Essays on Vertical Cooperation, Intellectual Property Protection, and the International Development and Diffusion of New Technologies

Thesis submitted for the degree of

Doctor of Philosophy

At the University of Leicester

By

Zhuohan Zhang

School of Business

Economics Division

University of Leicester

October 2017

Essays on Vertical Cooperation, Intellectual Property Protection, and the International Development and Diffusion of New Technologies–

Zhuohan Zhang

Abstract

In the first essay, we develop a theoretical model, to analyse the trade-off between two modes, *vertical partnership* and *vertical merger*, of the cooperation between a high-tech northern firm and a southern firm that has low-labour-cost advantage. We conclude that if there is high "importance/degree" of asymmetric information on the quality of the northern firm's technology, the *vertical partnership* mode making it possible to screen out low-quality technologies, tends to arise as the equilibrium cooperation mode, rather than the *vertical merger* mode achieving higher overall cost efficiency. In the second essay, we examine empirically how two legal regimes of intellectual property protection in a country, *patent protection* and *trade secret protection*, affect the foreign-sourced R&D investment into the country. We find that both patent and trade secret protection may have positive or negative effects on the foreign-sourced R&D investment, but mostly, the dominant effects of both regimes on the foreign-sourced R&D investment are their positive effects that stem from the "appropriability" channel: both patent and trade secret protection can increase the appropriability of R&D achievements. Also, when patent and trade secret protection work for boosting the foreign-sourced R&D investment, the two regimes complement each other. In the third essay, we examine empirically how the manufacturing R&D investment and service R&D investment in a country, respectively, are affected by the *patent protection* and *trade secret protection* regimes in the country. We find that on the one hand, patent protection positively affects both the levels of R&D investment in manufacturing and in services. On the other hand, trade secret protection has no significant effect on the R&D investment in manufacturing, while our results weakly indicate a U-shaped effect of trade secret protection on the R&D investment in services.

Acknowledgements

I would like to take this opportunity to express my deepest appreciation to my two supervisors, Fabrizio Adriani and Piercarlo Zanchettin, and also Tania Oliveira who is not my official supervisor but really helps me a lot with my Phd work. I am always grateful to their helpful guidance, suggestions, and comments on my Phd research work through these years.

I am also quite grateful to my two examiners, Dimitrios Varvarigos and Gianfranco Atzeni, for their valuable suggestions and comments on my thesis.

Moreover, I want to thank my friends, Guangyi Xin, Eric Akobeng, Sneha Gaddam, and Li Lin, for their kind help with my Phd research work or thesis writing-up.

Lastly and most importantly, I must greatly thank my parents, as they always try their best to help me overcome difficulties in my study and life.

Declaration

Chapter 2 entitled “Vertical Partnership Vs. Vertical Merger under Asymmetric Information” has been presented by poster at the II Annual PhD Conference in Economics of the University of Leicester, and presented orally at the 10th Annual Meeting of the Portuguese Economic Journal (Coimbra) and the XXXI Jornadas de Economía Industrial (Palma).

Contents

List of Tables

List of Figures

Chapter 1

Introduction

In this thesis, we will discuss several issues in vertical cooperation, intellectual property (IP) protection, and the international development and diffusion of new technologies. The first essay (Chapter 2) is theoretical work, while the latter two essays (Chapter 3 and Chapter 4) are empirical studies.

In Chapter 2, we develop a theoretical model to discuss some novelty in the vertical cooperation between a high-tech northern firm, which possesses an innovative technology for a new product, and a southern firm, which can mobilize relatively cheap and qualified labour in its home country to produce the northern firm's product. We argue that, if the northern firm's technology is embodied in a high-tech intermediate good of the new product and there is asymmetric information on the quality of the northern firm's technology, an interesting trade-off arises when comparing two modes of the cooperation between the two firms. The trade-off exists between the possibility to screen out low-quality technologies through a cooperation mode, *vertical partnership*, and higher overall cost efficiency achieved by another cooperation mode, *vertical merger*.

Our detailed analysis concludes that *vertical partnerships*, rather than *vertical mergers*, tend to arise as the equilibrium mode of cooperation when asymmetric information on the quality of northern firm's technology is important, as the *quality screening* value of partnerships tends to dominate the *cost efficiency* value of vertical mergers. Higher "degree/importance" of asymmetric information on the quality of northern firm's technology, specifically, comes from: 1) higher southern firm's uncertainty about the quality of technology, and/or 2) higher efficiency (quality) gaps between high- and low-quality technologies.

In Chapter 3, based on an unbalanced panel dataset that covers 25 countries for the five quinquennial periods from 1990 to 2010, we examine empirically that how two legal regimes of IP protection in a country, *patent protection* and *trade secret protection*, affect the foreign-sourced Research and Development (R&D) investment into the country. Our results indicate that both patent and trade secret protection may have positive or negative effects on the foreign-sourced R&D investment, but mostly, the dominant effects of both regimes on the foreign-sourced R&D investment are their positive effects that stem from the "appropriability" channel: both patent and trade secret protection can increase the appropriability of R&D achievements. Also, when patent and trade secret protection work for boosting the foreign-sourced R&D investment, the two regimes are complementary to each other.

Only in rare cases, on the foreign-sourced R&D investment, one or both regimes' positive effects from the appriopriability channel become too weak, and thus outweighed by their negative effects stemming from other channels. For patent protection, its negative effect tends to become dominant if the strength of trade secret protection is quite low, since if the trade secret protection is quite weak and thus cannot give sufficient complementarity for the patent protection, the positive effect of patent protection will become too weak and thus outweighed by its negative effect. As for trade secret protection, since it alone exhibits a U-shaped effect in the absence of the complementarity between patent and trade secret protection, the negative effect of trade secret protection tends to become dominant if the combinative strength of patent and trade secret protection is quite low. In this situation, the patent protection is quite weak and thus cannot give sufficient complementarity for the trade secret protection. Also, the trade secret protection itself is quite weak, and thus makes the country's foreign-sourced R&D investment dominated by the investment in adaptions/customizations or non-core technologies that rely lightly on trade secret protection. Both factors tend to make the positive effect of trade secret protection too weak and thus outweighed by its negative effect.

Chapter 4 still deals with the effects of patent and trade secret protection on R&D investment. However, in this chapter, we focus on the sectoral difference. Based on an unbalanced panel dataset that covers 21 countries for the five quinquennial periods from 1990 to 2010, we examine empirically how the R&D investment in a country's manufacturing sector and that in its services sector, respectively, are affected by the country's legal protection of patent and trade secret. Our results show that on the one hand, patent protection positively affects both the R&D investment in manufacturing and that in services. On the other hand, trade secret protection has no significant effect on the R&D investment in manufacturing, while our results weakly indicate a U-shaped effect of trade secret protection on the R&D investment in services. In the U-shaped effect of trade secret protection, specifically, if the strength of trade secret protection exceeds a threshold, the marginal effect of trade secret protection on the service R&D investment is positive; otherwise, this marginal effect turns to negative.

We try to give an explanation for the U-shaped effect of trade secret protection on the service R&D investment. In a country, weak trade secret protection leads to an environment where benefited from the inter-firm labour mobility and knowledge flow allowed by weak trade secret protection, there are active start-up and spin-off activities in the service sector, and active R&D activities in the start-up service firms, but the start-up service firms' R&D work tends to be lowly-innovative, and thus rarely needs trade secret laws to protect the appropriability of R&D achievements. In this environment, strengthening trade secret protection will discourage start-ups and spin-offs, since it decreases the labour mobility and knowledge flow from mature firms to start-up firms. Then strengthening trade secret protection will lead to fewer start-up firms, and thus a smaller total amount of the lowly-innovative R&D investment made by the start-up firms. At first, this negative effect on the start-up firms' lowly-innovative R&D investment is dominant in the effect of trade secret protection on the total service R&D investment, but when the trade secret protection is strengthened further, the situation will change. When the strength of trade secret protection becomes high enough, some firms with enough

R&D ability begin to invest in the highly-innovative R&D work that needs trade secret laws to protect the appropriability of its innovative achievements. Then strengthening the trade secret protection further spurs these firms with enough R&D ability to make more highly-innovative R&D investment, since stronger trade secret protection increases the appropriability of the innovative R&D achievements. Gradually, these innovative firms become stronger and stronger, and then the positive effect on these firms' highly-innovative R&D investment becomes dominant in the effect of trade secret protection on the total service R&D investment.

Chapter 2

Vertical Partnership Vs. Vertical Merger under Asymmetric Information

1. Introduction

By now, many theoretical and empirical studies on technology transfer have considered the effect of information asymmetries about new technologies on licensing agreements (Gallini, 1984; Gallini and Winter, 1985; Katz and Shapiro, 1985 & 1986; Kamien and Tauman, 1986; Rockett, 1990; Gallini and Wright, 1990). Less attention has been paid on asymmetric information about the quality of new technologies as a possible explanation of alternative modes of cooperation involving technology transfer than licensing.

In this chapter, we argue that, when licensing agreements become infeasible because of strong information asymmetries and high risk of imitation, vertically separated partnerships, whereby new technology embodied in high-tech intermediate goods is transferred via standard trade relationships, may dominate vertical mergers, the other natural alternative to licensing.

As stressed by Gallini and Wright (1990), when inventors have ex-ante private information on the quality of new technology and final technology users can easily imitate the new technology ex-post, opportunistic behaviour may arise from both parties of a licensing relationship. Superior information on own technology incentivizes licensors to overstate quality before the technology is transferred (pre-contractual opportunism), whereas the licensees may imitate the licensor's technology, and thereby exploit the technology in ways that circumvent royalty payments, after the technology has been transferred (post-contractual opportunism). Potential licensors and licensees will then hold conflicting views on the licensing contract: licensors will claim up-front payments (fixed fee), licensees will strictly prefer output-based royalties.

A possible compromise solution of this conflict of views is a licensing contract comprising both a fixed fee and output-based royalties (Galling and Wright, 1990).[1] However, even this solution can fail when strong information asymmetries and high risks of imitation will combine in making it hard and costly for the parties to find an agreement on the relative weights of the two modes of payments.

As patent protection reduces both ex-ante asymmetries (innovative knowledge must be disclosed in patent applications) and the risk of ex-post imitation, situations where licensing becomes hard to negotiate are likely to involve transfers of technology which contains unpatented know-how.[2] According to the study of Taylor and Silberston (1973), good examples of these situations can be found in the machinery and electronics industry, where many technologies contain a large amount of research results and technical expertise not filed in patent specifications. This can be due to technological components, research results and know-how not being patentable, following-up from previous patented technology, or simply being better protected with trade secret because of high risks of imitation. Associated with this relative importance of unpatented technology, Taylor and Silberston (1973) document a lower use of licensing in this industry relative to other sectors.

---

[1] Macho-Stadler, Martinez-Giralt and Perez-Castrillo (1996) provide empirical evidence of this solution. They find that licensing contracts where unpatented know-how (the quality of which is more difficult to be verified ex-ante) is transferred along with patented technology are more likely to contain royalties. Similarly, Cebrién (2009) provides supporting evidence that bilateral opportunism in a licensing case tends to yield licensing contracts which contain both fixed fees and output-based royalties.

[2] There is indeed empirical evidence of a positive relationship between the strength of patent protection in a country and total receipt of licensing payments (royalties and licensing fees) in that country (Yang and Maskus, 2001; Kanwar, 2012). This evidence suggests strong complementarities between patenting and licensing, so that most of the licensed technologies are protected by the patent system.

Our focus is on international technology transfers. Consider a high-tech *northern firm*, which possesses an innovative technology for a new product, and a *southern firm*, which can mobilize relatively cheap and qualified labour in its home country to produce the northern firm's product, say in the machinery and electronics industry. If *green-field FDI* (i.e., the northern firm opens its own plant in the southern country), an option extensively discussed in the previous literature (e.g., Nocke and Yeaple, 2007; Raff, Ryan, and Stähler, 2009), is ruled out by the southern firm alone being able to mobilize cheap and qualified labour in the southern country, and *licensing* is not feasible for the reasons discussed before,[3] the two firms should consider other modes of cooperation to combine northern technology and cheap southern labour to produce and sell the northern firm's product in the southern country.

A possible option would be a *vertical merger*, whereby the northern firm and southern firm merge into a single entity which locates the entire production line of the northern firm's product in the southern country. We compare the vertical merger option with another mode of cooperation, *vertical partnership*, which would be possible if the northern firm's technology is embodied in a high-tech intermediate good, which is then combined with labour to produce the final product. In this cooperation mode, the northern firm uses its home country (relatively expensive) labour to produce the high-tech intermediate good and sells the intermediate good to the southern firm. The southern firm then combines the intermediate good with the (cheap) southern labour to produce and sell the final product in the southern country.

In terms of overall labour cost, a vertical partnership is obviously less efficient than a vertical merged entity, as the intermediate good production still employs the expensive northern labour in a partnership, while both intermediate good and final product are produced with the cheap southern labour in a merger. However, in the presence of asymmetric information on the quality of the northern firm's technology (captured in

[3] More precisely, in the model we assume that ex-post imitation costs are sufficiently low to rule out any possible use of output-based royalties payments, which the southern firm would almost certainly default on. We then show (in Appendix 2.1) that fixed-fee licensing is either strictly dominated by, or at the very most equivalent to, at least one of the two cooperation modes we focus on, vertical merger and vertical partnership.

the model by high or low efficiency of the new technology in the production of the intermediate good), the vertical partnership mode can allow the southern firm to screen out (and thereby avoid cooperating with) a northern firm endowed with a technology of low quality by making effective *separating price offers* for the provision of intermediate good.

It is important to note that this screening effect cannot be obtained by the southern firm through *vertical merger offers*. The intuitive reason for this is the following. Although higher production efficiency of a high quality type of northern firm makes room for intermediate good price offers (by the southern firm) sufficiently low to be acceptable only by said high-quality type, it also provides the high-quality type with a higher outside option in the case the negotiation breaks down and the northern firm can only try to enter the southern market by performing all production stages at home and then exporting the final product to the southern country. By enjoying a higher outside option, a high-quality type of northern firm will always demand a higher share in a vertically merged firm's join profits than a low-quality type would. Therefore, any (southern firm's) merger offer (that is, a joint-profit share) which would please the high-quality type would also please the low-quality type, so that screening out low-quality technologies would never be possible while seeking vertical merger cooperation.

The comparison between vertical partnership and vertical merger will then revolves around a trade-off between the possibility to screen out low-quality technologies (for the vertical partnership) and higher overall cost efficiency (for the vertical merger). Not surprisingly, the resolution of the trade-off crucially depends on the "degree/importance" of asymmetric information on the northern firm's technology.

For simplicity, we take the perspective of the southern firm, and give it full bargaining power in the model.[4] This will make our results clear cut, but similar qualitatively effects would arise under milder assumptions on the bargaining power distribution. Higher southern firm's uncertainty about the quality of technology (more equalized prior

[4] Empirical evidence indicates that nowadays, many firms from large emerging countries such as China are quite strong, and thereby can even make technology-sourcing acquisitions targeting technologically advanced firms from developed countries (e.g., Chen, Li and Meng, 2016). It's therefore not unrealistic to assume that the southern firm has strong bargaining power.

beliefs that the technology is of any of the two quality types) and higher efficiency (quality) gaps between high- and low-quality technologies combine in a notion of *asymmetric information importance* which helps summarizing and interpreting our main result. *Vertical partnerships* tend to arise as the equilibrium mode of cooperation when asymmetric information is important (sufficiently equalized probabilities and/or large technology quality gap), as the *quality screening* value of partnerships tends to dominate the *cost efficiency* value of vertical mergers. The other important determinant of the trade-off resolution is of course the north-south wage gap. Alongside the intuitive effect making large wage gaps work in favour of vertical mergers, we find other indirect effects making large wage gaps work in favour of vertical partnerships, and thereby make the overall effect of the wage gap interestingly less straightforward.

Some empirical evidence in the machinery and electronics industry supports our theoretical explanation of vertical partnerships. One example comes from the manufacturing industries of integrated circuit (IC) chips and final electronics products equipped with IC chips.

The manufacturing process of IC chips contains two main stages, the design of new chip blueprints and the large-scale production of these chips, which are typically taken by different companies. While a designer can patent a blueprint, both the chip design technology itself and the follow-up large-scale production technology contain many unpatented research results and technical expertise. As discussed before, licensing may be a problematic way to transfer these unpatented components, and hence these technologies. As an alternative to licensing, vertical partnerships exist in the chain from chip design to chip large-scale production, and in the chain from chips production to the production of final electronics products (Gao and Yang, 2003; Report on the Group of Twenty (G20) National Innovation Competitiveness Development, 2011-2013).

In a vertical partnership of the former chain, a chip design company (our northern firm) designs a new chip, and then sells the use right of this blueprint (our high-tech intermediate good) to a foreign contracted manufacturer (our southern firm). The contracted manufacturer combines the blueprint with the cheap labour in its home country to perform large-scale production of the chip (our final high-tech product).

In a vertical partnership of the latter chain, a manufacturing company (northern firm) buys the use right of a chip's blueprint from a chip designer, and then uses its exclusive technology to develop and produce the chip effectively. After that, the manufacturing company sells the chip (high-tech intermediate good) to a foreign electronics producer (southern firm). The electronics producer combines the chip with home country cheap labour to produce the final electronics product (final high-tech product).

These cases appear in several Asian newly industrialized countries (NICs). For the vertical chain from chip design to large-scale production, Ernst (2005) provides empirical evidence that many chip design activities moved from developed countries to some Asian NICs for several reasons. One important factor is the lower labour costs in these Asian NICs.[5] Nowadays, several chip design clusters have formed in these Asian NICs, such as those in Beijing-China, Shanghai-China, Hsinchuh-Taiwan, and Seoul-South Korea. At the same time, many investigations show that these Asian NICs are still mainly large-scale producers of IC chips designed by developed countries' companies. For instance, Gao and Yang (2003) finds that about 80% of the chips produced in China are designed by foreign designers.[6]

[5] The approximate annual cost of employing a chip design engineer in 2002 is $28,000 in Shanghai-China, $24,000 in Suzhou-China, $30,000 in India, less than $60,000 in Taiwan, and less than $65,000 in South Korea. These cost levels are much lower than the $300,000 of the Silicon Valley-USA, and the $150,000 of Canada.

[6] Furthermore, in 2012, 66.1% of the total revenue of the Semiconductor Manufacturing International Corporation (SMIC), the largest foundry of IC chips in China, comes from the production of the chips designed by foreign designers (data from the 2012 annual financial report of SMIC, at $http://www.smics.com/attachment/20130429173201001642069_en.pdf$).

A similar situation exists in the vertical chain of production from chips to final electronics products. A large number of IC chips are now produced in Asian NICs. In China, some large industrial clusters of chip production have formed, such as those in Beijing, Shanghai and Shenzhen (Gao and Yang, 2003). A report by the Ministry of Industry and Information Technology of China (2012) shows that the quantity of IC chips produced in China in 2012 reached 82.3 billion. Similar to chips design, the advantage of cheap labour is an important factor that spurs the development of chip production in China.[7]

However, the production of final electronics products in China still heavily relies on imported IC chips. For instance, according to the G20 report on *National Innovation Competitiveness Development (2011-2013)*, 80% of the IC chips used in China are imported.

The previous discussion has evidenced that although several Asian NICs have significantly developed both chips design and chips production activities, vertical partnerships between these Asian NICs and developed countries still account for a large part of the vertical relations along both chains: from chips design to chips large-scale production, and from chips production to the production of final electronics products. It seems then improper to explain the existence of vertical partnerships in this sector of these countries by a lack of skilled labour, or a lack of external economies of scale in these Asian NICs. We argue that a possible reason for them is that vertical partnerships ameliorate asymmetric information problems related to technologies developed by developed countries.

The remainder of the paper is structured as follows. Section 2 presents the construction of our theoretical model. Section 3 gives the equilibrium analysis. Section 4 discusses the trade-off between vertical partnership and vertical merger. Section 5 gives some concluding remarks. Section 6 discusses some limitations of this paper. All main results are proved in Appendix 1, while Appendix 2 collects the proof of some additional claims and secondary results.

[7] In an interview by Reuters, Rujing Zhang, the CEO of SMIC indicates that the average total cost of chip production in China is about 20% lower than that in Europe and Northern America (retrieved from http://news.ccidnet.com/art/1366/20040923/158204_1.html, 2004). Rujing Zhang points out that the lower cost of chip production in China is caused by the lower costs in labour, electricity, water and land.

2. The Model

2.1. Set-up, Demand and Technology

In our set-up, there are two countries, "north", N, and "south", S, and two firms: the northern firm, F_N, located in country N, and the southern firm, F_S, located in country S. Wage rates in N and S are w_N and w_S, respectively, with $w_N > w_S$. F_N develops a new technology to produce a new product, for which there is a potential market in the southern country, S.

For simplicity, we assume that the potential demand for the new product in the S-market is inelastic up to a maximum price, $\bar{p}$:

$$D = \begin{cases} \bar{D} > 0 & \text{if } p \leq \bar{p}, \\ 0 & \text{if } p > \bar{p}, \end{cases}$$

where p is the price of the new product.

To produce the fixed quantity $\bar{D}$ of new product, the technology employs one unit of labour and a fixed quantity $I > 0$ of a high-tech intermediate good. This final stage of the technology is "standard", in the sense that it can be predicted by the southern firm without any need to re-discover or reverse engineer the northern firm's technology. The initial stage, namely, the production technology of the high-tech intermediate good, on the contrary, is the truly innovative one.

