator. The estimator of Kyriazidou (1997) developed in the MATA language of STATA can deal with sample selection and censored regression in the context of panel data, which is a valuable tool for future research using panel data. When estimating the impact of human capital on industrial upgrading, taking into account the quality of human capital is an improvement compared to focusing only on human capital stock (Chapter 2). Using a firm's advertisement expenditure as the variable included in the selection equation but not the level equation is also an innovation (Chapter 3).

7.2 Limitations and future research

The thesis is the starting point of a long-term research agenda on the technological catch-up and growth dynamics. The research can be further improved and extended in the following directions.

First, in the thesis, the institutional quality measures are at the macroeconomic level. In the future, it will be worthwhile to explore in more detail what kind of institutional arrangements matter most for firm-level R&D activities and how these arrangements work at the microeconomic level. Such knowledge will help formulate more effective policies that could enhance the R&D activities of a country.

Second, it will be helpful to examine dimensions of technological catch-up other than inter-sectoral industrial upgrading, intensification of R&D and changing positions in the global value chain. Future studies could examine, for example, performances and academic output of universities and research institutes, and could develop a composite measure of countries' performances in technological catch-up by taking into account these various dimensions.

Third, it would be an interesting extension to develop a theoretical framework that could coherently link the determinants of technological catch-up, performance in technological catch-up and economic growth. It is likely that several theoretical models highlighting the various channels would be required. The empirical findings of the thesis serve as a solid base to inform future theoretical works.

Fourth, currently available data did not allow me to differentiate between various types of R&D activities, ie, basic research, applied research and experimental development. Information about the proportions of various types of research could be valuable if we hope to measure a country's technological catch-up performance more accurately. Future work on this topic will be conducted if more disaggregated data on R&D types become available ideally from firm-level surveys.

Sixth, the intertwining relationships between global production sharing and technological catch-up and industrial upgrading deserve in-depth study in the future. A theoretical framework and discussion for examining this issue will be highly valuable for setting the tone for studies of technological catch-up and industrial upgrading as the fragmentation of production continues to deepen and impact on the global distribution of FDI and trade flows.

Seventh, it will be worthwhile to conduct more case studies of technological catch-up and industrial upgrading for individual countries. Examining the policies and development history of individual countries in more detail may reveal channels of technological catch-up that have not yet been paid attention in the literature. Also, a typology of the ways of technological catch-up and the relevant policies of major countries in the world could be developed to enhance our understanding of this issue.

To summarize, there is clearly scope for ongoing broad and deep research into the complex relationships between technological catch-up, industrial upgrading and economic development. By adding to the global pool of knowledge on these relationships, this thesis not only assists developing countries' policy makings that aim at enhancing technological catch-up but also identifies directions for future research into this intriguing and important topic.

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