To produce the quantity I of intermediate good, the northern firm's innovative technology requires q units of labour, where q sets the quality of the new technology. Specifically, $q \in \{h, l\}$ with $l < h$. In words, technology can be of a good type (high quality), requiring an input of labour, l, or of a bad type (low quality), requiring a higher input of labour, h. While the actual type (quality) of the northern firm's technology is private information of the northern firm, prior common (and hence, the southern firm's) beliefs are that the technology is of the good type ($q = l$) with probability θ, and therefore of the bad type

($q = h$) with probability $1 - \theta$.

In the case the two firms do not cooperate, the southern firm can successfully "reverse engineer" the northern firm's technology with a probability, $\pi(q)$, which decreases with the quality of the northern firm's technology. For simplicity, we assume that the bad-type technology can be reverse engineered by F_S with probability one: $\pi(h) = 1$. The good-type technology, on the contrary, just offers F_S a lower probability of successful imitation: $\pi(l) \in (0,1)$. Again for simplicity, we rule out any imitation (reverse engineering) cost.

Finally, only the southern firm, F_S, knows how to obtain the cheap labour in its home country, S, so that the northern firm, F_N, can locate production in country S only by cooperating with F_S.

2.2. Cooperation Modes and Default Positions

We assume that F_N and F_S may cooperate in two alternative ways: *vertical merger* and *vertical partnership*.

Under the *vertical merger* mode of cooperation, F_N and F_S merge into a single entity equipped with both the new technology of F_N and the cheap labour F_S can secure in the country S. Therefore the merged entity uses the relatively cheap labour of country S to produce both the intermediate good and final product, and then sells the final product in the S-market as a monopolistic seller. The merged firm's profit arising from this production and sale is then shared by the two initial firms.

Under the *vertical partnership* mode of cooperation, F_N uses the relatively expensive labour of country N to produce the intermediate good at home. It then sells the intermediate good to F_S. F_S combines the imported intermediate good with the relatively cheap labour of country S to produce the final product, and then sells the final product in the S-market as a monopolistic seller.

In the absence of cooperation, the "default" positions of the two firms depend on whether

F_S succeeds in reverse engineering the new technology of F_N. If F_S fails, F_N can monopolize the S-market by producing both the intermediate good and final product at home (employing the relatively expensive labour), and then exporting (for simplicity, at no export cost) the final product to country S.

If, on the contrary, F_S succeeds in reverse engineering the new technology, then both firms can produce the intermediate good and final product using the same technology, but at different labour costs. Assuming Bertrand competition in the S-market, the low-cost firm, F_S, will engage in limit pricing by setting p at the quotient of F_N's total production cost divided by the market demand $\bar{D}$, driving F_N out from the S-market.

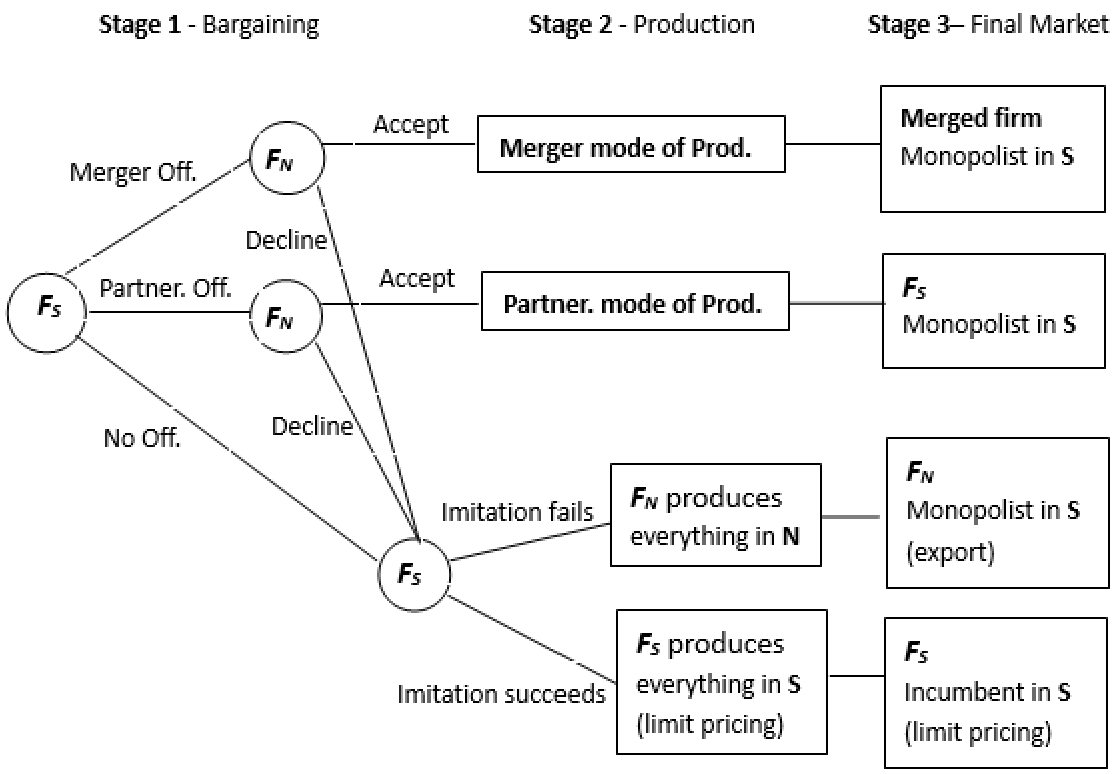
2.3. Bargaining and Timing

Our focus is on the role asymmetric information about the northern firm's technology plays on the mode of cooperation between the two firms. This role is clearly amplified by strengthening the bargaining power of the uninformed party, F_S. To simplify the analysis, we make the extreme assumption that F_S has full bargaining power. Specifically, at the first stage of our model (bargaining stage), F_S has the first mover advantage of choosing whether to make a take-or-leave-it cooperation offer and if so, whether to offer a share α of the profit of a merged firm (vertical merger offer), or a price t for the total provision of intermediate good (vertical partnership offer). If F_S does not make any offer or its offer is declined by F_N, then F_S costlessly tries to reverse engineer F_N's technology. Afterwards the two firms will enter one of the two default positions described before, depending on the outcome of F_S's imitation trial.

On the contrary, if F_N accepts a merger or a partnership offer, the two firms will enter the resulting cooperation mode, at the profit shares (merger) or at the intermediate good price (partnership) stated in F_S's accepted offer.

Figure 1 below summarizes the timing of our model.

Figure 1. Timing of the Model



3. Equilibrium Analysis

In this section, we will analyze the possible types of equilibrium in our model.

To rule out some trivial cases, we make a general assumption for all our analysis hereinafter: we assume that the size of S-market is large enough, such that if monopolizing the S-market, a firm will earn a positive profit no matter which technology, type l (good type) or h (bad type), is used to produce the product, and how the production line is located between the two countries.[8]

Then for analyzing the possible types of equilibrium, we start from the choice of the first mover, F_S. Since F_S has full bargaining power, if F_S wants to let F_N accept a vertical merger or a vertical partnership offer, the offer will leave F_S itself a profit as large as possible, and thereby just give F_N a profit that exactly meets F_N's minimum requirement: a profit equal to F_N's expected profit that F_N will earn if declining the offer and thereby entering a default position.

Therefore to see what share α of the merged firm's profit will be given to F_N in a vertical merger offer, or what price t for the intermediate good will be stated to F_N in a vertical partnership offer, we should examine F_N's expected profit facing the two possible default positions described in Section 2.2.

In the default position where F_S fails in reverse engineering a type q ($q \in \{l,h\}$) F_N's technology, the type q F_N will monopolize the S-market by producing both the intermediate good and final product at home (employing the relatively expensive labour of country N), and then exporting the final product to country S. Hence the type q F_N earns a positive profit calculated as

[8] Specifically, we just need to assume that when the technology is type h (bad type), and the whole production line is located in country N, employing the relatively expensive labour of country N to produce both the intermediate good and final product, the firm can earn a positive profit by monopolizing the S-market, namely, the profit $\bar{p}\bar{D} - w_N - w_N h > 0$. Then since this production mode consumes the highest total cost among all the possible production modes, if even a positive profit can arise from this production mode combined with monopoly over the S-market, a positive profit can arise from any other lower-cost production mode combined with monopoly over the S-market.

$\bar{p}\bar{D} - w_N - w_N q$, where $q \in \{l, h\}$.

On the contrary, in the other default position where F_S succeeds in reverse engineering, F_N will be driven out from the S-market by F_S's limit pricing in Bertrand competition, and thereby earn zero profit.

There is a probability, $\pi(q)$, with which F_S can successfully reverse engineer a type q ($q \in \{l, h\}$) F_N's technology, and thereby bring the two firms into the latter default position where F_N earns zero profit. Therefore, with probability $1 - \pi(q)$, F_S will fail to reverse engineer the type q F_N's technology, and thereby bring the two firms into the former default position where F_N earns the positive profit, $\bar{p}\bar{D} - w_N - w_N q$. Therefore facing the two possible default positions, F_N's expected profit is

$(1 - \pi(q))(\bar{p}\bar{D} - w_N - w_N q)$, where $q \in \{l, h\}$.

Then since $\pi(l) < 1$, a type l (good type) F_N has a positive expected profit, $(1 - \pi(l))(\bar{p}\bar{D} - w_N - w_N l)$, facing the two possible default positions.

On the contrary, since $\pi(h) = 1$, a type h (bad type) F_N's expected profit facing the two possible default positions is zero (a bad type F_N will always suffer F_S's successful reverse engineering, be driven out by F_S's limit pricing, and then earn zero profit).

Therefore on the one hand, to let a type l (good type) F_N accept a vertical merger offer, F_S will give a share, denoted as α^l, of the merged firm's profit to F_N, such that $\alpha^l > 0$, giving F_N a positive profit equal to a type l (good type) F_N's positive expected profit facing the two possible default positions, namely, equal to the profit $(1 - \pi(l))(\bar{p}\bar{D} - w_N - w_N l) > 0$.

On the other hand, to let a type h (bad type) F_N accept a vertical merger offer, F_S will give a share, denoted as α^h, of the merged firm's profit to F_N, such that $\alpha^h = 0$, giving F_N zero profit equal to a type h (bad type) F_N's zero expected profit facing the two possible default positions.

Thus we have the following Lemma 1.[9]

Lemma 1. *Under our general assumption that monopolizing the S-market always achieves a positive profit (regardless of the type of technology used in production, and the location of production line), we always have* $\alpha^l > \alpha^h = 0$.

Indicated by Lemma 1, F_S may choose either of the two vertical merger offers, α^l and α^h, that lead to two different types of equilibrium.[10] We denote these two types of equilibrium as Equilibrium (M1) and Equilibrium (M2) below.

Equilibrium (M1). F_S makes the vertical merger offer of α^l. Since $\alpha^l > \alpha^h$, the offer of α^l gives a type l (good type) F_N a positive profit equal to the type l F_N's expected profit facing the two possible default positions, while this offer gives a type h (bad type) F_N a positive profit greater than the type h F_N's zero expected profit facing the two possible default positions. Then no matter F_N is type l (good type) or h (bad type), it will accept the offer, and thereby bring the two firms into a vertical merger.

Equilibrium (M2). F_S makes the vertical merger offer of α^h. Since $\alpha^h < \alpha^l$, the offer of α^h gives F_N a zero profit equal to a type h (bad type) F_N's zero expected profit facing the two possible default positions, while smaller than a type l (good type) F_N's positive expected profit facing the two possible default positions. Then if F_N is type h (bad type), it will accept the offer and thereby bring the two firms into a vertical merger, while if F_N

[9] The proof of Lemma 1 is presented in Appendix 1.1.

[10] As mentioned in Footnote 3, We can assume F_S may also choose an offer of fixed-fee licensing. An offer of fixed-fee licensing means F_S gives F_N a fixed fee to gain the technology, and then F_S produces both the intermediate good and final product in country S. Similar to the intuition for choosing a vertical partnership or a vertical merger offer, F_S may choose either of two types of fixed-fee licensing offer: 1) a licensing offer that meets a type h (bad type) F_N's minimum requirement; and 2) a licensing offer that meets a type l (good type) F_N's minimum requirement. We can prove that the former licensing offer is equivalent to the vertical merger offer of α^h, while the latter licensing offer is always dominated by the vertical merger offer of α^l. Then we can exclude the option of fixed-fee licensing from our theoretical analysis. The detailed proof and intuition are presented in Appendix 2.1.

is type l (good type), it will decline the offer and thereby bring the two firms into one of the two possible default positions, depending on the outcome of F_S's trial in reverse engineering F_N's technology.

As for vertical partnership offers, on the one hand, to let a type l (good type) F_N accept a vertical partnership offer, F_S will state a price, denoted as t^l, for the total provision of intermediate good by F_N, such that t^l gives F_N a profit equal to a type l (good type) F_N's positive expected profit facing the two possible default positions, namely, equal to the profit $(1-\pi(l))(\bar{p}\bar{D}-w_N-w_Nl)>0$. We can see the profit given by t^l to a type l (good type) F_N equals t^l deducting the type l F_N's cost, w_Nl, for producing the intermediate good in country N (employing the relatively expensive labour of country N), and then we let this profit equal the type l F_N's positive expected profit facing the two possible default positions, namely, we have

$$t^l - w_Nl = (1-\pi(l))(\bar{p}\bar{D}-w_N-w_Nl) \iff$$

$$t^l = w_Nl + (1-\pi(l))(\bar{p}\bar{D}-w_N-w_Nl)$$

On the other hand, to let a type h (bad type) F_N accept a vertical partnership offer, F_S will state a price, denoted as t^h, for the total provision of intermediate good by F_N, such that t^h gives F_N a profit equal to a type h (bad type) F_N's zero expected profit facing the two possible default positions. We can see the profit given by t^h to a type h (bad type) F_N equals t^h deducting the type h F_N's cost, w_Nh, for producing the intermediate good in country N (employing the relatively expensive labour of country N), and then we let this profit equal the type h F_N's zero expected profit facing the two possible default positions, namely, we have

$$t^h - w_Nh = 0 \iff$$

$$t^h = w_Nh + 0 = w_Nh$$

Therefore from the expressions of t^l and t^h, we see that we may have either $t^l < t^h$ or $t^l > t^h$, namely, there is ambiguity on the sign of $t^l - t^h$. The ambiguity stems from the coexistence of two opposing forces: on the one hand, t^h has to compensate a bad type F_N for the higher cost of home production, whereas on the other hand, t^l has to account for the expected profit of a good type F_N that emanates from the likelihood that F_S will not be able to reverse engineer the technology, thus granting monopoly power to the good type F_N. The former force tends to make t^h above t^l, whereas in contrast, the latter force tends to make t^l above t^h.

We analyse how this ambiguity on the sign of $t^l - t^h$ is affected by the values of l and h, and thereby have the following Lemma 2.[11]

Lemma 2. *We can have either $t^l < t^h$ or $t^l > t^h$. If the gap between l and h exceeds a threshold such that*

$h > f^1(l) = \pi(l)l + \frac{(1-\pi(l))(\bar{p}\bar{D}-w_N)}{w_N}$, *where $f^1(l)$ increases with l,*

we have $t^l < t^h$.

Otherwise, if $h < f^1(l)$, we have $t^l > t^h$.

Lemma 2 tells us how the gap between h and l affects which of the two opposing forces we mentioned before prevails, and thus the sign of $t^l - t^h$. If the gap between h and l and thus the gap between the production costs of F_N's two types is large enough, the former force that t^h has to compensate the higher production cost of a bad type F_N prevails, making t^h above t^l. Otherwise, if the gap between h and l and thus the gap in production costs is not large enough, the former force stemming from the cost gap is too weak, and thus outweighed by the latter force that t^l has to account for the expected profit of a good type F_N emanating from the likelihood of F_S's failed reverse engineering, making t^l above t^h.

[11] The proof of Lemma 2 is presented in Appendix 1.2.

Actually, a larger gap between h and l has another effect opposite to the effect we discussed above, namely, an effect that enhances the latter force making t^l above t^h: a larger gap between h and l caused by a lower l means that a good type F_N has higher efficiency, and thus a higher expected profit to be captured by t^l. However, this effect of larger gap between h and l is always dominated by the effect we discussed in the previous paragraph.

Indicated by Lemma 2, we should discuss the types of vertical partnership offer and resulting equilibrium in the situation $t^l < t^h$, and those in the situation $t^l > t^h$, respectively.

On the one hand, if $h > f^1(l)$ and thereby $t^l < t^h$, F_S may choose either of the two vertical partnership offers, t^l and t^h, that lead to two different types of equilibrium. We denote these two types of equilibrium as Equilibrium (P1) and Equilibrium (P2) below.

Equilibrium (P1). F_S makes the vertical partnership offer of t^l. Since $t^l < t^h$, the offer of t^l gives a type l (good type) F_N a positive profit equal to the type l F_N's expected profit facing the two possible default positions, while this offer gives a type h (bad type) F_N a negative profit smaller than the type h F_N's zero expected profit facing the two possible default positions (since t^l is even smaller than and thus cannot cover the type h F_N's production cost). Then if F_N is type l (good type), it will accept the offer and thereby bring the two firms into a vertical partnership, while if F_N is type h (bad type), it will decline the offer and thereby bring the two firms into the default position where F_S successfully reverse engineers F_N's technology, drives F_N out by limit pricing, and then monopolizes the S-market.

Equilibrium (P2). F_S makes the vertical partnership offer of t^h. Since $t^h > t^l$, the offer of t^h gives a type h (bad type) F_N a zero profit equal to the type h F_N's zero expected profit facing the two possible default positions, and this offer gives a type l (good type) F_N a positive profit greater than the type l F_N's expected profit facing the two possible default positions. Then no matter F_N is type l (good type) or h (bad type), it will accept the offer, and thereby bring the two firms into a vertical partnership.

We can see if F_S makes the vertical partnership offer of t^l, with $t^l < t^h$, and then the offer is only acceptable to a type l (good type) F_N, resulting in Equilibrium (P1), F_S can screen out and thereby avoid cooperating with a type h (bad type) F_N. This screening function can never be achieved by a vertical merger offer.

On the other hand, if $h < f^1(l)$ and thereby $t^l > t^h$, F_S can still choose either of the two vertical partnership offers, t^l and t^h, but now instead of Equilibrium (P1) and Equilibrium (P2), the two offers will lead to another two types of equilibrium, respectively. We denote these two new types of equilibrium as Equilibrium (P1*) and Equilibrium (P2*) below.

Equilibrium $(\mathbf{P1}^*)$. F_S makes the vertical partnership offer of t^l. Since $t^l > t^h$, the offer of t^l gives a type l (good type) F_N a positive profit equal to the type l F_N's expected profit facing the two possible default positions, and this offer gives a type h (bad type) F_N a positive profit greater than the type h F_N's zero expected profit facing the two possible default positions. Then no matter F_N is type l (good type) or h (bad type), it will accept the offer, and thereby bring the two firms into a vertical partnership.

Equilibrium $(\mathbf{P2}^*)$. F_S makes the vertical partnership offer of t^h. Since $t^h < t^l$, the offer of t^h gives a type h (bad type) F_N a zero profit equal to the type h F_N's zero expected profit facing the two possible default positions, while this offer gives a type l (good type) F_N a positive profit smaller than the type l F_N's expected profit facing the two possible default positions. Then if F_N is type h (bad type), it will accept the offer and thereby bring the two firms into a vertical partnership, while if F_N is type l (good type), it will decline the offer and thereby bring the two firms into one of the two possible default positions, depending on the outcome of F_S's trial in reverse engineering F_N's technology.

We have found six types of equilibrium, (M1), (M2), (P1), (P2), (P1*) and (P2*). Among these six types, the set of (P1) and (P2) and the set of (P1*) and (P2*) are alternatives to each other. (P1*) and (P2*) are replaced by (P1) and (P2) if $t^l < t^h$, and vice versa if $t^l > t^h$. Then in one situation, either $t^l < t^h$ or $t^l > t^h$, there are just four possible types of equilibrium in our model, either (M1), (M2), (P1) and (P2), or (M1), (M2), (P1*) and

(P2*).

When either $t^l < t^h$ or $t^l > t^h$, the first mover, F_S, faces the choice among four offers (two merger offers, α^l and α^h, with $\alpha^l > \alpha^h$, and also two partnership offers, t^l and t^h, with either $t^l < t^h$ or $t^l > t^h$) that respectively lead to four types of equilibrium (either (M1), (M2), (P1) and (P2), or (M1), (M2), (P1*) and (P2*)). Then F_S will compare its expected profits among the four possible types of equilibrium, and then choose an offer leading to a type of equilibrium that gives F_S the highest expected profit.

Moreover, by the settings of our model, F_S has another choice: F_S can make no offer at the first stage (bargaining stage), and thereby directly bring the two firms into one of the two possible default positions. However, we can prove that F_S will never make this choice of no offer, since this choice is always dominated by the vertical merger offer of $\alpha^h = 0$.[12] Then it's impossible for our model to have a type of equilibrium that results from F_S's choice of no offer. The intuition is that the merger offer of $\alpha^h = 0$ helps F_S avoid the competition with a type h (bad type) F_N. In the merger of $\alpha^h = 0$ with a type h (bad type) F_N, F_S can sell the products at the highest price $\bar{p}$, and then get the whole profit without any left to F_N. However, in the default position competing with a type h (bad type) F_N, F_S can still get the whole profit but has to set a price lower than $\bar{p}$ to drive out F_N, and thereby earns a smaller profit than that in the merger of $\alpha^h = 0$.[13]

4. Partnership Vs. Merger

In this section, by referring to the types of equilibrium we have found, we will discuss the trade-off we focus on: the trade-off between the possibility to screen out low-quality technologies (for the vertical partnership) and higher overall cost efficiency (for the vertical merger). Now this trade-off manifests as F_S's trade-off between the vertical partnership offer that can screen out a type h (bad type) F_N, and either of the two vertical

[12] The detailed proof is presented in Appendix 2.2.

[13] Even if we relax our assumption $\pi(h) = 1$ to $\pi(h) \in (\pi(l), 1)$, and then get $\alpha^h \in (0, \alpha^l)$ rather than $\alpha^h = 0$, F_S's option of making no offer will still be excluded. The detailed proof and intuition of this situation are presented in Appendix 2.3.

merger offers that may achieve a merger whose overall cost efficiency is higher than a partnership's (since the merged firm employs the relatively cheap labour of country S to produce both the intermediate good and final product, but in a partnership, the production of intermediate good still employs the relatively expensive labour of country N).

Therefore among the six types of equilibrium we have found, only three types, Equilibrium (P1) resulting from the partnership offer of t^l, with $t^l < t^h$, Equilibrium (M1) resulting from the merger offer of α^l, and Equilibrium (M2) resulting from the merger offer of α^h, refer to the trade-off we focus on. Then at first, we find a series of conditions to limit the possible types of equilibrium in our model to these three, (P1), (M1), and (M2). These conditions include the condition that makes $t^l < t^h$ and thereby rule out Equilibrium (P1*) and Equilibrium (P2*), and also several conditions that make F_S possibly prefer Equilibrium (P1), Equilibrium (M1) or Equilibrium (M2), but never prefer Equilibrium (P2).

Then we present these conditions in the following Lemma 3.[14]

[14] The proof of Lemma 3 is presented in Appendix 1.3.

Lemma 3. *(P1), (M1) and (M2) are the only possible types of equilibrium in the model if:*

(i). $max\{f^1(l), \frac{\bar{p}\bar{D}-w_N}{2w_N-w_S}\} < h < \frac{\bar{p}\bar{D}-w_N}{w_N}$,

where $f^1(l) = \pi(l)l + \frac{(1-\pi(l))(\bar{p}\bar{D}-w_N)}{w_N}$, *which increases with l;*

(ii). $l < min\{\frac{\pi(l)\bar{p}\bar{D}+(1-2\pi(l))w_N}{2\pi(l)w_N-w_S}, f^1(h)\}$,

where $f^1(h) = \frac{\bar{p}\bar{D}(w_N-w_S)h-\pi(l)(\bar{p}\bar{D}-w_N)[\bar{p}\bar{D}-w_S(1+h)]}{\bar{p}\bar{D}(w_N-w_S)-\pi(l)w_N[\bar{p}\bar{D}-w_S(1+h)]}$, *which increases with h;*

and

(iii). $F^1(h,l) < F^2(h,l)$,

where $F^1(h,l) = \frac{(w_N-w_S)l}{(w_N-w_S)(1+h)-(1-\alpha^l)[\bar{p}\bar{D}-w_S(1+h)]}$, *which decreases with h while increases with l, and* $F^2(h,l) = \frac{\pi(l)[\bar{p}\bar{D}-(2w_N-w_S)(1+l)]+w_N-w_S}{\bar{p}\bar{D}-w_N(1+h)}$ *which increases with h while decreases with l.*

For convenience, hereinafter we refer to (i), (ii) and (iii) as Condition (C).

Under the Condition (C) presented in Lemma 3, F_S's choice is limited to the three offers (the partnership offer of t^l, with $t^l < t^h$, and the two merger offers, α^l and α^h) that lead to Equilibrium (P1), Equilibrium (M1) and Equilibrium (M2), respectively, which refer to the trade-off we focus on.[15] Afterwards, we analyse how F_S's choice among the three offers is affected by the probability θ with which F_N is type l (good type), and thereby get the following Proposition 1.[16]

[15] Supplementing our main analysis that focuses on the firms' strategies, we also make a welfare analysis (referring to consumer surplus and then the total social welfare) for these three types of equilibrium, presented in Appendix 2.4.

[16] The proof of Proposition 1 is presented in Appendix 1.4.

Proposition 1. *Under Condition (C) presented in Lemma 3, there's a range of* θ *as* $[\underline{\theta}, \overline{\theta}]$ *such that:*

(1). If $\theta < \underline{\theta}$*,* F_S *makes the vertical merger offer of* α^h*, with* $\alpha^h = 0 < \alpha^l$*, and then the offer is only acceptable to a type h (bad type)* F_N *(the offer leads to Equilibrium (M2));*

(2). If $\theta \in [\underline{\theta}, \overline{\theta}]$*,* F_S *makes the vertical partnership offer of* t^l*, with* $t^l < t^h$*, and then the offer is only acceptable to a type l (good type)* F_N*, namely, the offer can screen out a type h (bad type)* F_N *(the offer leads to Equilibrium (P1));*

and

(3). If $\theta > \overline{\theta}$*,* F_S *makes the vertical merger offer of* α^l*, with* $\alpha^l > \alpha^h = 0$*, and then the offer is acceptable to* F_N *no matter* F_N *is type l (good type) or h (bad type) (the offer leads to Equilibrium (M1)).*

Proposition 1 tells us that for F_S to choose the vertical partnership offer that screens out a type h (bad type) F_N, namely, only attracts a type l (good type) F_N for cooperation, the probability θ, with which F_N is type l (good type), should not be too extreme, namely, neither too low nor too high.

One one hand, if θ is too low, it will be more economical to choose the vertical merger offer that gives up cooperating with the low-probability type l (good type) F_N. This merger offer, however, attracts the high-probability type h (bad type) F_N for a merger bringing higher overall cost efficiency than that in a partnership, and also giving F_S a fair profit share.

On the other hand, if θ is too high, it will be more economical to choose the other vertical merger offer that gives up screening out the low-probability type h (bad type) F_N. This merger offer, however, attracts the high-probability type l (good type) F_N for a merger bringing higher overall cost efficiency than that in a partnership, and also giving F_S a fair profit share.

Afterwards, we use the range $[\underline{\theta}, \overline{\theta}]$ presented in Proposition 1, the range of θ for F_S to choose the vertical partnership offer screening out a type h (bad type) F_N, as a benchmark, and then analyse how this range $[\underline{\theta}, \overline{\theta}]$ and thereby F_S's choice is affected by another two important issues: the technology gap between a type l (good type) F_N and a type h (bad type) one, and the wage gap between country N and country S.

We analyse how the range $[\underline{\theta}, \overline{\theta}]$ is affected by the technology gap between a type l (good type F_N and a type h (bad type) one (the technology gap manifests as the range $[l, h]$), and thereby get the following Proposition 2.[17]

Proposition 2. *Suppose initially, the range $[l, h] = [l_0, h_0]$, and the range $[\underline{\theta}, \overline{\theta}] = [\underline{\theta}_0, \overline{\theta}_0]$. Then if the range $[l, h] = [l_0, h_0]$ widens to a new $[l, h] \supset [l_0, h_0]$, the range $[\underline{\theta}, \overline{\theta}] = [\underline{\theta}_0, \overline{\theta}_0]$ will widen to a new $[\underline{\theta}, \overline{\theta}] \supset [\underline{\theta}_0, \overline{\theta}_0]$.*

Proposition 2 tells us that widening the initial technology gap, between a type l (good type) F_N and a type h (bad type) one, will widen/relax the range $[\underline{\theta}, \overline{\theta}]$ for F_S to choose the vertical partnership offer screening out a type h (bad type) F_N. This indicates that a larger technology gap between two types of F_N tends to make F_S choose the partnership offer with screening function.

Combining Proposition 1 and Proposition 2, we can see that for F_S to choose the vertical partnership offer screening out a type h (bad type) F_N, there are two conditions: 1) F_S has a sufficiently high uncertainty about the quality of F_N's technology, and this means F_S has sufficiently equalized prior beliefs that F_N is of any of the two quality types, namely, there is a sufficiently small difference between θ and $1-\theta$; and 2) there is a sufficiently large technology gap between a type l (good type) F_N and a type h (bad type) one.[18]

[17] The proof of Proposition 2 is presented in Appendix 1.5.

[18] To visually display the issues depicted in Proposition 1 and Proposition 2, we give a numerical example with a graph, presented in Appendix 2.5.

We can summarize the above two conditions, into one condition for F_S to choose the vertical partnership offer screening out a type h (bad type) F_N: there should be a sufficiently high "degree/importance" of asymmetric information on F_N's technology quality type (sufficiently equalized probabilities of different technology qualities, and/or large technology quality gap), and then the quality screening value achieved by the partnership offer can dominate the cost efficiency value achieved in a merger.

Also, we analyse how the range $[\underline{\theta}, \overline{\theta}]$, for F_S to choose the vertical partnership offer screening out a type h (bad type) F_N, is affected by the wage gap between country N and country S (the wage gap manifests as the range $[w_S, w_N]$). We find this effect is somewhat complicated, and then we should discuss how each country's wage rate affects each bound of the range $[\underline{\theta}, \overline{\theta}]$.

Firstly, we analyse the effect of w_N, the wage rate of country N, on $\underline{\theta}$, the lower bound of the range $[\underline{\theta}, \overline{\theta}]$, and thereby get the following Lemma 4.[19]

Lemma 4. *If the gap between l and h exceeds a threshold, such that $l < f^2(h) = \frac{(\pi(l)\bar{p}\bar{D} - w_S)(1+h) + \bar{p}\bar{D}}{\pi(l)[2\bar{p}\bar{D} - w_S(1+h)]} - 1$, where $f^2(h)$ increases with h, $\underline{\theta}$ decreases with w_N; otherwise, if $l > f^2(h)$, $\underline{\theta}$ increases with w_N.*

Secondly, we analyse the effect of w_S, the wage rate of country S, on $\underline{\theta}$, the lower bound of the range $[\underline{\theta}, \overline{\theta}]$, and thereby get the following Lemma 5.[20]

Lemma 5. *If l falls below a threshold such that $l < \frac{1}{\pi(l)} - 1$, $\underline{\theta}$ increases with w_S; otherwise, if $l > \frac{1}{\pi(l)} - 1$, $\underline{\theta}$ decreases with w_S.*

[19] The proof of Lemma 4 is presented in Appendix 1.6.

[20] The proof of Lemma 5 is presented in Appendix 1.7.

Then Lemma 4 and Lemma 5 together tell us how the wage gap between the two countries affects $\underline{\theta}$, leading to the following Proposition 3.[21]

Proposition 3. *Suppose initially, the range* $[w_S, w_N] = [w_S^0, w_N^0]$.

Then under the condition of

$$l < min\{f^2(h), \frac{1}{\pi(l)} - 1\},$$

$$\text{where } f^2(h) = \frac{(\pi(l)\bar{p}\bar{D} - w_S)(1+h) + \bar{p}\bar{D}}{\pi(l)[2\bar{p}\bar{D} - w_S(1+h)]} - 1, \text{ which increases with } h,$$

if the range $[w_S, w_N] = [w_S^0, w_N^0]$ *widens to a new* $[w_S, w_N] \supset [w_S^0, w_N^0]$, $\underline{\theta}$ *will decrease.*

However, under the condition of

$$l > max\{f^2(h), \frac{1}{\pi(l)} - 1\},$$

if the range $[w_S, w_N] = [w_S^0, w_N^0]$ *widens to a new* $[w_S, w_N] \supset [w_S^0, w_N^0]$, $\underline{\theta}$ *will increase.*

Thirdly, we analyse the effect of w_N, the wage rate of country N, on $\overline{\theta}$, the upper bound of the range $[\underline{\theta}, \overline{\theta}]$, and thereby get the following Lemma 6.[22]

Lemma 6. $\overline{\theta}$ *increases with* w_N.

Fourthly, we analyze the effect of w_S, the wage rate of country S, on $\overline{\theta}$, the upper bound of the range $[\underline{\theta}, \overline{\theta}]$, and thereby get the following Lemma 7.[23]

[21] The proof of Proposition 3 is presented in Appendix 1.8.
[22] The proof of Lemma 6 is presented in Appendix 1.9.
[23] The proof of Lemma 7 is presented in Appendix 1.10.

Lemma 7. *If $\pi(l)$ exceeds a threshold such that* $\pi(l) > \frac{(w_N - w_S)(1+l)\{[\bar{p}\bar{D} - w_N(1+l)][\bar{p}\bar{D} - w_S(1+h)] - [\bar{p}\bar{D} - w_N(1+h)][\bar{p}\bar{D} - w_S(1+l)]\}}{[\bar{p}\bar{D} - w_N(1+l)]\{[\bar{p}\bar{D} - w_N(1+h)][\bar{p}\bar{D} - w_S(1+l)] + (w_N - w_S)(1+l)[\bar{p}\bar{D} - w_S(1+h)]\}}$, *$\overline{\theta}$ decreases with w_S; otherwise, if* $\pi(l) < \frac{(w_N - w_S)(1+l)\{[\bar{p}\bar{D} - w_N(1+l)][\bar{p}\bar{D} - w_S(1+h)] - [\bar{p}\bar{D} - w_N(1+h)][\bar{p}\bar{D} - w_S(1+l)]\}}{[\bar{p}\bar{D} - w_N(1+l)]\{[\bar{p}\bar{D} - w_N(1+h)][\bar{p}\bar{D} - w_S(1+l)] + (w_N - w_S)(1+l)[\bar{p}\bar{D} - w_S(1+h)]\}}$, *$\overline{\theta}$ increases with w_S.*

Then Lemma 6 and Lemma 7 together tell us how the wage gap between the two countries affects $\overline{\theta}$, leading to the following Proposition 4.[24]

Proposition 4. *Suppose initially, the range $[w_S, w_N] = [w_S^0, w_N^0]$.*

If $\pi(l) > \frac{(w_N - w_S)(1+l)\{[\bar{p}\bar{D} - w_N(1+l)][\bar{p}\bar{D} - w_S(1+h)] - [\bar{p}\bar{D} - w_N(1+h)][\bar{p}\bar{D} - w_S(1+l)]\}}{[\bar{p}\bar{D} - w_N(1+l)]\{[\bar{p}\bar{D} - w_N(1+h)][\bar{p}\bar{D} - w_S(1+l)] + (w_N - w_S)(1+l)[\bar{p}\bar{D} - w_S(1+h)]\}}$,

widening the range $[w_S, w_N] = [w_S^0, w_N^0]$, to any new $[w_S, w_N] \supset [w_S^0, w_N^0]$, will raise $\overline{\theta}$.

Even if $\pi(l) \leq \frac{(w_N - w_S)(1+l)\{[\bar{p}\bar{D} - w_N(1+l)][\bar{p}\bar{D} - w_S(1+h)] - [\bar{p}\bar{D} - w_N(1+h)][\bar{p}\bar{D} - w_S(1+l)]\}}{[\bar{p}\bar{D} - w_N(1+l)]\{[\bar{p}\bar{D} - w_N(1+h)][\bar{p}\bar{D} - w_S(1+l)] + (w_N - w_S)(1+l)[\bar{p}\bar{D} - w_S(1+h)]\}}$,

"upward unidirectionally" widening the range $[w_S, w_N] = [w_S^0, w_N^0]$, namely, raising $w_N = w_N^0$ to any new $w_N > w_N^0$, while keeping $w_S = w_S^0$, will still raise $\overline{\theta}$.

Proposition 3 and Proposition 4 depict how the wage gap affects F_S's choice in two situations, respectively. On the one hand, Proposition 3 depicts the wage gap's effect(s) in a situation under which if the probability θ is relatively low, and then F_S faces the trade-off between the vertical merger offer only acceptable to a type h (bad type) F_N, and the vertical partnership offer screening out a type h (bad type) F_N. On the other hand, Proposition 4 depicts the wage gap's effect(s) in another situation under which if the probability θ is relatively high, and then F_S faces the trade-off between the vertical merger offer acceptable to F_N no matter F_N is any of the two types, and the vertical partnership offer screening out a type h (bad type) F_N.

[24] The proof of Proposition 4 is presented in Appendix 1.11.

In both situations, there is an intuitive effect making a larger wage gap between the two countries work in favour of one of the vertical merger offers: a larger wage gap means a larger difference in overall cost efficiency by which a merger (where the production of both the intermediate good and final product employs the relatively cheap labour of country *S*) exceeds a partnership (where the production of intermediate good still employs the relatively expensive labour of country *N*). However, referring to the two firms' possible competition after offer rejection, there are other indirect effects which make a larger wage gap work in favour of the partnership offer with screening function, and thereby make the overall effect of the wage gap interestingly less straightforward.

In the situation corresponding to Proposition 3, there is an indirect effect that favours the partnership offer screening out a type h (bad type) F_N. This effect is that a larger wage gap between the two countries gives F_S a stronger labour-cost advantage, and then F_S has a higher tendency to make use of its labour-cost advantage, for getting a favourable deal in cooperation with a type l (good type) F_N that has relatively strong technological advantage, or for winning the competition with a type h (bad type) F_N that has relatively weak technological advantage. Then F_S is more towards an offer that may achieve cooperation with a type l (good type) F_N, or competition with a type h (bad type) F_N. This is just the partnership offer screening out a type h (bad type) F_N. On the contrary, F_S is less towards an offer that may achieve the opposite: cooperation with a type h (bad type) F_N, or competition with a type l (good type) F_N. This is just the merger offer only acceptable to a type h (bad type) F_N.

We can see Proposition 3 shows that, if the technology gap between two types of F_N is sufficiently large, widening the initial wage gap will decrease/relax the lower bound of the range $[\underline{\theta}, \overline{\theta}]$ for F_S to choose the partnership offer with screening function. On the contrary, if the technology gap between two types of F_N is not sufficiently large, widening the initial wage gap will increase/tighten the lower bound of the range $[\underline{\theta}, \overline{\theta}]$ for F_S to choose the partnership offer with screening function. This means if the technology gap between two types of F_N is sufficiently large, the difference between two types is important enough, and then F_S will focus on this difference. Therefore the indirect effect corresponding to this difference prevails, making the overall effect of a larger wage gap work in the same direction as the indirect effect, namely, work in favour of the partnership offer with screening function. On the contrary, if the technology gap between two types of F_N is not sufficiently large, the difference between two types is not important enough, and then F_S will ignore this difference while focus on the difference in overall cost efficiency between merger and partnership. Therefore the intuitive effect corresponding to the difference in cost efficiency prevails, making the overall effect of a larger wage gap work in the same direction as the intuitive effect, namely, work in favour of the merger offer feasible in this situation.

Also, in the situation corresponding to Proposition 4, there is also an indirect effect, which is similar to, but not totally the same as, that in the situation corresponding to Proposition 3. The indirect effect here is that a larger wage gap between the two countries gives F_S a stronger labour-cost advantage, and then if suffering a type h (bad type) F_N, F_S has a higher tendency to make use of its labour-cost advantage, for winning the competition with the type h (bad type) F_N, rather than engage in an "unfavourable merger" with this type h (bad type) F_N: a merger with a type h (bad type) F_N that gives the F_N a profit share α^l greater than this type h (bad type) F_N's minimum requirement, that is just $\alpha^h = 0 < \alpha^l$. Then F_S is more towards the partnership offer that screens out, and thereby avoids cooperating with a type h (bad type) F_N, since this offer may achieve competition with a type h (bad type) F_N. On the contrary, F_S is less towards the merger offer (α^l) acceptable to an F_N of any of the two types, since this offer may achieve an "unfavourable merger" with a type h (bad type) F_N (giving profit share α^l, greater than the type h (bad type) F_N's minimum requirement that is just $\alpha^h = 0 < \alpha^l$).

We can see Proposition 4 shows that, mostly, widening the initial wage gap will increase/relax the upper bound of the range $[\underline{\theta}, \overline{\theta}]$ for F_S to choose the partnership offer with screening function. This means mostly, in the situation corresponding to Proposition 4, the indirect effect, which makes a larger wage gap work in favour of the partnership offer with screening function, prevails over the intuitive effect, which makes a larger wage gap work in favour of the merger offer feasible in this situation. Therefore the overall effect of a larger wage gap works in the same direction as the indirect effect, namely, works in favour of the partnership offer with screening function.

Just in an exceptional circumstance that $\pi(l) \in (\frac{\bar{p}\bar{D}-w_N(1+h)}{\bar{p}\bar{D}-w_N(1+l)}, \frac{(w_N-w_S)(1+l)\{[\bar{p}\bar{D}-w_N(1+l)][\bar{p}\bar{D}-w_S(1+h)]-[\bar{p}\bar{D}-w_N(1+h)][\bar{p}\bar{D}-w_S(1+l)]\}}{[\bar{p}\bar{D}-w_N(1+l)]\{[\bar{p}\bar{D}-w_N(1+h)][\bar{p}\bar{D}-w_S(1+l)]+(w_N-w_S)(1+l)[\bar{p}\bar{D}-w_S(1+h)]\}})$, where the upper bound is the threshold of $\pi(l)$ presented in Lemma 7, and the lower bound comes from the condition $t^l < t^h$ ($\pi(l)$ should be high enough to make a type l (good type) F_N's expected profit by no cooperation small enough, thereby making the t^l low enough), and a widening of the wage gap mainly comes from a decrease in w_S, the widening of wage gap will lower/tighten $\overline{\theta}$, working in favour of the merger offer feasible in this situation: the merger offer of α^l.

The intuition in this exceptional circumstance is that if $\pi(l)$ is low enough and then the profit share α^l is high enough, a decrease in w_S has a strong enough effect to reduce the share α^l and thereby increase the profit share $(1-\alpha^l)$ left to F_S. This effect on the profit shares complements the effect that a lower w_S increases the total profit of the merged entity, forming a strong enough total effect to make the "unfavourable merger" of α^l with a type h (bad type) F_N not so unfavourable as before. This total effect in favour of the "unfavourable merger" offsets some of the wage gap's indirect effect we discussed before, which is the indirect effect that a widening of the wage gap, here caused by a decrease in w_S, favours F_S's default position competing with a type h (bad type) F_N rather than the "unfavourable merger" with this F_N. Then this "favouring default position" indirect effect discussed before becomes relatively weak here, and thereby outweighed by the intuitive effect that a widening of the wage gap, here caused by a decrease in w_S, increases the cost efficiency gap that a merger exceeds a partnership, thereby favouring the feasible merger offer. Thus eventually, in this exceptional circumstance, a widening of the wage gap caused by a decrease in w_S works in favour of the merger offer of α^l.

5. Concluding Remarks

In this chapter, we develop a theoretical model to discuss some novelty in the vertical cooperation between a high-tech northern firm, which possesses an innovative technology for a new product, and a southern firm, which can mobilize relatively cheap and qualified labour in its home country to produce the northern firm's product. We argue that, if greenfield FDI (i.e., the northern firm opens its own plant in the southern country) is ruled out by the southern firm alone being able to mobilize cheap and qualified labour in the southern country, and licensing is not feasible because of both strong information asymmetries on the northern firm's technology (i.e., technology information known to the northern firm itself but not to the southern firm), and high risk of the southern firm's imitation (once getting the northern firm's technology through licensing), the two firms should consider other cooperation modes to combine northern technology and cheap southern labour to produce and sell the northern firm's product in the southern country.

A possible mode is *vertical merger*, whereby the northern firm and southern firm merge into a single entity which locates the entire production line of the northern firm's product in the southern country. Also, if the northern firm's technology is embodied in a high-tech intermediate good, which is then combined with labour to produce the final product, there is another possible cooperation mode, *vertical partnership*, whereby the northern firm uses its home country (relatively expensive) labour to produce the high-tech intermediate good and sells the intermediate good to the southern firm, and the southern firm then combines the intermediate good with the (cheap) southern labour to produce and sell the final product in the southern country.

On the one hand, vertical partnership is obviously less cost-efficient than a vertical merged entity, as the intermediate good production still employs the expensive northern labour in a partnership, while both intermediate good and final product are produced with the cheap southern labour in a merger. On the other hand, in the presence of asymmetric information on the quality of the northern firm's technology, the vertical partnership mode can allow the southern firm to screen out (and thereby avoid cooperating with) a northern firm endowed with a technology of low quality by making effective *separating price offers* for the provision of intermediate good. This screening function is never possible in the vertical merger mode.

Then there is an interesting trade-off between the possibility to screen out low-quality technologies (for the vertical partnership) and higher overall cost efficiency (for the vertical merger). Our detailed analysis concludes that *vertical partnerships*, rather than *vertical mergers*, tend to arise as the equilibrium mode of cooperation when asymmetric information on the quality of northern firm's technology is important, as the *quality screening* value of partnerships tends to dominate the *cost efficiency* value of vertical mergers. Higher "degree/importance" of asymmetric information on the quality of northern firm's technology, specifically, comes from: 1) higher southern firm's uncertainty about the quality of technology (more equalized prior beliefs that the technology is of any of the two quality types), and/or 2) higher efficiency (quality) gaps between high- and low-quality technologies.

Also, we analyse how the wage gap between the northern and southern country affects the trade-off between vertical partnership and vertical merger. An obvious intuitive effect makes large wage gaps work in favour of vertical mergers, since a larger wage gap leads to a lager difference in overall cost efficiency by which a merger exceeds a partnership. However, we find other indirect effects which make large wage gaps work in favour of vertical partnerships, and thereby make the overall effect of the wage gap interestingly less straightforward. Eventually, our detailed analysis indicates that: 1) If there is a relatively low probability with which the northern firm's technology is high-quality, while a relatively large efficiency gap between high- and low-quality technologies, the overall effect of a larger wage gap tends to work in favour of vertical partnership; 2) If there is a relatively low probability with which the northern firm's technology is high-quality, and a relatively small efficiency gap between high- and low-quality technologies, the overall effect of a larger wage gap tends to work in favour of vertical merger; and 3) Mostly, if there is a relatively high probability with which the northern firm's technology is high-quality, the overall effect of a larger wage gap tends to work in favour of vertical partnership.

6. Limitations

6.1. Scope of Empirical Implications

The first limitation of this theoretical work is the scope of empirical cases that can be captured by our theoretical model. Since in our model, the innovative technology is totally embodied in an ”high-tech intermediate good”, the model can capture some product innovations of intermediate goods, such as those in the example we mentioned in the introduction: the IC chip blueprints as intermediate goods for producing the final IC chips, and the IC chips as intermediate goods for producing the final electronic products. In addition, our model may capture some process innovations that can be embodied in tangible production tools. In these product/process innovations, different qualities of innovative technologies should manifest as different levels of the costs for producing the intermediate goods/production tools. In contrast, if the innovation is a product innovation of final good, or an intangible process innovation, and/or if different qualities of the innovative technology manifest as different market values of the product rather than different cost levels, the case cannot be captured by our model.

6.2. Allocation of Bargaining Powers

The second limitation comes from the extreme assumption that the uninformed party, the southern firm, has full bargaining power. Under this assumption, the northern firm can just decide whether to accept the southern firm’s cooperation offer, but has no power to argue for the cooperation mode and profit share. Then if accepting the southern firm’s offer, the northern firm always just gets its “reservation” profit, namely, a profit equal to the firm’s expected profit by no cooperation.

If we relax this assumption, namely, shift some bargaining power to the northern firm, the two firms will engage in a more complicated negotiation and finally may reach a Nash equilibrium. If the resulting equilibrium is a cooperation, the northern firm may get a profit that exceeds rather than just equals its reservation profit.

Then along with other parameters, the levels of the two firms’ bargaining powers also affect that the negotiation between F_S and F_N may result in what cooperation mode, and what profit shares in the cooperation. Specifically, in a cooperation, the bargaining powers will determine each firm’s “surplus” profit: the difference by which a firm’s actual profit exceeds its reservation profit.

Thus on the one hand, since a type l (good type) F_N's reservation profit is always greater than a type h (bad type) one's, the model may still have two types of equilibria where F_S makes a merger offer:

Equilibrium (M1). F_S makes a merger offer stating a profit share that gives F_N an profit no less than a type l (good type) F_N's reservation profit (and naturally more than a type h (bad type) one's), and then no matter F_N is type l (good type) or h (bad type), F_N will accept the offer and thereby bring the two firms into a merger.

Equilibrium (M2). F_S makes a merger offer stating a profit share that gives F_N a profit no less than a type h (bad type) F_N's reservation profit, but less than a type l (good type) one's, and then if F_N is type h (bad type), F_N will accept the offer and thereby bring the two firms into a merger, while if F_N is type l (good type), F_N will decline the offer and thereby bring the two firms into one of the two default positions, depending on the outcome of F_S's trial in reverse engineering F_N's technology.

We can see that to guarantee the existence of Equilibrium (M2), F_N's bargaining power should be sufficiently low relative to F_S's. Otherwise, although a type h (bad type) F_N's reservation profit is relatively low, the type h F_N merging with F_S will still get a profit much higher than this F_N's reservation profit, and even higher than a type l (good type) F_N's relatively high reservation profit. This makes Equilibrium (M2) disappear.

On the other hand, since in a partnership offer by F_S, the price stated for the intermediate good supplied by F_N should cover the F_N's sum of production cost and reservation profit, and a type l (good type) F_N's production cost is lower than a type h (bad type) one's, there is a situation that the price stated to a type l (good type) F_N is lower than the price stated to a type h (bad type) one: a type l (good type) F_N's production cost is much lower than a type h (bad type) one's, and thereby makes a type l (good type) F_N's sum of production cost and reservation profit is smaller than a type h (bad type) one's, although the relation between F_N's two types' reservation profits goes in the opposite direction. Then in this situation, the model still has two types of equilibria where F_S makes a partnership offer:

Equilibrium (**P1**). F_S makes a partnership offer stating a price no lower than a type l (good type) F_N's sum of production cost and reservation profit, but lower than a type h (bad type) one's, and then if F_N is type l (good type), F_N will accept the offer and thereby bring the two firms into a partnership, while if F_N is type h (bad type), F_N will decline the offer and thereby bring the two firms into the default position where F_S successfully reverse engineers F_N's technology, drives F_N out by limit pricing, and then monopolizes the S-market.

.

Equilibrium (**P2**). F_S makes a partnership offer stating a price no lower than a type h (bad type) F_N's sum of production cost and reservation profit (and naturally higher than a type l (good type) one's), and then no matter F_N is type l (good type) or h (bad type), F_N will accept the offer and thereby bring the two firms into a partnership.

We can see that to guarantee the existence of Equilibrium (P1), it is still required that F_N's bargaining power should be sufficiently low relative to F_S's. Otherwise, although a type l (good type) F_N's sum of production cost and reservation profit is relatively low, the type l F_N partnering with F_S will still get an intermediate-good price much higher than this F_N's sum of production cost and reservation profit, and even higher than a type h (bad type) F_N's relatively high sum of production cost and reservation profit. This makes Equilibrium (P1) disappear.

Then it is still that by making the partnership offer only acceptable to a type l (good type) F_N and resulting in Equilibrium (P1), F_S can screen out and thereby avoid cooperating with a type h (bad type) F_N. This screening function can never be achieved by a merger offer.

Therefore, there should be a series of conditions, similar to Condition (C) in the discussion on our initial model, that limit F_S's possible choices to the three offers we focus on: the partnership offer resulting in Equilibrium (P1) where the offer screens out a type h (bad type) F_N, and the two merger offers respectively resulting in Equilibrium (M1) and (M2), where a merger may be achieved and thus bring overall cost efficiency higher than that in a partnership. Also, for the existence of Equilibrium (M2) and Equilibrium (P1), there are extra condition(s) satisfying which means F_N's bargaining power is sufficiently low relative to F_S's. Then under all these conditions, we can see that for F_S to choose the partnership offer that screens out a type h (bad type) F_N, rather than one of the merger offers that may bring higher overall cost efficiency, the condition is still that there is a sufficiently high "degree/importance" of asymmetric information on F_N's technology quality type (sufficiently equalized probabilities of different technology qualities, and/or large technology quality gap), and then the quality screening value achieved by the partnership offer dominates the cost efficiency value achieved in a merger.

Thus we can see that if the northern firm has some bargaining power, but its bargaining power is still sufficiently low relative to the southern firm's, the effects at play in the *cost efficiency vs. technology screening* trade-off of our study still works in a similar direction, since even after shifting the allocation of bargaining power towards the northern firm, separating technological quality through merger offers would still be problematic, as a northern firm with higher quality technology enjoys a higher outside option, while the higher production efficiency of this northern firm would still create room for optimal separating partnership agreements. However, if the northern firm's bargaining power is quite high, the effects in the *cost efficiency vs. technology screening* trade-off tend to disappear. Specifically, it is obvious that these effects in the *cost efficiency vs. technology screening* trade-off do not exist in another extreme situation that the northern firm has full bargaining power. In this situation, the northern firm rather than southern firm has the initiative to make a take-or-leave offer, and any offer by the northern firm will just let the southern firm get its reservation profit. Then there is no opportunity for the southern firm to screen the northern firm's technology quality.

6.3. Elasticity of Demand

The third limitation comes from the assumption of an inelastic demand for the new product in the potential market of the southern country. If we relax this assumption, namely, assume a demand with some elasticity, additional effects will be caused by the price elasticity of demand, and then with these effects, we can have a more proper welfare analysis (referring to consumer surplus and then the total social welfare). However, we expect that even with an elastic demand, the basic trade-off between cost efficiency and screening which underlies the comparison between vertical merger and vertical partnership would still generate the same qualitative effects.

6.4. The Southern Firm's Probability of Reverse Engineering

Moreover, another limitation comes from the assumption that the southern firm's probability to successfully reverse engineer a good or bad type northern firm's technology is given. Alternatively, we can make an extended assumption that the northern firm could make extra investment to reduce the southern firm's probability of successful reverse engineering. This is supported by much theoretical and empirical literature indicating that a firm may invest in barrier(s) to the imitation of the firm's technology(/ies) (Reed and Defillippi, 1990; Zander and Kogut, 1995; González-Álvarez and Nieto-Antolín, 2007; Keupp et al., 2010). Under this extended assumption, we can let M denote the northern firm's extra investment, and thereby specify a setting as following:

$\pi(q) = \frac{\pi_0(q)}{1+\lambda M}$, where $q \in \{l, h\}$, with $0 < \pi_0(l) < \pi_0(h) \leq 1$, and λ is a positive constant.

In this setting, the southern firm's probability of successful reverse engineering (on the technology of a northern firm of any type), $\pi(q)$, decreases with the northern firm's extra investment, while still falls in the range $(0, 1]$. Also, the "autonomous" probability for a good type northern firm's technology to be successfully reverse engineered, $\pi_0(l)$, is still lower than that for a bad type one's to be successfully reverse engineered, $\pi_0(h)$, where the "autonomous" probability, $\pi_0(q)$, means that when a northern firm makes zero extra investment, what probability it suffers for its technology to be successfully reverse engineered. Then the northern firm faces a trade-off: a larger extra investment decreases the southern firm's probability of successful reverse engineering and thus increases the northern firm's expected profit by no cooperation, but a larger extra investment also means a larger extra cost consumed by the northern firm and thus decreases the northern firm's profit in any situation. Thus the northern firm will find an optimal amount of extra investment to maximize its expected profit by no cooperation, since this profit is also what the northern firm gets in any cooperation under the assumption that the southern firm has full bargaining power. We can prove that if both a good type northern firm and a bad type one make their optimal amounts of extra investment, respectively, the probability for the good type northern firm's technology to be successfully reverse engineered is always lower than that for the bad type one's, and also, the good type northern firm's expected profit by no cooperation is always greater than the bad type one's.[25] This consists with our initial model.[26]

Therefore, we can expect that under the extended assumption capturing the northern firm's investment for hampering the southern firm's reverse engineering, if we take the setting specified in the previous paragraph, the effects at play in the *cost efficiency vs. technology screening* trade-off of our study will work in a direction similar to that in our initial model. However, it still awaits further research to examine that in other settings capturing the northern firm's "barrier to reverse engineering" investment, whether the effects at play in the *cost efficiency vs. technology screening* trade-off will still exist and if exist, how these effects will work.

[25] The detailed proof is presented in Appendix 2.6

[26] Here under the optimal amount of extra investment by the northern firm of each type, we have $0 < \pi(l) < \pi(h) \leq 1$, slightly different from our initial model where we always have $\pi(h) = 1$, but as mentioned in Footnote 12 and proved in Appendix 2.3, this slight difference will not invalidate the exclusion of the southern firm's no-offer choice, and thus will not significantly change the discussion.

Appendix 1 –

1.1. Proof of Lemma 1

We can calculate a type q ($q \in \{l,h\}$) F_N's expected profit facing the two possible default positions as

$$(1-\pi(q))(\bar{p}\bar{D}-w_N-w_Nq).$$

Also, If a type q F_N accepts a merger offer from F_S and then the two firms engage in a vertical merger, the merged entity's profit will be

$$\bar{p}\bar{D}-w_S-w_Sq.$$

Then a share α^q ($\alpha^q \in \{\alpha^l,\alpha^h\}$) of this merged entity's profit should equal a type q F_N's expected profit facing the two possible default positions, namely,

$$\alpha^q(\bar{p}\bar{D}-w_S-w_Sq) = (1-\pi(q))(\bar{p}\bar{D}-w_N-w_Nq).$$

In addition, under our general assumption that monopolizing the S-market always achieves a positive profit, we have

$$(\bar{p}\bar{D}-w_N-w_Nq) > 0, \text{ where } q \in \{l,h\}$$

Then since $\pi(l) < 1$, we have

$$\alpha^l(\bar{p}\bar{D}-w_S-w_Sl) = (1-\pi(l))(\bar{p}\bar{D}-w_N-w_Nl) > 0 \iff$$

$$\alpha^l = (1-\pi(l))[\tfrac{\bar{p}\bar{D}-w_N(1+l)}{\bar{p}\bar{D}-w_S(1+l)}] > 0,$$

and since $\pi(h) = 1$, we have

$$\alpha^h(\bar{p}\bar{D}-w_S-w_Sh) = (1-\pi(h))(\bar{p}\bar{D}-w_N-w_Nh) = 0 \iff$$

$\alpha^h = 0.$

Thus we always have $\alpha^l > \alpha^h = 0$.

1.2. Proof of Lemma 2

A type q ($q \in \{l, h\}$) F_N's expected profit facing the two possible default positions is still

$$(1-\pi(q))(\bar{p}\bar{D} - w_N - w_N q).$$

Also, if a type q F_N accepts F_S's vertical partnership offer of $t = t^q$ ($t^q \in \{t^l, t^h\}$), and then the two firms engage in a vertical partnership, F_N's profit will be

$$t^q - w_N q.$$

These two profits should equal each other, namely,

$$t^q - w_N q = (1-\pi(q))(\bar{p}\bar{D} - w_N - w_N q).$$

Therefore $t^l - w_N l = (1-\pi(l))(\bar{p}\bar{D} - w_N - w_N l) \iff$

$$t^l = w_N l + (1-\pi(l))(\bar{p}\bar{D} - w_N - w_N l) = \pi(l) w_N l + (1-\pi(l))(\bar{p}\bar{D} - w_N),$$

and since $\pi(h) = 1$, $t^h - w_N h = (1-\pi(h))(\bar{p}\bar{D} - w_N - w_N h) = 0 \iff$

$$t^h = w_N h.$$

Thus if $\pi(l) w_N l + (1-\pi(l))(\bar{p}\bar{D} - w_N) < w_N h \iff$

$$h > f^1(l) = \pi(l) l + \frac{(1-\pi(l))(\bar{p}\bar{D} - w_N)}{w_N},$$

we have $t^l < t^h$.

Otherwise, if $h < f^1(l) = \pi(l)l + \frac{(1-\pi(l))(\bar{p}\bar{D}-w_N)}{w_N}$,

we have $t^l > t^h$.

1.3. Proof of Lemma 3

Firstly, under our our general assumption that monopolizing the S-market always achieves a positive profit, we have

$\bar{p}\bar{D} - w_N - w_N h > 0 \iff h < \frac{\bar{p}\bar{D}-w_N}{w_N}$.

Secondly, it was proved in Lemma 2 that if $h > f^1(l)$, we have $t^l < t^h$, and then Equilibrium (P1*) and Equilibrium (P2*) are excluded.

Thirdly, we can calculate F_S's expected profits in Equilibrium (P1) and Equilibrium (P2), respectively , as

(P1): $\theta\left(\bar{p}\bar{D} - w_S - t^l\right) + (1-\theta)\left(p_N(h)\bar{D} - w_S - w_S h\right) =$
$\theta\left[\pi(l)\left(\bar{p}\bar{D} - w_N - w_N l\right) + w_N - w_S\right] + (1-\theta)\left(w_N - w_S\right)(1+h)$,

where $p_N(h)$ is the price set by F_S in limit pricing to beat a type h (bad type) F_N in Bertrand competition, such that $p_N(h)$ equals the quotient of a type h (bad type) F_N's total production cost divided by the market demand $\bar{D}$, namely, $p_N(h) = \frac{w_N + w_N h}{\bar{D}}$.

(P2): $\theta\left(\bar{p}\bar{D} - w_S - t^h\right) + (1-\theta)\left(\bar{p}\bar{D} - w_S - t^h\right) =$
$\theta\left(\bar{p}\bar{D} - w_S - w_N h\right) + (1-\theta)(\bar{p}\bar{D} - w_S - w_N h)$.

Comparing the profit in (P2) with that in (P1), we can see the first term of the profit in (P2) is always smaller than that of the profit in (P1), since $t^h > t^l$. Then we will have "profit in (P2)"<"profit in (P1)", if the second term of the profit in (P2) is also smaller than that of the profit in (P1), namely,

$$(1-\theta)\left(\bar{p}\bar{D}-w_S-w_N h\right)<(1-\theta)(w_N-w_S)(1+h) \iff$$

$$h>\tfrac{\bar{p}\bar{D}-w_N}{2w_N-w_S}.$$

Therefore if $h>\frac{\bar{p}\bar{D}-w_N}{2w_N-w_S}$, F_S prefers the offer leading to Equilibrium (P1) rather than that leading to (P2), and then Equilibrium (P2) is excluded.

Fourthly, we can also calculate F_S's expected profits in Equilibrium (M1) and Equilibrium (M2), respectively, as

(M1): $\theta\left(1-\alpha^l\right)\left(\bar{p}\bar{D}-w_S-w_S l\right)+(1-\theta)\left(1-\alpha^l\right)\left(\bar{p}\bar{D}-w_S-w_S h\right)=$
$\theta\left[\pi(l)(\bar{p}\bar{D}-w_N-w_N l)+(w_N-w_S)(1+l)\right]+(1-\theta)\left(1-\alpha^l\right)\left(\bar{p}\bar{D}-w_S-w_S h\right);$

(M2): $\theta\pi(l)\left[p_N(l)\bar{D}-w_S-w_S l\right]+(1-\theta)\left(\bar{p}\bar{D}-w_S-w_S h\right)=$
$\theta\pi(l)(w_N-w_S)(1+l)+(1-\theta)\left(\bar{p}\bar{D}-w_S-w_S h\right),$

where $p_N(l)$ is the price set by F_S in limit pricing to beat a type l (good type) F_N in Bertrand competition, such that $p_N(l)$ equals the quotient of a type l (good type) F_N's total production cost divided by the market demand $\bar{D}$, namely, $p_N(l)=\frac{w_N+w_N l}{\bar{D}}$.

Comparing the profit in (M1) with that in (M2), we can see the first term of the profit in (M1) is always greater than that of the profit in (M2), namely,

$$\theta\left[\pi(l)(\bar{p}\bar{D}-w_N-w_N l)+(w_N-w_S)(1+l)\right]>\theta\pi(l)(w_N-w_S)(1+l).$$

In contrast, since $\alpha^l>0$, the second term of the profit in (M1) is always smaller than that of the profit in (M2), namely

$$(1-\theta)\left(1-\alpha^l\right)\left(\bar{p}\bar{D}-w_S-w_S h\right)<(1-\theta)\left(\bar{p}\bar{D}-w_S-w_S h\right).$$

Therefore we can have either "profit in (M1)">"profit in (M2)" or "profit in (M1)"<"profit in (M2)", depending on the value of θ, and then both the offer leading to Equilibrium (M1) and that leading to (M2) are possible choices for F_S.

In addition, comparing the profit in (P1) with that in (M1), we can see the first term of the profit in (P1) is always smaller than that of of the profit in (M1), namely,

$$\theta\left[\pi(l)\left(\bar{p}\bar{D}-w_N-w_Nl\right)+w_N-w_S\right]$$
$$<\theta\left[\pi(l)(\bar{p}\bar{D}-w_N-w_Nl)+(w_N-w_S)(1+l)\right].$$

Then to make the profit in (P1) possibly greater than that in (M1), we should make the second term of the profit in (P1) greater than that of the profit in (M1), namely,

$$(1-\theta)(w_N-w_S)(1+h)>(1-\theta)\left(1-\alpha^l\right)(\bar{p}\bar{D}-w_S-w_Sh) \iff$$

$$h>\frac{(1-\alpha^l)\bar{p}\bar{D}}{w_N-w_S\alpha^l}-1$$

Therefore, if $h>\frac{(1-\alpha^l)\bar{p}\bar{D}}{w_N-w_S\alpha^l}-1$, we can have either "profit in (P1)">"profit in (M1)" or "profit in (P1)"<"profit in (M1)", depending on the value of θ, and then both the offer leading to Equilibrium (P1) and that leading to (M1) are possible choices for F_S. The condition $h>\frac{(1-\alpha^l)\bar{p}\bar{D}}{w_N-w_S\alpha^l}-1$ can be transformed into
$l<f^1(h)=\frac{\bar{p}\bar{D}(w_N-w_S)h-\pi(l)(\bar{p}\bar{D}-w_N)[\bar{p}\bar{D}-w_S(1+h)]}{\bar{p}\bar{D}(w_N-w_S)-\pi(l)w_N[\bar{p}\bar{D}-w_S(1+h)]}$, where $f^1(h)$ increases with h.

Then, under the condition that $l<f^1(h)=\frac{\bar{p}\bar{D}(w_N-w_S)h-\pi(l)(\bar{p}\bar{D}-w_N)[\bar{p}\bar{D}-w_S(1+h)]}{\bar{p}\bar{D}(w_N-w_S)-\pi(l)w_N[\bar{p}\bar{D}-w_S(1+h)]}$, we can see the first term of the profit in (P1) is smaller than that of the profit in (M1), while the second term of the profit in (P1) is larger than that of the profit in (M1). Also, since both of the first terms contain θ, while both of the second terms contain $(1-\theta)$, a smaller θ and thereby a larger $(1-\theta)$ makes both the profit in (P1) and that in (M1) attach smaller weights to their first terms, while attach larger weights to their second terms. This means a smaller θ and thereby a larger $(1-\theta)$ tends to make "profit in (P1)">"profit in (M1)", namely, make the partnership offer of t^l ($t^l<t^h$) prevail over the merger offer of α^l.

Thus we can see that, the values of θ for F_S to choose the partnership offer of t^l ($t^l < t^h$) are smaller than those for F_S to choose the merger offer of α^l. There's an upper bound of θ for F_S to choose the partnership offer of t^l ($t^l < t^h$), rather than the merger offer of α^l. Then denoting this upper bound by $\overline{\theta}$, we can get the expression of $\overline{\theta}$ since $\overline{\theta}$ is just the value of θ when "profit in (P1)"="profit in (M1)", such that

$$\overline{\theta}\left[\pi(l)\left(\bar{p}\bar{D}-w_N-w_N l\right)+w_N-w_S\right]+\left(1-\overline{\theta}\right)\left(w_N-w_S\right)(1+h)=$$
$$\overline{\theta}\left[\pi(l)(\bar{p}\bar{D}-w_N-w_N l)+\left(w_N-w_S\right)(1+l)\right]+\left(1-\overline{\theta}\right)\left(1-\alpha^l\right)\left(\bar{p}\bar{D}-w_S-w_S h\right)$$

$$\Longleftrightarrow \overline{\theta}=\frac{(w_N-w_S)(1+h)-(1-\alpha^l)[\bar{p}\bar{D}-w_S(1+h)]}{(w_N-w_S)l+(w_N-w_S)(1+h)-(1-\alpha^l)[\bar{p}\bar{D}-w_S(1+h)]}=\frac{1}{\frac{(w_N-w_S)l}{(w_N-w_S)(1+h)-(1-\alpha^l)[\bar{p}\bar{D}-w_S(1+h)]}+1}.$$

Moreover, comparing the profit in (P1) with that in (M2), we can see under our general assumption that monopolizing the S-market always achieves a positive profit, we have

$$\bar{p}\bar{D}-w_N-w_N h>0 \Longleftrightarrow$$

$$p_N(h)=\frac{w_N+w_N h}{D}<\bar{p} \Longleftrightarrow$$

$$(1-\theta)(p_N(h)\bar{D}-w_S-w_S h)<(1-\theta)(\bar{p}\bar{D}-w_S-w_S h),$$

namely, the second term of the profit in (P1) is smaller than that of the profit in (M2).

Then to make the profit in (P1) possibly greater than that in (M2), we should make the first term of the profit in (P1) greater than that of the profit in (M2), namely,

$$\theta\left[\pi(l)\left(\bar{p}\bar{D}-w_N-w_N l\right)+w_N-w_S\right]>\theta\pi(l)\left(w_N-w_S\right)(1+l) \Longleftrightarrow$$

$$l<\frac{\pi(l)\bar{p}\bar{D}+(1-2\pi(l))w_N}{2\pi(l)w_N-w_S}.$$

Therefore, if $l<\frac{\pi(l)\bar{p}\bar{D}+(1-2\pi(l))w_N}{2\pi(l)w_N-w_S}$, we can have either "profit in (P1)">"profit in (M2)" or "profit in (P1)"<"profit in (M2)", depending on the value of θ, and then both the offer leading to Equilibrium (P1) and that leading to (M2) are possible choices for F_S.

Then, under our general assumption that monopolizing the S-market always achieves a positive profit, and also the condition that $l < \frac{\pi(l)\bar{p}\bar{D}+(1-2\pi(l))w_N}{2\pi(l)w_N-w_S}$, we can see the first term of the profit in (P1) is greater than that of the profit in (M2), while the second term of the profit in (P1) is smaller than that of the profit in (M2). Also, since both of the first terms contain θ, while both of the second terms contain $(1-\theta)$, a larger θ and thereby a smaller $(1-\theta)$ makes both the profit in (P1) and that in (M2) attach larger weights to their first terms, while attach smaller weights to their second terms. This means a larger θ and thereby a smaller $(1-\theta)$ tends to make "profit in (P1)">"profit in (M2)", namely, make the partnership offer of t^l ($t^l < t^h$) prevail over the merger offer of α^h.

Thus we can see that, the values of θ for F_S to choose the partnership offer of t^l ($t^l < t^h$) are larger than those for F_S to choose the merger offer of α^h. There's a lower bound of θ for F_S to choose the partnership offer of t^l ($t^l < t^h$), rather than the merger offer of α^h. Then denoting this lower bound by $\underline{\theta}$, we can get the expression of $\underline{\theta}$ since $\underline{\theta}$ is just the value of θ when "profit in (P1)"="profit in (M2)", such that

$$\underline{\theta}\left[\pi(l)\left(\bar{p}\bar{D}-w_N-w_Nl\right)+w_N-w_S\right]+\left(1-\underline{\theta}\right)\left(w_N-w_S\right)\left(1+h\right)=$$
$$\underline{\theta}\pi(l)\left(w_N-w_S\right)\left(1+l\right)+\left(1-\underline{\theta}\right)\left(\bar{p}\bar{D}-w_S-w_Sh\right)$$

$$\Longleftrightarrow\ \underline{\theta}=\frac{\bar{p}\bar{D}-w_N(1+h)}{\pi(l)[\bar{p}\bar{D}-(2w_N-w_S)(1+l)]+w_N-w_S+\bar{p}\bar{D}-w_N(1+h)}=\frac{1}{\frac{\pi(l)[\bar{p}\bar{D}-(2w_N-w_S)(1+l)]+w_N-w_S}{\bar{p}\bar{D}-w_N(1+h)}+1}.$$

Then, to guarantee the existence of the range $[\underline{\theta},\overline{\theta}]$ for F_S to choose the partnership offer of t^l ($t^l < t^h$), we should have

$$\overline{\theta}=\frac{1}{\frac{(w_N-w_S)l}{(w_N-w_S)(1+h)-(1-\alpha^l)[\bar{p}\bar{D}-w_S(1+h)]}+1}>\underline{\theta}=\frac{1}{\frac{\pi(l)[\bar{p}\bar{D}-(2w_N-w_S)(1+l)]+w_N-w_S}{\bar{p}\bar{D}-w_N(1+h)}+1}$$

$$\Longleftrightarrow\ \frac{(w_N-w_S)l}{(w_N-w_S)(1+h)-(1-\alpha^l)[\bar{p}\bar{D}-w_S(1+h)]}<\frac{\pi(l)[\bar{p}\bar{D}-(2w_N-w_S)(1+l)]+w_N-w_S}{\bar{p}\bar{D}-w_N(1+h)}.$$

Denoting $F^1(h,l)=\frac{(w_N-w_S)l}{(w_N-w_S)(1+h)-(1-\alpha^l)[\bar{p}\bar{D}-w_S(1+h)]}$, and $F^2(h,l)=\frac{\pi(l)[\bar{p}\bar{D}-(2w_N-w_S)(1+l)]+w_N-w_S}{\bar{p}\bar{D}-w_N(1+h)}$, this condition can be expressed as

$F^1(h,l) < F^2(h,l)$,

where $F^1(h,l) = \frac{(w_N - w_S)l}{(w_N - w_S)(1+h) - (1-\alpha^l)[\bar{p}\bar{D} - w_S(1+h)]}$, which decreases with h while increases with l, and $F^2(h,l) = \frac{\pi(l)[\bar{p}\bar{D} - (2w_N - w_S)(1+l)] + w_N - w_S}{\bar{p}\bar{D} - w_N(1+h)}$, which increases with h while decreases with l.

Thus, putting all these conditions together, we can see that to let the three offers that respectively lead to Equilibrium (P1), Equilibrium (M1) and Equilibrium (M2) become the only possible choices for F_S, and then (P1), (M1) and (M2) become the only possible types of equilibrium in the model, we should have:

(i). $max\{f^1(l), \frac{\bar{p}\bar{D} - w_N}{2w_N - w_S}\} < h < \frac{\bar{p}\bar{D} - w_N}{w_N}$,

where $f^1(l) = \pi(l)l + \frac{(1-\pi(l))(\bar{p}\bar{D} - w_N)}{w_N}$, which increases with l;

(ii). $l < min\{\frac{\pi(l)\bar{p}\bar{D} + (1-2\pi(l))w_N}{2\pi(l)w_N - w_S}, f^1(h)\}$,

where $f^1(h) = \frac{\bar{p}\bar{D}(w_N - w_S)h - \pi(l)(\bar{p}\bar{D} - w_N)[\bar{p}\bar{D} - w_S(1+h)]}{\bar{p}\bar{D}(w_N - w_S) - \pi(l)w_N[\bar{p}\bar{D} - w_S(1+h)]}$, which increases with h;

and

(iii). $F^1(h,l) < F^2(h,l)$,

where $F^1(h,l) = \frac{(w_N - w_S)l}{(w_N - w_S)(1+h) - (1-\alpha^l)[\bar{p}\bar{D} - w_S(1+h)]}$, which decreases with h while increases with l, and $F^2(h,l) = \frac{\pi(l)[\bar{p}\bar{D} - (2w_N - w_S)(1+l)] + w_N - w_S}{\bar{p}\bar{D} - w_N(1+h)}$, which increases with h while decreases with l.

1.4. Proof of Proposition 1

As proved in Appendix 1.3 (proof of lemma 3), under the condition that $l < f^1(h) = \frac{\bar{p}\bar{D}(w_N - w_S)h - \pi(l)(\bar{p}\bar{D} - w_N)[\bar{p}\bar{D} - w_S(1+h)]}{\bar{p}\bar{D}(w_N - w_S) - \pi(l)w_N[\bar{p}\bar{D} - w_S(1+h)]}$, we can see the first term of the profit in (P1) is smaller than that of the profit in (M1), while the second term of the profit in (P1) is larger than that of the profit in (M1). Also, since both of the first terms contain θ, while both of the second terms contain $(1-\theta)$, a smaller θ and thereby a larger $(1-\theta)$ makes both the profit in (P1) and that in (M1) attach smaller weights to their first terms, while attach larger weights to their second terms. This means a smaller θ and thereby a larger $(1-\theta)$ tends to make "profit in (P1)">"profit in (M1)", namely, make the partnership offer of t^l ($t^l < t^h$) prevail over the merger offer of α^l. Thus we can see that, the values of θ for F_S to choose the partnership offer of t^l ($t^l < t^h$) are smaller than those for F_S to choose the merger offer of α^l, and then there's an upper bound of θ as $\overline{\theta}$ for F_S to choose the partnership offer of t^l ($t^l < t^h$), rather than the merger offer of α^l.

Also, as proved in Appendix 1.3 (proof of lemma 3), under our general assumption that monopolizing the S-market always achieves a positive profit, and also the condition that $l < \frac{\pi(l)\bar{p}\bar{D}+(1-2\pi(l))w_N}{2\pi(l)w_N-w_S}$, we can see the first term of the profit in (P1) is greater than that of the profit in (M2), while the second term of the profit in (P1) is smaller than that of the profit in (M2). Also, since both of the first terms contain θ, while both of the second terms contain $(1-\theta)$, a larger θ and thereby a smaller $(1-\theta)$ makes both the profit in (P1) and that in (M2) attach larger weights to their first terms, while attach smaller weights to their second terms. This means a larger θ and thereby a smaller $(1-\theta)$ tends to make "profit in (P1)">"profit in (M2)", namely, make the partnership offer of t^l ($t^l < t^h$) prevail over the merger offer of α^h. Thus we can see that, the values of θ for F_S to choose the partnership offer of t^l ($t^l < t^h$) are larger than those for F_S to choose the merger offer of α^h, and then there's a lower bound of θ as $\underline{\theta}$ for F_S to choose the partnership offer of t^l ($t^l < t^h$), rather than the merger offer of α^h.

Moreover, in Appendix 1.3 (proof of lemma 3), we get

$$\overline{\theta} = \frac{1}{\frac{(w_N-w_S)l}{(w_N-w_S)(1+h)-(1-\alpha^l)[\bar{p}\bar{D}-w_S(1+h)]}+1} = \frac{1}{F^1(h,l)+1},$$

where $F^1(h,l) = \frac{(w_N-w_S)l}{(w_N-w_S)(1+h)-(1-\alpha^l)[\bar{p}\bar{D}-w_S(1+h)]}$;

and

$$\underline{\theta} = \frac{1}{\frac{\pi(l)[\bar{p}\bar{D}-(2w_N-w_S)(1+l)]+w_N-w_S}{\bar{p}\bar{D}-w_N(1+h)}+1} = \frac{1}{F^2(h,l)+1},$$

where $F^2(h,l) = \frac{\pi(l)[\bar{p}\bar{D}-(2w_N-w_S)(1+l)]+w_N-w_S}{\bar{p}\bar{D}-w_N(1+h)}$.

Then if $F^1(h,l) < F^2(h,l)$, we have $\overline{\theta} > \underline{\theta}$ that guarantees the existence of $[\underline{\theta}, \overline{\theta}]$.

Thus under Condition (C) that collects all the conditions for the existence of $\underline{\theta}$, $\overline{\theta}$ and the range $[\underline{\theta}, \overline{\theta}]$, we have the range $[\underline{\theta}, \overline{\theta}]$ such that:

(1). If $\theta < \underline{\theta}$, F_S makes the vertical merger offer of α^h ($\alpha^h = 0 < \alpha^l$);

(2). If $\theta \in [\underline{\theta}, \overline{\theta}]$, F_S makes the vertical partnership offer of t^l ($t^l < t^h$);

and

(3). If $\theta > \overline{\theta}$, F_S makes the vertical merger offer of α^l ($\alpha^l > \alpha^h = 0$).

1.5. Proof of Proposition 2

As derived in Appendix 1.3 (proof of lemma 3), we get

$$\overline{\theta} = \frac{1}{\frac{(w_N-w_S)l}{(w_N-w_S)(1+h)-(1-\alpha^l)[\bar{p}\bar{D}-w_S(1+h)]}+1} = \frac{1}{F^1(h,l)+1},$$

where $F^1(h,l) = \frac{(w_N-w_S)l}{(w_N-w_S)(1+h)-(1-\alpha^l)[\bar{p}\bar{D}-w_S(1+h)]}$, which decreases with h while increases with l.

Then since $\overline{\theta}$ decreases with $F^1(h,l)$, we have that $\overline{\theta}$ increases with h while decreases with l.

Also, as derived in Appendix 1.3 (proof of lemma 3), we get

$$\underline{\theta} = \frac{1}{\frac{\pi(l)[\bar{p}\bar{D}-(2w_N-w_S)(1+l)]+w_N-w_S}{\bar{p}\bar{D}-w_N(1+h)}+1} = \frac{1}{F^2(h,l)+1},$$

where $F^2(h,l) = \frac{\pi(l)[\bar{p}\bar{D}-(2w_N-w_S)(1+l)]+w_N-w_S}{\bar{p}\bar{D}-w_N(1+h)}$, which increases with h while decreases with l.

Then since $\underline{\theta}$ decreases with $F^2(h,l)$, we have that $\underline{\theta}$ decreases with h while increases with l.

Thus we can see $\overline{\theta}$ increases with h, while decreases with l. Also, $\underline{\theta}$ decreases with h, while increases with l. Then since the widening of $[l,h]$ from $[l,h] = [l_0,h_0]$ to $[l,h] \supset [l_0,h_0]$ means either h increases, or l decreases, or both, this widening leads to an increase in $\overline{\theta}$ while a decrease in $\underline{\theta}$, and thereby a widening of $[\underline{\theta},\overline{\theta}]$ from $[\underline{\theta},\overline{\theta}] = [\underline{\theta}_0,\overline{\theta}_0]$ to $[\underline{\theta},\overline{\theta}] \supset [\underline{\theta}_0,\overline{\theta}_0]$.

1.6. Proof of Lemma 4

As derived in Appendix 1.5 (proof of Proposition 2), we have

$$\underline{\theta} = \frac{\bar{p}\bar{D}-w_N(1+h)}{\pi(l)[\bar{p}\bar{D}-(2w_N-w_S)(1+l)]+w_N-w_S+\bar{p}\bar{D}-w_N(1+h)} = \frac{1}{\frac{\pi(l)[\bar{p}\bar{D}-(2w_N-w_S)(1+l)]+w_N-w_S}{\bar{p}\bar{D}-w_N(1+h)}+1}.$$

Denote $f^1(w_N) = \frac{\pi(l)[\bar{p}\bar{D}-(2w_N-w_S)(1+l)]+w_N-w_S}{\bar{p}\bar{D}-w_N(1+h)}$, and thereby $\underline{\theta} = \frac{1}{f^1(w_N)+1}$. Then we can get $\frac{d(f^1(w_N))}{d(w_N)} = \frac{(1+h)[\pi(l)\bar{p}\bar{D}+\pi(l)(1+l)w_S-w_S]-\bar{p}\bar{D}[2\pi(l)(1+l)-1]}{[\bar{p}\bar{D}-w_N(1+h)]^2}$.

Therefore if $\frac{d(f^1(w_N))}{d(w_N)} > 0 \iff l < f^2(h) = \frac{(\pi(l)\bar{p}\bar{D}-w_S)(1+h)+\bar{p}\bar{D}}{\pi(l)[2\bar{p}\bar{D}-w_S(1+h)]} - 1$, we have $f^1(w_N)$ increases with w_N, and then $\underline{\theta}$ decreases with w_N since $\underline{\theta}$ decreases with $f^1(w_N)$. Otherwise, if $\frac{d(f^1(w_N))}{d(w_N)} < 0 \iff l > f^2(h)$, we have $f^1(w_N)$ decreases with w_N, and then $\underline{\theta}$ increases with w_N since $\underline{\theta}$ decreases with $f^1(w_N)$.

1.7. Proof of Lemma 5

As derived in Appendix 1.6 (proof of Lemma 4), we have

$\underline{\theta} = \frac{1}{\frac{\pi(l)[\bar{p}\bar{D}-(2w_N-w_S)(1+l)]+w_N-w_S}{\bar{p}\bar{D}-w_N(1+h)}+1}$.

Denote $f^1(w_S) = \frac{\pi(l)[\bar{p}\bar{D}-(2w_N-w_S)(1+l)]+w_N-w_S}{\bar{p}\bar{D}-w_N(1+h)}$, and thereby $\underline{\theta} = \frac{1}{f^1(w_S)+1}$. Then we can get $\frac{d(f^1(w_S))}{d(w_S)} = \frac{\pi(l)(1+l)-1}{\bar{p}\bar{D}-w_N(1+h)}$.

Therefore if $\frac{d(f^1(w_S))}{d(w_S)} < 0 \iff l < \frac{1}{\pi(l)} - 1$, we have $f^1(w_S)$ decreases with w_S, and then $\underline{\theta}$ increases with w_S since $\underline{\theta}$ decreases with $f^1(w_S)$. Otherwise, if $\frac{d(f^1(w_S))}{d(w_S)} > 0 \iff l > \frac{1}{\pi(l)} - 1$, we have $f^1(w_S)$ increases with w_S, and then $\underline{\theta}$ decreases with w_S since $\underline{\theta}$ decreases with $f^1(w_S)$.

1.8. Proof of Proposition 3

The condition of $l < min\{f^2(h), \frac{1}{\pi(l)} - 1\}$ means we have both $l < f^2(h)$, and $l < \frac{1}{\pi(l)} - 1$. From Lemma 4, we can see if $l < f^2(h)$, $\underline{\theta}$ decreases with w_N. In addition, from Lemma 5, we can see if $l < \frac{1}{\pi(l)} - 1$, $\underline{\theta}$ increases with w_S.

The widening of $[w_S, w_N]$ from $[w_S, w_N] = [w_S^0, w_N^0]$ to $[w_S, w_N] \supset [w_S^0, w_N^0]$ means either w_N increases, or w_S decreases, or both. Then under the condition of $l < min\{f^2(h), \frac{1}{\pi(l)} - 1\}$, this widening leads to a decrease in $\underline{\theta}$.

Also, the condition of $l > max\{f^2(h), \frac{1}{\pi(l)} - 1\}$ means we have both $l > f^2(h)$, and $l > \frac{1}{\pi(l)} - 1$. From Lemma 4, we can see if $l > f^2(h)$, $\underline{\theta}$ increases with w_N. In addition, from Lemma 5, we can see if $l > \frac{1}{\pi(l)} - 1$, $\underline{\theta}$ decreases with w_S.

The widening of $[w_S, w_N]$ from $[w_S, w_N] = [w_S^0, w_N^0]$ to $[w_S, w_N] \supset [w_S^0, w_N^0]$ means either w_N increases, or w_S decreases, or both. Then under the condition of $l > max\{f^2(h), \frac{1}{\pi(l)} - 1\}$, this widening leads to an increase in $\underline{\theta}$.

1.9. Proof of Lemma 6

As derived in Appendix 1.5 (proof of Proposition 2), we have

$$\overline{\theta} = \frac{(w_N - w_S)(1+h) - (1-\alpha^l)[\bar{p}\bar{D} - w_S(1+h)]}{(w_N - w_S)l + (w_N - w_S)(1+h) - (1-\alpha^l)[\bar{p}\bar{D} - w_S(1+h)]}.$$

Also, as derived in Appendix 1.1 (proof of Lemma 1), we have

$$\alpha^l = (1-\pi(l))[\frac{\bar{p}\bar{D} - w_N(1+l)}{\bar{p}\bar{D} - w_S(1+l)}] > 0.$$

Then we have

$$\overline{\theta} = \frac{(w_N - w_S)(1+h) - \{1-(1-\pi(l))[\frac{\bar{p}\bar{D} - w_N(1+l)}{\bar{p}\bar{D} - w_S(1+l)}]\}[\bar{p}\bar{D} - w_S(1+h)]}{(w_N - w_S)l + (w_N - w_S)(1+h) - \{1-(1-\pi(l))[\frac{\bar{p}\bar{D} - w_N(1+l)}{\bar{p}\bar{D} - w_S(1+l)}]\}[\bar{p}\bar{D} - w_S(1+h)]}.$$
$$= \frac{1}{\frac{(w_N - w_S)l}{w_N(1+h) - \bar{p}\bar{D} + (1-\pi(l))[\bar{p}\bar{D} - w_N(1+l)][\frac{\bar{p}\bar{D} - w_S(1+h)}{\bar{p}\bar{D} - w_S(1+l)}]} + 1}.$$

Denote $f^2(w_N) = \frac{(w_N - w_S)l}{w_N(1+h) - \bar{p}\bar{D} + (1-\pi(l))[\bar{p}\bar{D} - w_N(1+l)][\frac{\bar{p}\bar{D} - w_S(1+h)}{\bar{p}\bar{D} - w_S(1+l)}]}$, and thereby $\overline{\theta} = \frac{1}{f^2(w_N)+1}$. Then we can get

$$\frac{d(f^2(w_N))}{d(w_N)} = -\frac{\pi(l)[\bar{p}\bar{D} - w_S(1+h)]l}{\{w_N(1+h) - \bar{p}\bar{D} + (1-\pi(l))[\bar{p}\bar{D} - w_N(1+l)][\frac{\bar{p}\bar{D} - w_S(1+h)}{\bar{p}\bar{D} - w_S(1+l)}]\}^2} < 0.$$

Therefore we have $f^2(w_N)$ decreases with w_N, and then $\overline{\theta}$ increases with w_N since $\overline{\theta}$ decreases with $f^2(w_N)$.

1.10. Proof of Lemma 7

As derived in Appendix 1.9 (proof of Lemma 6), we have

$$\overline{\theta} = \frac{1}{\frac{(w_N - w_S)l}{w_N(1+h) - \bar{p}\bar{D} + (1-\pi(l))[\bar{p}\bar{D} - w_N(1+l)][\frac{\bar{p}\bar{D} - w_S(1+h)}{\bar{p}\bar{D} - w_S(1+l)}]} + 1}.$$

Denote $f^2(w_S) = \frac{(w_N - w_S)l}{w_N(1+h) - \bar{p}\bar{D} + (1-\pi(l))[\bar{p}\bar{D} - w_N(1+l)][\frac{\bar{p}\bar{D} - w_S(1+h)}{\bar{p}\bar{D} - w_S(1+l)}]}$, and thereby $\overline{\theta} = \frac{1}{f^2(w_S)+1}$. Then we can get

$$\frac{d(f^2(w_S))}{d(w_S)} = \frac{\pi(l)[\bar{p}\bar{D} - w_N(1+h)][\bar{p}\bar{D} - w_N(1+l)][\bar{p}\bar{D} - w_S(1+l)]l}{\{(1-\pi(l))[\bar{p}\bar{D} - w_N(1+l)][\bar{p}\bar{D} - w_S(1+h)] - [\bar{p}\bar{D} - w_N(1+h)][\bar{p}\bar{D} - w_S(1+l)]\}^2} -$$
$$\frac{(w_N - w_S)(1+l)l}{(1-\pi(l))[\bar{p}\bar{D} - w_N(1+l)][\bar{p}\bar{D} - w_S(1+h)] - [\bar{p}\bar{D} - w_N(1+h)][\bar{p}\bar{D} - w_S(1+l)]}.$$

Therefore, if $\frac{d(f^2(w_S))}{d(w_S)} = \frac{(w_N-w_S)(1+l)l}{(1-\pi(l))[\bar{p}\bar{D}-w_N(1+l)][\bar{p}\bar{D}-w_S(1+h)]-[\bar{p}\bar{D}-w_N(1+h)][\bar{p}\bar{D}-w_S(1+l)]} > 0$

$\iff \pi(l) > \frac{(w_N-w_S)(1+l)\{[\bar{p}\bar{D}-w_N(1+l)][\bar{p}\bar{D}-w_S(1+h)]-[\bar{p}\bar{D}-w_N(1+h)][\bar{p}\bar{D}-w_S(1+l)]\}}{[\bar{p}\bar{D}-w_N(1+l)]\{[\bar{p}\bar{D}-w_N(1+h)][\bar{p}\bar{D}-w_S(1+l)]+(w_N-w_S)(1+l)[\bar{p}\bar{D}-w_S(1+h)]\}}$,

we have $f^2(w_S)$ increases with w_S, and then $\overline{\theta}$ decreases with w_S since $\overline{\theta}$ decreases with $f^2(w_S)$.

Otherwise, if $\frac{d(f^2(w_S))}{d(w_S)} = \frac{(w_N-w_S)(1+l)l}{(1-\pi(l))[\bar{p}\bar{D}-w_N(1+l)][\bar{p}\bar{D}-w_S(1+h)]-[\bar{p}\bar{D}-w_N(1+h)][\bar{p}\bar{D}-w_S(1+l)]} < 0$

$\iff \pi(l) < \frac{(w_N-w_S)(1+l)\{[\bar{p}\bar{D}-w_N(1+l)][\bar{p}\bar{D}-w_S(1+h)]-[\bar{p}\bar{D}-w_N(1+h)][\bar{p}\bar{D}-w_S(1+l)]\}}{[\bar{p}\bar{D}-w_N(1+l)]\{[\bar{p}\bar{D}-w_N(1+h)][\bar{p}\bar{D}-w_S(1+l)]+(w_N-w_S)(1+l)[\bar{p}\bar{D}-w_S(1+h)]\}}$,

we have $f^2(w_S)$ decreases with w_S, and then $\overline{\theta}$ increases with w_S since $\overline{\theta}$ decreases with $f^2(w_S)$.

1.11. Proof of Proposition 4

Lemma 6 and Lemma 7 together tell us that if $\pi(l) > \frac{(w_N-w_S)(1+l)\{[\bar{p}\bar{D}-w_N(1+l)][\bar{p}\bar{D}-w_S(1+h)]-[\bar{p}\bar{D}-w_N(1+h)][\bar{p}\bar{D}-w_S(1+l)]\}}{[\bar{p}\bar{D}-w_N(1+l)]\{[\bar{p}\bar{D}-w_N(1+h)][\bar{p}\bar{D}-w_S(1+l)]+(w_N-w_S)(1+l)[\bar{p}\bar{D}-w_S(1+h)]\}}$, $\overline{\theta}$ increases with w_N, while decreases with w_S. Then since the widening of $[w_S, w_N]$ from $[w_S, w_N] = [w_S^0, w_N^0]$ to $[w_S, w_N] \supset [w_S^0, w_N^0]$ means either w_N increases, or w_S decreases, or both, this widening will raise $\overline{\theta}$.

Also, since Lemma 6 tells us that $\overline{\theta}$ always increases with w_N, we can see that even if $\pi(l) \leq \frac{(w_N-w_S)(1+l)\{[\bar{p}\bar{D}-w_N(1+l)][\bar{p}\bar{D}-w_S(1+h)]-[\bar{p}\bar{D}-w_N(1+h)][\bar{p}\bar{D}-w_S(1+l)]\}}{[\bar{p}\bar{D}-w_N(1+l)]\{[\bar{p}\bar{D}-w_N(1+h)][\bar{p}\bar{D}-w_S(1+l)]+(w_N-w_S)(1+l)[\bar{p}\bar{D}-w_S(1+h)]\}}$, "upward unidirectionally" widening the range $[w_S, w_N] = [w_S^0, w_N^0]$, namely, raising $w_N = w_N^0$ to any new $w_N > w_N^0$, while keeping $w_S = w_S^0$, will still raise $\overline{\theta}$.

Appendix 2 –

2.1. Proof for excluding the option of fixed-fee licensing

Let e denote the up-front licensing fee stated by F_S in a fixed-fee licensing offer. Then F_S may make either of the two following types of fixed-fee licensing offer:

1) F_S makes a licensing offer of $e = 0$. The licensing fee, $e = 0$, is equal to a type h (bad type) F_N's expected profit facing the two possible default positions, but smaller than a type l (good type) F_N's. Then this licensing offer of $e = 0$ is only acceptable to a type h (bad type) F_N.

2) F_S makes a licensing offer of $e = (1-\pi(l))[\bar{p}\bar{D} - w_N(1+l)]$. The licensing fee, $e = (1-\pi(l))[\bar{p}\bar{D} - w_N(1+l)]$, is equal to a type l (good type) F_N's expected profit facing the two possible default positions, and larger than a type h (bad type) F_N's. Then this licensing offer of $e = (1-\pi(l))[\bar{p}\bar{D} - w_N(1+l)]$ is acceptable to F_N no matter F_N is any of the two types.

We can see that on the one hand, the former licensing offer of $e = 0$ is equivalent to the vertical merger offer of $\alpha^h = 0$, since both offers give F_N zero profit.

On the other hand, we can prove that the latter licensing offer of $e = (1-\pi(l))[\bar{p}\bar{D} - w_N(1+l)]$, is always dominated by the vertical merger offer of α^l.

By making the licensing offer of $e = (1-\pi(l))[\bar{p}\bar{D} - w_N(1+l)]$, F_S's expected profit is calculated as

$$\theta\{[\bar{p}\bar{D} - w_S(1+l)] - (1-\pi(l))[\bar{p}\bar{D} - w_N(1+l)]\} + (1-\theta)\{[\bar{p}\bar{D} - w_S(1+h)] - (1-\pi(l))[\bar{p}\bar{D} - w_N(1+l)]\}.$$

Also, as derived in Appendix 1.1 (proof of Lemma 1), we have

$$\alpha^l = (1-\pi(l))\left[\frac{\bar{p}\bar{D} - w_N(1+l)}{\bar{p}\bar{D} - w_S(1+l)}\right].$$

Then by making the vertical merger offer of $\alpha^l = (1-\pi(l))\,[\frac{\bar{p}\bar{D}-w_N(1+l)}{\bar{p}\bar{D}-w_S(1+l)}]$, F_S's expected profit is calculated as

$$\theta(1-\alpha^l)[\bar{p}\bar{D}-w_S(1+l)]+(1-\theta)(1-\alpha^l)[\bar{p}\bar{D}-w_S(1+h)] =$$
$$\theta\{1-(1-\pi(l))\,[\frac{\bar{p}\bar{D}-w_N(1+l)}{\bar{p}\bar{D}-w_S(1+l)}]\}[\bar{p}\bar{D}-w_S(1+l)]+(1-\theta)\{1-(1-\pi(l))\,[\frac{\bar{p}\bar{D}-w_N(1+l)}{\bar{p}\bar{D}-w_S(1+l)}]\}[\bar{p}\bar{D}-w_S(1+h)] =$$
$$\theta\{[\bar{p}\bar{D}-w_S(1+l)]-(1-\pi(l))[\bar{p}\bar{D}-w_N(1+l)]\}+$$
$$(1-\theta)\{[\bar{p}\bar{D}-w_S(1+h)]-(1-\pi(l))[\bar{p}\bar{D}-w_N(1+l)][\frac{\bar{p}\bar{D}-w_S(1+h)}{\bar{p}\bar{D}-w_S(1+l)}]\}.$$

We can see F_S's expected profit by the merger offer of α^l always exceeds that by the licensing offer of $e=(1-\pi(l))[\bar{p}\bar{D}-w_N(1+l)]$. Then the licensing offer of $e=(1-\pi(l))[\bar{p}\bar{D}-w_N(1+l)]$ is always dominated by the merger offer of α^l. The intuition is that by making the licensing offer of $e=(1-\pi(l))[\bar{p}\bar{D}-w_N(1+l)]$, if facing a bad type F_N, F_S has to bear the entire loss caused by the worse-than-expected technology. By making the merger offer of α^l, however, F_S just bears a part of this loss. This means for F_S, the licensing offer of $e=(1-\pi(l))[\bar{p}\bar{D}-w_N(1+l)]$ does even worse than the merger offer of α^l, in dealing with the problem of asymmetric information on F_N's technology.

Thus we have proved that a fixed-fee licensing offer will be either equivalent to, or dominated by a vertical merger offer. Then we can exclude the option of fixed-fee licensing from our theoretical analysis.

2.2. Proof for excluding the choice of no offer

By making no offer and then directly facing the two possible default positions, F_S's expected profit is calculated as

$$\theta\pi(l)\,(p_N(l)\bar{D}-w-wl)+(1-\theta)\,(p_N(h)\bar{D}-w-wh),$$

where $p_N(q)$, with $q\in\{l,h\}$, is the price set by F_S in limit pricing to beat a type q F_N in Bertrand competition, such that $p_N(q)$ ($q\in\{l,h\}$) equals the quotient of a type q F_N's total production cost divided by the market demand $\bar{D}$, namely, $p_N(q)=\frac{w_N+w_N q}{\bar{D}}$ ($q\in\{l,h\}$).

Also, by making the vertical merger offer of $\alpha^h = 0$, F_S's expected profit is calculated as

$$\theta\pi(l)\,(p_N(l)\bar{D} - w - wl) + (1-\theta)\,(\bar{p}\bar{D} - w - wh).$$

We can see F_S's expected profit by the merger offer of $\alpha^h = 0$ always exceeds that by no offer, since under our general assumption that monopolizing the S-market always achieves a positive profit, we have

$$\bar{p}\bar{D} - w_N - w_N h > 0 \iff \bar{p} > p_N(h) = \tfrac{w_N + w_N h}{D}.$$

Then F_S will never make no offer since this choice is always dominated by the merger offer of $\alpha^h = 0$.

2.3. Proof for excluding the choice of no offer when $\pi(h) \in (\pi(l), 1)$

If we relax the assumption $\pi(h) = 1$ to $\pi(h) \in (\pi(l), 1)$, namely, let F_S no longer always successfully reverse engineer a type h (bad type) F_N's technology (the probability for F_S to reverse a type h (bad type) F_N's technology is still greater than that to reverse engineer a type l (good type) one's, i.e. $\pi(h) > \pi(l)$), we will have

$$\alpha^h = (1-\pi(h))[\tfrac{\bar{p}\bar{D} - w_N(1+h)}{\bar{p}\bar{D} - w_S(1+h)}] \in (0, \alpha^l).$$

Then by making no offer and thus directly facing the two possible default positions, F_S's expected profit is calculated as

$$\theta\pi(l)\,(p_N(l)\bar{D} - w_S - w_S l) + (1-\theta)\,(p_N(h)\bar{D} - w_S - w_S h) =$$
$$\theta\pi(l)(w_N - w_S)(1+l) + (1-\theta)\pi(h)(w_N - w_S)(1+h),$$

where $p_N(q)$, with $q \in \{l, h\}$, is the price set by F_S in limit pricing to beat a type q F_N in Bertrand competition, such that $p_N(q)$ ($q \in \{l, h\}$) equals the quotient of a type q F_N's total production cost divided by the market demand $\bar{D}$, namely, $p_N(q) = \frac{w_N + w_N q}{D}$ ($q \in \{l, h\}$).

Also, by making the vertical merger offer of $\alpha^h = (1-\pi(h))[\frac{\bar{p}\bar{D}-w_N(1+h)}{\bar{p}\bar{D}-w_S(1+h)}]$, F_S's expected profit is calculated as

$$\theta\pi(l)\,(p_N(l)\bar{D}-w_S-w_Sl)+(1-\theta)\,(1-\alpha^h)\,(\bar{p}\bar{D}-w_S-w_Sh)=$$
$$\theta\pi(l)(w_N-w_S)(1+l)+(1-\theta)\,[\pi(h)(\bar{p}\bar{D}-w_N-w_Nh)+(w_N-w_S)\,(1+h)].$$

We can see F_S's expected profit by the merger offer of $\alpha^h = (1-\pi(h))[\frac{\bar{p}\bar{D}-w_N(1+h)}{\bar{p}\bar{D}-w_S(1+h)}]$ always exceeds that by no offer, since the first term of the profit by the merger offer of α^h is the same as that of the profit by no offer, while the second term of the profit by the merger offer of α^h is always greater than that of the profit by no offer.

Then F_S's choice of no offer is always dominated by the vertical merger offer of $\alpha^h = (1-\pi(h))[\frac{\bar{p}\bar{D}-w_N(1+h)}{\bar{p}\bar{D}-w_S(1+h)}]$. The intuition is that for F_S, a "favourable merger" with a type q F_N ($q \in \{l,h\}$), namely, a merger that just gives the type q F_N a profit satisfying the F_N's minimum requirement is always better than a competition with this F_N. This intuition also applied before to a part in the proof of Lemma 3 (Appendix 1.3): F_S's expected profit in a merger of α^l with a type l F_N (the first term of the profit in (M1)) is always greater than that in a competition with this type l F_N (the first term of the profit in (M2)).

2.4. Welfare Analysis

We give a welfare analysis for the three types of equilibrium, (P1), (M1) and (M2), that referring to the trade-off we focus on.

Since the quantity of final good traded in the market is always $\bar{D}$, the type of equilibrium that maximizes the expected social welfare is (M1). This is because the merger offer of $\alpha = \alpha_l$ guarantees that no matter F_N is type l or h, the merger can be achieved and then the whole production process consumes the lowest total cost, since both the intermediate and final goods are produced by using the cheaper labour in S. Moreover, (M1) is also the type of equilibrium that maximizes the expected total producer surplus (profit) of the two firms as a whole. This is because in (M1), the final good can always be sold at the highest price $\bar{P}$, regardless of F_N's type.

Also, the type of equilibrium that maximizes the expected consumer surplus should be either (P1) or (M2). This is because in either (P1) or (M2), there's a probability with which the consumers enjoy a price lower than $\bar{P}$, to buy a quantity $\bar{D}$ of the final good, while in (M1) the consumers always buy this quantity at $\bar{P}$. In (P1), it's the probability $(1-\theta)$ with which F_N is type h and rejects F_S's partnership offer, and then F_S succeeds to reverse-engineer F_N's technology, and kicks out F_N in a Bertrand competition by selling the final good at $p_N(h) < \bar{P}$. In (M2), it's the probability $\pi(l)\theta$ with which F_N is type l and rejects F_S's merger offer, and then F_S succeeds to reverse-engineer F_N's technology, and kicks out F_N in a Bertrand competition by selling the final good at $p_N(l) < \bar{P}$. Then assuming the consumers' average psychological value for one unit of the final good is v, we can calculate the expected consumer surplus in (P1) and that in (M2), respectively, as

(P1): $\theta(v-\bar{P})\bar{D}+(1-\theta)[v-p_N(h)]\bar{D} = \theta(v-\bar{P})\bar{D}+(1-\theta)[v-\frac{w_N+w_N h}{\bar{D}}]\bar{D}$.

(M2): $[1-\pi(l)\theta](v-\bar{P})\bar{D}+\pi(l)\theta[v-p_N(l)]\bar{D} = [1-\pi(l)\theta](v-\bar{P})\bar{D}+\pi(l)\theta[v-\frac{w_N+w_N l}{\bar{D}}]\bar{D}$;

Therefore we can see if

$$[(1-\theta)h-\pi(l)\theta l]w_N-[1-\theta-\pi(l)\theta](\bar{P}\bar{D}-w_N) < 0,$$

it's Equilibrium (P1) that maximizes the expected consumer surplus.

Otherwise, if

$$[1-\pi(l)\theta](v-\bar{P})\bar{D}+\pi(l)\theta[v-\frac{w_N+w_N l}{\bar{D}}]\bar{D} > \theta(v-\bar{P})\bar{D}+(1-\theta)[v-\frac{w_N+w_N h}{\bar{D}}]\bar{D} \iff$$

$$[(1-\theta)h-\pi(l)\theta l]w_N-[1-\theta-\pi(l)\theta](\bar{P}\bar{D}-w_N) > 0,$$

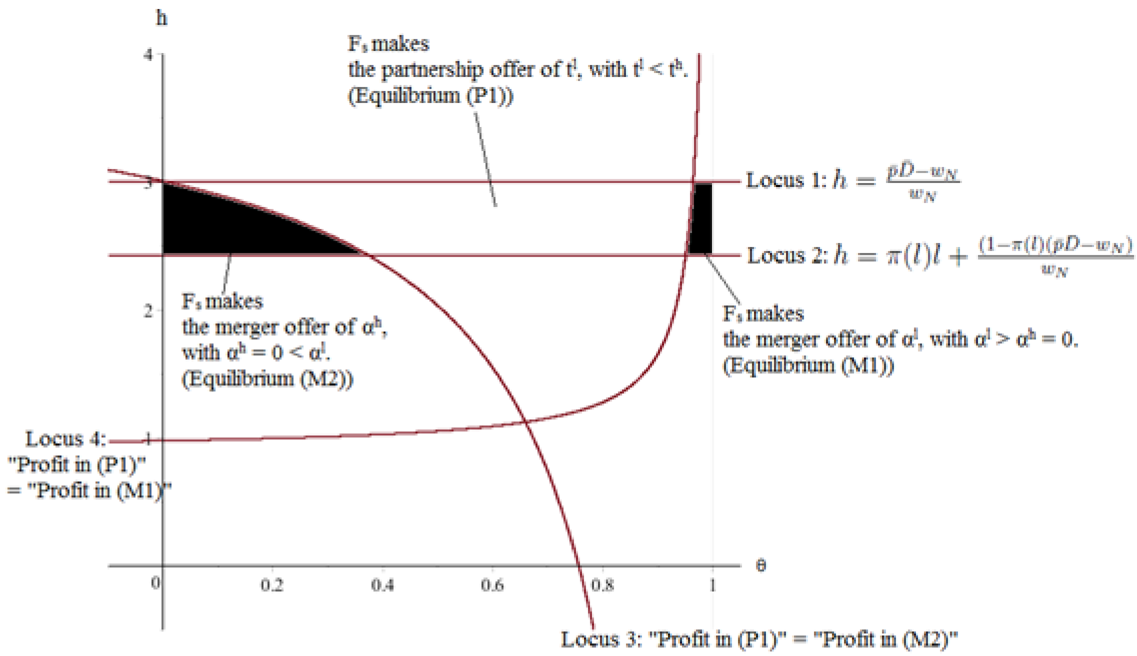
it's Equilibrium (M2) that maximizes the expected consumer surplus.

2.5. Numerical Example with Graph

We give a numerical example with a graph, to visually show the issues depicted in Proposition 1 and Proposition 2.

We assume that $\bar{p} = 2$, $\bar{D} = 2$, $w_N = 1$, $w_S = 0.5$, $l = 0.1$ and $\pi(l) = 0.2$. Then we plot the relevant loci of the two remaining parameters, θ and h, in a coordinate system that has the values of θ and h on the horizontal and vertical axis, respectively. The following Figure 2 shows this coordinate system with the relevant loci.

Figure 2. Graph for Proposition 1 and Proposition 2



In Figure 2, at first, to locate the area that satisfies the Condition (C) presented in Lemma 3, we have two loci of horizontal lines: Locus 1, the upper horizontal line, where $h = \frac{\bar{p}\bar{D}-w_N}{w_N}$, and Locus 2, the lower horizontal line, where $h = \pi(l)l + \frac{(1-\pi(l)(\bar{p}\bar{D}-w_N)}{w_N}$. Then the area between Locus 1 and Locus 2 satisfies the condition $\pi(l)l + \frac{(1-\pi(l)(\bar{p}\bar{D}-w_N)}{w_N} < h < \frac{\bar{p}\bar{D}-w_N}{w_N}$, one of the conditions in Condition (C). In addition, we check and confirm that under our numerical assumptions, this area between Locus 1 and Locus 2 also satisfies all the other conditions in Condition (C). Then the issues depicted in Proposition 1 and Proposition 2 can be visually shown in this area.

We can see the area between Locus 1 and Locus 2 are divided into three smaller areas, by another two loci of curves: Locus 3 where the profit in Equilibrium (P1) equals that in Equilibrium (M2), and Locus 4 where the profit in Equilibrium (P1) equals that in Equilibrium (M1). When θ and h locate in the area left to Locus 3, the left black area in the figure, F_S makes the vertical merger offer of α_h, with $\alpha_h = 0 < \alpha_l$, and then the offer is only acceptable to a type h (bad type) F_N. This offer leads to Equilibrium (M2). When θ and h locate in the area right to Locus 3 while left to Locus 4, the area between the two black areas in the figure (and still between Locus 1 and Locus 2), F_S makes the vertical partnership offer of t^l, with $t^l < t^h$, and then the offer is only acceptable to a type l (good type) F_N, namely, the offer can screen out a type h (bad type) F_N. This offer leads to Equilibrium (P1). Also, when θ and h locate in the area right to Locus 4, the right black area in the figure, F_S makes the vertical merger offer of α_l, with $\alpha_l > \alpha_h = 0$, and then the offer is acceptable to F_N no matter F_N is any of the two types. This offer leads to Equilibrium (M1).

Therefore, in the area, between Locus 1 and Locus 2, that satisfies Condition (C), as θ increases and thus moves from left to right, F_S's choice tends to change in the following order: the merger offer of α_h ($\alpha_h = 0 < \alpha_l$) $\longrightarrow$ the partnership offer of t^l ($t^l < t^h$) $\longrightarrow$ the merger offer of α_l ($\alpha_l > \alpha_h = 0$). This trend consists with Proposition 1.

Moreover, we can see as h increases and thereby the range $[l,h]$ widens (since l is fixed), the range of θ, for F_S to choose the partnership offer of t^l ($t^l < t^h$) that screens out a type h (bad type) F_N, also widens. This trend consists with Proposition 2.

2.6. Proof regarding the setting $\pi(q) = \frac{\pi_0(q)}{1+\lambda M}$

In the setting $\pi(q) = \frac{\pi_0(q)}{1+\lambda M}$ ($q \in \{l,h\}$, with $0 < \pi_0(l) < \pi_0(h) \leq 1$), we calculate F_N's expected profit by no cooperation as

$$(1 - \tfrac{\pi_0(q)}{1+\lambda M})(\bar{p}\bar{D} - w_N - w_N q) - M, \text{ where } q \in \{l,h\}.$$

To find an optimal M that maximizes this profit, we get the derivative of this profit with respect to M as

$$\tfrac{\lambda \pi_0(q)}{(1+\lambda M)^2}(\bar{p}\bar{D} - w_N - w_N q) - 1, \text{ where } q \in \{l,h\}.$$

Then when

$$\tfrac{\lambda \pi_0(q)}{(1+\lambda M)^2}(\bar{p}\bar{D} - w_N - w_N q) - 1 = 0 \iff \tfrac{\pi_0(q)}{1+\lambda M} = \sqrt{\tfrac{\pi_0(q)}{\lambda(\bar{p}\bar{D} - w_N - w_N q)}}$$

$\iff M = \frac{\sqrt{\lambda \pi_0(q)(\bar{p}\bar{D}-w_N-w_Nq)}-1}{\lambda}$,

the profit is maximized.

In this situation, a type l F_N has $\pi(l) = \frac{\pi_0(l)}{1+\lambda M} = \sqrt{\frac{\pi_0(l)}{\lambda(\bar{p}\bar{D}-w_N-w_Nl)}}$, while a type h F_N has $\pi(h) = \frac{\pi_0(h)}{1+\lambda M} = \sqrt{\frac{\pi_0(h)}{\lambda(\bar{p}\bar{D}-w_N-w_Nh)}}$. Then we always have $\pi(l) < \pi(h)$, since $\pi_0(l) < \pi_0(h)$ while $\bar{p}\bar{D} - w_N - w_Nl > \bar{p}\bar{D} - w_N - w_Nh$.

Also, since the profit is maximized when $M = \frac{\sqrt{\lambda \pi_0(q)(\bar{p}\bar{D}-w_N-w_Nq)}-1}{\lambda}$, we get the maximized profit as

$$(1 - \sqrt{\frac{\pi_0(q)}{\lambda(\bar{p}\bar{D}-w_N-w_Nq)}})(\bar{p}\bar{D} - w_N - w_Nq) - \frac{\sqrt{\lambda \pi_0(q)(\bar{p}\bar{D}-w_N-w_Nq)}-1}{\lambda} = \frac{1}{\lambda}\{[\sqrt{\lambda(\bar{p}\bar{D} - w_N - w_Nq)} - \sqrt{\pi_0(q)}]^2 + 1 - \pi_0(q)\},$$

where $q \in \{l,h\}$, and

$\sqrt{\lambda(\bar{p}\bar{D} - w_N - w_Nq)} - \sqrt{\pi_0(q)} > 0$, since

$\pi(q) = \sqrt{\frac{\pi_0(q)}{\lambda(\bar{p}\bar{D}-w_N-w_Nq)}} < 1 \iff \sqrt{\lambda(\bar{p}\bar{D} - w_N - w_Nq)} > \sqrt{\pi_0(q)}$.

Thus a type l F_N's maximized profit is $\frac{1}{\lambda}\{[\sqrt{\lambda(\bar{p}\bar{D} - w_N - w_Nl)} - \sqrt{\pi_0(l)}]^2 + 1 - \pi_0(l)\}$, while a type h one's is $\frac{1}{\lambda}\{[\sqrt{\lambda(\bar{p}\bar{D} - w_N - w_Nh)} - \sqrt{\pi_0(h)}]^2 + 1 - \pi_0(h)\}$. Then we can see the type l F_N's maximized profit is greater than the type h one's, since $\pi_0(l) < \pi_0(h)$ while $\bar{p}\bar{D} - w_N - w_Nl > \bar{p}\bar{D} - w_N - w_Nh$.

Chapter 3

Effects of Patent and Trade Secret Protection on Foreign-sourced R&D Investment

1. Introduction

Many countries around the world see the legal protection of intellectual property (IP) as a tool to nurture innovation. Stronger IP protection is seen as conducive to environments where research and development (R&D) activities and technology transfer can flourish, and thereby promote economic development. However, existing theoretical and empirical literature shows ambiguous effects of IP protection on R&D, and this issue is continuously debated in economics. Within this debate, the effect of a country's IP protection on the foreign-sourced R&D investment is a topic of particular interest. This is because foreign-sourced R&D investment involves cross-border technology or resource transfers, thus exhibiting some qualitative differences from domestic-sourced R&D investment.

There are various legal regimes of IP protection, but two of them, patent protection and trade secret protection, have attracted the most attention. The effect of patent protection on R&D has been widely studied both theoretically and empirically. However, to our knowledge, there are only a couple of empirical studies that focus on how patent protection in the host country affects foreign-sourced R&D investment (Kumar, 1996 & 2001). Moreover, due to lack of indicators on trade secret protection, most of the literature on trade secret has focused on theoretical aspects. There is relatively little empirical evidence on the effect of trade secret protection on general R&D, not to mention specific evidence on the effect of trade secret protection on foreign-sourced R&D investment.

Therefore, we are aware of no empirical investigation, simultaneously focusing on the effects of both patent and trade secret protection on the foreign-sourced R&D investment. Our work aims at filling in this gap.

Our results are based on an unbalanced panel dataset that covers 25 countries for the five quinquennial periods from 1990 to 2010. In our empirical model, a patent rights index constructed by Ginarte and Park (1997) is used to measure each country's strength of patent protection. Also, we measure trade secret protection in each country with a relatively new index that is constructed by Lippoldt and Schultz (2014).

We estimate the empirical model in alternative specifications, compare the results, and then prefer one of the model specifications that include country fixed-effect (FE) terms. The results from our preferred model specification indicate that both patent and trade secret protection may either boost or discourage foreign-sourced R&D investment. Also, for boosting the foreign-sourced R&D investment into a country, there is strong complementarity between patent and trade secret protection. In the absence of the complementarity between the two regimes, the patent protection alone exhibits a linear negative effect on the foreign-sourced R&D investment. As for trade secret protection, in the absence of the complementarity between the two regimes, the trade secret protection alone exhibits a U-shaped effect on the foreign-sourced R&D investment. Then, the sign of the marginal effect of patent protection on the foreign-sourced R&D investment crucially depends on the strength of trade secret protection. If the strength of trade secret protection is high enough, the positive effect of patent protection is strong enough to outweigh its negative effect, making the net marginal effect of patent protection positive; otherwise, the net marginal effect of patent protection turns to negative. Also, the sign of the marginal effect of trade secret protection depends on the combination of the strength of patent protection and that of trade secret protection itself. If the combinative strength of patent and trade secret protection is high enough, the positive effect of trade secret protection is strong enough to outweigh its negative effect, making the net marginal effect of trade secret protection positive; otherwise, the net marginal effect of trade secret protection turns to negative.

Checking all the observations, we find that in most observations, both patent and trade secret protection exhibit positive marginal effects. Only in a few observations, one or both regimes' marginal effects turn to negative. This indicates that mostly, the dominant effects of both patent and trade secret protection are their positive effects that stem from the "appriopriability" channel: both patent and trade secret protection increase the appriopriability of R&D achievements. Only in rare cases, one or both regimes' positive effects from the appriopriability channel become too weak, and thus outweighed by their negative effects stemming from other channels.

Among the existing literature, we can see much theoretical literature predicts an inverted-U-shaped effect of patent protection on the R&D activities in a country (e.g., Gallini, 1992; Cadot and Lippman, 1995; Horowitz and Lai, 1996; Shapiro, 2001; O'Donoghue and Zweimuller, 2004). However, there is quite weak empirical support for an inverted-U-shaped effect of patent protection on R&D investment. Only the finding by Qian (2007) supports this inverted-U-shaped effect. The findings by Varsakelis (2001), Kanwar and Evenson (2003), Park (2005) and Allred and Park (2007a) just show a positive effect of patent protection on R&D investment. Contrary to the theoretical prediction, Allred and Park (2007b) find that patent protection exhibits a U-shaped effect on the R&D investment in developed countries.

Closely related to our work, Kumar (1996; 2001) investigates the effect of patent protection on foreign-sourced R&D investment. His findings show neither an inverted-U-shaped nor U-shaped effect of patent protection. Depending on the host country's characteristics, the effect of patent protection on foreign-sourced R&D investment may be positive or negative. The effect tends to be positive in developed countries, while negative in developing countries. Kumar explains his findings by noting the different nature of the foreign-sourced R&D investment in developed countries, and that in developing countries: foreign-sourced R&D investment in developed countries is more creative/new development-oriented, while it is more adaption or customization-oriented in developing countries. Then the negative effect of patent protection on the adaption or customization-oriented R&D investment in developing countries can be explained by noting that, stronger patent protection, by preventing imitation, reduces the need for R&D investment aimed at making imitation more difficult. This is consistent with the theoretical work by Reed and Defillippi (1990). These authors' work argues that firms may invest in de-facto barriers to imitation in order to enhance the protection of their IP above and beyond the available legal protection. We will refer to this channel for explaining the negative marginal effects of patent protection that appear in our results.

Kumar's (1996; 2001) analysis does not include proxies for trade secret protection, and is therefore silent about the effect of trade secret protection. Moreover, the omission of a key variable like trade secret protection means that the model is likely to be miss-specified. Our work adds to the literature by overcoming these limitations.

As suggested by some existing theoretical literature, and indirectly hinted by some existing empirical evidence, we can see that due to different channels, trade secret protection may have both positive and negative effects on R&D activities (e.g., Kitch, 1980; Friedman et al., 1991; Lokshin et al., 2006; Lemley, 2008; Lippoldt and Schultz, 2014). There is only one empirical study by Png (2017) that directly focuses on this issue, but it just examines the effect of state-level trade secret protection on the R&D investment within the USA. Then its results are not so related to our results about the effect of country-level trade secret protection on foreign-sourced R&D investment. Thus we will just relate the different effects of trade secret protection in different countries shown in our results, to the different channels suggested by the theoretical literature and indirectly hinted by the empirical evidence.

Besides the direct effects of patent and trade secret protection, we analyze the interaction between the two regimes. Some existing theoretical literature and hints given by empirical evidence suggest that, for boosting R&D activities in a country, patent and trade secret protection act as substitutes for each other (Anton and Yao, 2004; Denicolo and Franzoni, 2004; Moser, 2005; Kultti et al., 2007). However, some other theoretical literature and case studies indicate that for many innovations, patent and trade secret protection are both crucial (Arora, 1997; Jorda, 2008; Ottoz and Cugno, 2008). This suggests that for boosting the R&D investment on these innovations, patent and trade secret protection are complementary to each other. Our work provides the first direct empirical evidence on the interaction between the two regimes, supporting the suggestion of complementarity between these two regimes.

The remainder of this chapter is structured as follows. Section 2 provides a detailed review of the existing theoretical and empirical literature that discusses the effects of patent and trade secret protection on R&D, including the empirical literature that specifically discusses the effect of patent protection on the foreign-sourced R&D investment. Section 3 describes the empirical strategy. Section 4 discusses the empirical results. Section 5 gives some concluding remarks. Section 6 discusses some limitations of this chapter. Moreover, in two appendices for this chapter, we present our approach to model selection, and also the robustness analysis.

2. Effects of Patent and Trade Secret Protection on R&D: A Literature Review

2.1. Effects of Patent Protection on R&D

In much theoretical literature, patent protection is predicted to have an inverted-U-shaped effect on R&D. This is due to several reasons.

First, the length of patent life may have an inverted-U-shaped effect on R&D activities. Gallini (1992) suggests that when patent life is below a given threshold, an increase in patent life leads to higher returns from an innovation, and thus increases the incentive to innovate, since a longer patent life lengthens the patentee's monopoly over its innovation. However, when the patent life has exceeded the threshold, a further increase in patent life will have no effect on the incentive to innovate. This is because the benefit from longer monopoly rents will be outweighed by the loss due to more imitations: a longer patent life discourages the competitors from waiting for the end of patent life, and then spurs the competitors to invent around, or develop non-infringing imitations during the patent life. Cadot and Lippman (1995) point out that as the patent life lengthens, on the one hand, a firm's ability to appropriate its R&D investment increases. On the other hand, there is less rival entry, and thus the firm has lower incentive to generate new products that would only make the existing ones outdated. When the patent life does not exceed a threshold, the former effect prevails; otherwise, the latter prevails. Horowitz and Lai (1996) suggest that "the rate of innovation" is "the product of the size of innovation and the frequency of innovation". The size of innovation increases with the patent life, while the frequency of innovation decreases with the patent life. It's still that, below a threshold of patent life, the former effect prevails; otherwise, the latter prevails.

Second, the patent breadth may also have an inverted-U-shaped effect on R&D activities. O'Donoghue and Zweimuller (2004) categorize patent breadth into two types: lagging breadth, and leading breadth. The former determines what range of inferior products infringe, while the latter determines what range of superior products infringe. The leading breadth has an inverted-U-shaped effect on R&D activities. On the one hand, a larger leading breadth increases a new patent holder's markup, and thus its incentive to engage in R&D. On the other hand, a larger leading breadth weakens the new patent holder's bargaining position, with respect to the existing patent holders early in the patent life. This is because under a larger breadth, it's more difficult for the new patent holder to avoid stepping on existing patent rights. When the leading breadth does not exceed a threshold, the former effect prevails; otherwise, the latter prevails.

Besides the effects of patent life and patent breadth, the theoretical literature on "patent thicket" also provides support for the inverted-U-shaped effect of patent protection on R&D activities. For instance, Shapiro (2001) argues that if patent protection is quite strong, the incentive to file patents is great. Then if more patents have been issued, the innovators have to seek more permissions for building on patented previous technologies, and thereby suffer higher transaction costs. This negatively affects the incentive to innovate.

Despite the abundance of theoretical support, the empirical support for the inverted-U-shaped effect of patent protection on R&D investment is quite weak. Only Qian (2007) finds that a country's patent protection exhibits an inverted-U-shaped effect on the domestic pharmaceutical R&D investment. Unlike this finding, most empirical findings just support a positive effect of patent protection on R&D investment (Varsakelis, 2001; Kanwar and Evenson, 2003; Park, 2005; Allred and Park, 2007a).

Moreover, the effect of patent protection on R&D investment differs between developed and developing countries. In sharp contrast with the theory, Allred and Park (2007b) find a U-shaped effect of patent protection on firm-level R&D investment for 10 manufacturing industries in developed countries. However, they also find that, in developing countries, patent protection has no significant effect on firm-level R&D investment in the same industries. Kumar (1996; 2001) finds that the effect of patent protection on foreign-sourced R&D investment tends to be positive in developed countries while negative in developing countries

To sum up, although most of the theoretical literature predicts an inverted-U-shaped effect of patent protection on R&D, the empirical evidence is quite nuanced, and provides weak support for the predicted inverted-U-shaped effect. Therefore, the existing literature cannot help us predict an unambiguous effect of patent protection on the foreign-sourced R&D investment. This effect needs to be examined by our empirical work.

2.2. Effects of Trade Secret Protection on R&D

Standard theory indicates that trade secret protection can generate a positive effect on R&D through the “appropriability” channel. Stronger trade secret protection increases the appropriability of R&D work generating technical and confidential business information. This is because stronger protection makes it more difficult for employees, business partners and third parties to misappropriate or misuse the information that meets the trade secrets criteria (Kitch, 1980; Friedman et al., 1991; Lemley, 2008).

Nevertheless, some theoretical contributions and empirical evidence indicate that trade secret protection may also generate negative effects on R&D through two channels.

First, under weaker trade secret protection, technologies will be updated more frequently in order to make the leaked information outdated and thereby valueless. This clearly encourages more R&D efforts (Lippoldt and Schultz, 2014).

Second, weak trade secret protection encourages R&D information spillover among competitors, and the information leaking from competitors may assist with a firm's R&D work (Lokshin et al., 2006; Samila and Sorensen, 2011; Png, 2012; Lippoldt and Schultz, 2014; Png and Samila, 2015).

In spite of the existence of these channels where trade secret protection may generate both positive and negative effects on R&D, empirical investigations directly examining the effect of trade secret protection on R&D investment are rare. Png (2017) finds that within the USA, state-level trade secret protection positively affects the R&D investment among the larger firms, and that among the firms in high-tech industries, but has no significant effect on the R&D investment among the other firms.

To sum up, the existing literature cannot help us predict an unambiguous effect of trade secret protection on the foreign-sourced R&D investment. This effect needs to be examined by our empirical work.

2.3. Interaction between Patent Protection and Trade Secret Protection

Although the direct effects of patent and trade secret protection on R&D have attracted most of the interest, the two IP regimes' interaction is arguably at least as important. The literature on this is scarce and the available studies are reviewed below.

A number of studies indicate that patent protection and trade secret protection are substitutes (Anton and Yao, 2004; Denicolo and Franzoni, 2004; Moser, 2005; Kultti et al., 2007).

Nevertheless, some theoretical works and case studies indicate that, for many innovations, patent and trade secret protection are both crucial (Arora, 1997; Jorda, 2008; Ottoz and Cugno, 2008). In other words, the two regimes complement each other. The above literature summarizes the three circumstances under which patent and trade secret protection are both crucial as follows: (1) The innovation is protected by trade secret laws during its R&D stage, before the filing, publication or issuing of any patent application for the innovation (Jorda, 2008); (2) Some modules of the innovation are protected by patents, while essential knowhow about the operation of the innovation is kept secret (Arora, 1997; Jorda, 2008; Ottoz and Cugno, 2008); and (3) After the patent application for the innovation is submitted, new developments of the innovation are kept as trade secrets (Jorda, 2008; Ottoz and Cugno, 2008).

In spite of the existence of some theoretical literature on the interaction between the two regimes, and also some empirical evidence and case studies that give hints for this interaction, there is no empirical investigation that directly focuses on this interaction.

Thus the existing theoretical and empirical literature is also far from adequate, to help us unambiguously predict that when patent and trade secret protection work for boosting the foreign-sourced R&D investment, what interaction between the two regimes exists. This interaction needs to be examined by our empirical work.

3. Empirical Strategy

3.1. Measurement of Variables

Dependent Variable:

Our dependent variable measures the volume of foreign-sourced R&D investment into each country, and we then test how it is affected by the strengths of patent and trade secret protection.

We realize that trade secrets play a significant role in the operation of business enterprises, but not in that of governments, academic institutions and other non-profit institutions. Then instead of the foreign-sourced R&D investment performed by all institutions, we use the foreign-sourced R&D investment performed by business enterprises, denoted as ***FBERD***. Also, to exclude the effect of population size, we use the per capita value of ***FBERD*** as our dependent variable, denoted as ***FBERDperca***.

Explanatory Variables:

Our two explanatory variables are the country-level strength of patent protection, denoted as ***PP***, and the country-level strength of trade secret protection, denoted as ***TP***. We will use two indices to measure ***PP*** and ***TP***, respectively.

To measure ***PP***, we use the patent rights index constructed by Ginarte and Park (1997). Ginarte and Park (1997) examine five categories of each country's patent laws: (1) coverage; (2) membership in international patent treaties; (3) duration of protection; (4) enforcement regimes; and (5) restrictions on patent rights. Each of these categories contains several components, and each component is given a score. For each category, the sum of the components' scores gives a value ranging from 0 to 1. Then the sum of the five categories' values constitutes a value ranging from 0 to 5, and this becomes the overall value of the patent rights index. Higher values of the index indicate stronger patent protection. Table 1 presents the components and scoring method of this patent rights index.

Table 1. Components and Scoring Method of the Patent Rights Index

Components	**Scoring**	
(1) Coverage	**Available**	**Not available**
Patentability of pharmaceuticals	1/8	0
Patentability of chemicals	1/8	0
Patentability of food	1/8	0
Patentability of surgical products	1/8	0
Patentability of microorganisms	1/8	0
Patentability of utility models	1/8	0
Patentability of software	1/8	0
Patentability of plant and animal varieties	1/8	0
(2) Membership in international agreements	**Signatory**	**Not signatory**
Paris convention and revisions	1/5	0
Patent cooperation treaty	1/5	0
Protection of new varieties (UPOV)	1/5	0
Budapest treaty (microorganism deposits)	1/5	0
Trade-related intellectual property rights (TRIPS)	1/5	0
(3) Duration of protection	**Full**	**Partial**
	1	0< f<1, where f is the duration of protection as a fraction of 20 years from the date of application or 17 years from the date of grant (for grant-based patent systems).
(4) Enforcement regimes	**Available**	**Not available**
Preliminary (pre-trial) injunctions	1/3	0
Contributory infringement	1/3	0
Burden of proof reversal	1/3	0
(5) Restrictions on patent rights	**Does not exist**	**Exists**
Working requirements	1/3	0
Compulsory licensing	1/3	0
Revocation of patents	1/3	0
Overall score for the patent rights index: sum of points under (1)–(5).		

Also, to measure ***TP***, we use the trade secret protection index constructed by Lippoldt and Schultz (2014). Lippoldt and Schultz (2014) examine five categories of each country's trade secret laws: (1) definitions and coverage; (2) specific duties and misappropriation; (3) remedies and restrictions on liability; (4) enforcement, investigation and discovery, and also data exclusivity; and (5) system functioning and related regulation. Each of these categories contains several components, and each component is given a score. For each category, the sum of the components' scores is normalized to a value ranging from 0 to 1. Then the sum of the five categories' normalized values constitutes a value ranging from 0 to 5, and this becomes the overall value of the trade secret protection index. Higher values of the index indicate stronger trade secret protection. Table 2 presents the components and scoring method of this trade secret protection index.

Table 2. Components and Scoring Method of the Trade Secret Protection Index

Components and Scoring	Score Range	Normalised Score Range
1. Definitions and coverage	**0-13**	**0-1**
a) Scope		
• If scope covers all confidential business information, subject to: 1) deriving value from secrecy and 2) the owner's reasonable efforts to maintain secrecy, score = 1; If scope also subject to requirement that information is imparted to the recipient in confidence, score = ½	0-1	
b) Additional Elements of Definition		
• Inventory of trade secrets required (requirement=0; no requirement=1)	0-1	
• Must be reduced to writing (requirement=0; norequirement=1)	0-1	
• Must be identified as a trade secret to recipient (requirement=0; no requirement=1)	0-1	
• Written notice to recipient required (requirement=0; no requirement=1)	0-1	
c) Acts covered as civil infringement:		
• Breach of duty (not covered=0, partially covered=½,[27] covered=1)	0-1	
• Wrongful acquisition or misappropriation (not covered=0, covered=1)	0-1	
• Third party liability for acquisition with knowledge or reason to know (not available=0, available=1)	0-1	
• Third party liability for acquisition without knowledge – enjoin "innocent parties" (not available=0, available=1)	0-1	
d) Acts covered by criminal law		
• Breach of duty (not covered=0, partially covered=½, covered=1)	0-1	
• Wrongful acquisition or misappropriation (not covered=0,	0-1	

[27] E.g., employees, fiduciaries and third parties with access to information might be bound by the obligation of confidentiality. There might be partial coverage, if a country's legal regime cannot cover licensees.

covered=1)		
• Third party liability for acquisition with knowledge or reason to know (not available=0, available=1)	0-1	
• Third party liability for acquisition without knowledge, enjoin “innocent parties” (not available=0, available=1)	0-1	
2. Specific duties and misappropriation[28]	**0-5**	**0-1**
• Commercial relationship (covered if arising from: express agreement ½ + implied duty ½)	0-1	
• Current employment relationship (covered if arising from: express agreement ½ + implied duty ½)	0-1	
• Past employment relationship (covered if arising from: express agreement ½ + implied duty ½)	0-1	
• Restrictions on post-relationship duty of confidentiality (if any restrictions on matters beyond general skills and knowledge, by relationship: commercial ½ + employment ½)	0-1	
• Validity of contractual restrictions on competition (if unenforceable=0, significant limitations=½ (e.g., limited by time or place for either commercial or post-employment situations), generally enforceable=1)	0-1	
3. Remedies and restrictions on liability	**0-11**	**0-1**
a) Restrictions on liability		
• Additional elements of proof in infringement claims (if none: score = “civil=½” + “criminal=½” = 1; score 1 if there no criminal law and civil score is ½)	0-1	
b) Civil remedies		
• Preliminary injunction (if available = 1, if not = 0)	0-1	

[28] The treatment of duties refer to two components of this framework. Index component 1 (definitions and coverage) involves the general coverage of duties. The availability of recourse for specific duties is evaluated under component 2 (specific duties and misappropriation). This allows a detailed assessment, and thereby ensures the variation in key elements is reflected in the indicator.

• Ex parte action available under preliminary injunction (if available = 1, if not = 0)	0-1	
• Permanent injunction (if available = 1, if not = 0)	0-1	
• Injunction to eliminate wrongful head start (if available = 1, if not = 0)	0-1	
• Delivery or destruction of infringing materials (if available = 1, if not = 0)	0-1	
• Compensatory damages (direct or out of pocket damages or consideration of profits or other damages= 1)	0-1	
• Yielding of defendant's profits (if available = 1, if not = 0)	0-1	
• Availability of punitive or statutory damages (if available = 1, if not = 0)	0-1	
c) Criminal remedies		
• Fines, damages or loss of assets (if not available = 0, if minimal per expert opinion= ½, if substantial = 1)	0-1	
• Jail sentence (if available = 1, if not = 0)	0-1	
4. Enforcement, investigation and discovery; data exclusivity	**0-6**	**0-1**
a) Enforcement, investigation and discovery		
• Emergency search to preserve and obtain proof (unavailable=0, available but with significant restrictions= ½ (e.g., conducted solely by an official or 3rd party expert), readily available=1)	0-1	
• Ex parte emergency search availability (unavailable=0, available but with significant restrictions=½, readily available=1)	0-1	
• Pre-trial discovery (unavailable=0, documentary only or strict limitations = ½, ready availability of documentary and interrogatories = 1)	0-1	
• Protection of confidentiality of trade secrets in litigation (none=0, partial= ½, fully available=1)	0-1	
b) Data exclusivity		
• Drugs (years: 0=0; 0.1-3=1/3; 3.1-7.9=2/3; >8=1)	0-1	
• Agricultural chemicals (years: 0=0, 0.1-	0-1	

4.9=1/3, 5-8=2/3; >8=1)		
5. System functioning and related regulation	**0-4**	**0-1**
• Technology transfer: registration requirement (none=1; one or more = 0)	0-1	
• Technology transfer: substantive review or regulation (none=1; one or more = 0)	0-1	
• Fraser Institute score for Legal System and Security of Property Rights (score ranging from 0 to 10, divided by 10)[29]	0-1	
• Expert characterisation of the operation of the protection in practice (NB, based on internationally recognised or peer-reviewed sources; see country charts for details) (Negative = 0; none = ½; positive = 1)	0-1	
Index Total		**0-5**

[29] This score is computed by Gwartney et al. (2012), and then published by the Fraser Institute. According to objective indicators and expert assessments, it evaluates judicial independence, impartiality of courts, protection of property rights, military interference in the rule of law and politics, integrity of the legal system, legal enforcement of contracts, regulatory restrictions on the sale of real property, reliability of the police, and business costs of crime. The details are presented in Annex 1 of the “Economic Freedom of the World: 2012 Annual Report” by Gwartney et al. (2012), at: http://www.freetheworld.com/release_2012.html.

Control Variables:

Besides the explanatory variables ***PP*** and ***TP*** that are our main focus, to avoid omitted variable bias, we should also include some other independent variables that may affect the dependent variable, as the control variables in our model.

Firstly, we include the annual gross growth rate of per capita real GDP as a control variable, denoted as ***GDPgrow***. It is expected that a higher ***GDPgrow*** leads to a higher increase in the per capita demand for newly-innovated/adapted technologies, and thereby attracts a higher ***FBERDperca***.

Secondly, we include two variables to measure the stock of human capital. They are the rate of completing secondary education as the highest level in the population aged 15+, and the rate of completing tertiary education as the highest level in the population aged 25+, denoted as ***Sec*** and ***Ter***, respectively. Referring to Yang and Maskus (2001), the theoretical prediction for the effect of human capital abundance on ***FBERDperca*** is ambiguous. On the one hand, higher human capital abundance means local employees can do better in developing or adapting technologies. Then the foreign investors can bear less costs for training the local employees engaged in R&D work, and thereby become more willing to make R&D investment in the host country. On the other hand, higher human capital abundance leads to more efficient and less costly local imitation, discouraging the foreign investors' R&D efforts.

Thirdly, we include two control variables about the market openness and regulation: the index of freedom to trade internationally, and that of market regulation, both of which are computed by Gwartney et al. (2015), denoted as ***FT*** and ***Regu***, respectively. ***FT*** measures a country's tariffs, regulatory trade barriers, black-market exchange rates, and controls on the movement of capital and people (Gwartney et al., 2015). A higher value in this index means the country has lower tariffs, easier clearance and more efficient administration of customs, a more freely convertible currency, and fewer controls on the movement of physical and human capital. Also, ***Regu*** measures a country's credit market regulations, labour market regulations, and business regulations (Gwartney et al., 2015). A country with lighter regulations in these aspects gets a higher value in this index. The effect of ***FT*** on ***FBERDperca*** is theoretically ambiguous. A higher ***FT*** means exporting products to that country is easier. Then on the one hand, easier export of technological products to the country decreases the foreign investors' incentive to make R&D investment for market entry. On the other hand, it is easier for foreign investors to export to that country the materials, tools or intermediate goods needed for R&D work, or the products needing adaptive R&D work. This encourages the foreign investors' R&D efforts. The effect of ***Regu*** on ***FBERDperca***, however, is theoretically positive. A country with a higher ***Regu*** tends to have lighter regulation on inward foreign direct investment, and then it is more favourable for the foreign investors to make R&D investment.

Fourthly, we include the control variable of the labour participation rate in the population aged 15+, denoted as ***Labopa***. ***Labopa*** is theoretically predicted to positively affect ***FBERDperca***, since a higher ***Labopa*** means a greater labour supply, and thereby lower labour costs for R&D activities.

Finally, we include a "West Germany dummy", denoted as ***WGD***, to deal with the inconsistence in the data of Germany. In our sample, the data of Germany by 1990 refer only to the former West Germany, while those after 1990 refer to the reunified Germany. Then we include the dummy ***WGD***, such that ***WGD*** = 1 for the observations of Germany by 1990, while ***WGD*** = 0 for all the other observations. This dummy is used to reflect possible difference between the country effect of the former West Germany and that of the reunified Germany.

3.2. Data Sources

The data of ***FBERD*** come from two sources: the Organization for Economic Co-operation and Development (OECD), and the United Nations Educational, Scientific and Cultural Organization (UNESCO). Some observations exist in both sources, while the others only exist in one of them. The earliest observations exist in 1987. Both sources provide the data in national currency units at current prices, and also the data that have been converted into purchasing-power-parity (PPP) international dollars at constant prices. We check the data of the observations that exist in both sources, and find that the two sources provide exactly the same value of each observation in national currency units at current prices, but slightly different values of each observation in PPP international dollars at constant prices. Given this, we can suggest that the two sources use the same statistical scope for collecting all their raw data, while they may use different GDP deflators and/or PPP conversion factors to convert the data into PPP international dollars at constant prices. Then to avoid inconsistence within our observations, no matter for the observations that exist in both sources or for those that exist in only one source, we use the raw data, available in one or both sources, in national currency units at current prices. We then convert the raw data into PPP international dollars at 2005 constant prices, using the GDP deflators provided by the World Economic Outlook (WEO) Database (Oct. 2015 edition) published by the International Monetary Fund (IMF), and also the PPP conversion factors provided by the 2005 International Comparison Program (ICP) implemented by the World Bank.

Also, we get the data of GDP in national currency units at current prices from the WEO Database (Oct. 2015 edition), and use the GDP deflators from this database and the PPP conversion factors from the 2005 ICP to convert the GDP into PPP international dollars at 2005 constant prices.

To calculate the values of ***FBERDperca*** and the per capita GDP that is used for computing ***GDPgrow***, we use the data of population provided by the World Development Indicators (WDI) Database published by the World Bank, except the population of Taiwan that is unavailable in the WDI Database. Then for the Taiwan's population, we use the data provided by the International Data Base (IDB) published by the U.S. Census Bureau (USCB). The IDB by USCB is one of the sources to which the WDI Database refers for collecting the population data.

The data of ***Sec*** and ***Ter*** are provided by the Barro-Lee Educational Attainment Dataset. The dataset was firstly published in a paper authored by Barro and Lee (2010),[30] and onwards updated by the authors for several times.

The data of ***FT*** and ***Regu*** come from the 2015 Economic Freedom Dataset that is authored by Gwartney et al. (2015), and published by the Fraser Institute. The data used are chain-linked.[31]

The data of ***Labopa*** come from the ILOSTAT Database published by the International Labour Organization (ILO). The data are available from 1990.

The data of ***PP*** for the quinquennial periods during 1960 to 1990 come from a paper authored by Ginarte and Park (1997), and those for the periods by 1995, 2000 and 2005 come from another paper authored by Park (2008), while those for the period by 2010 come from a data file published on Park's personal webpage[32]. Also, the data of ***TP*** are provided by an OECD policy paper authored by Lippoldt and Schultz (2014). These data cover 37 countries for the six quinquennial periods by 1985, 1990, 1995, 2000, 2005 and 2010 (not all countries are covered in every year).

Then finally, limited to data availability for each variable, our sample is an unbalanced panel dataset including 94 observations that cover 25 countries for the five quinquennial periods during 1990 to 2010. The 25 countries in our sample are Australia, Argentina, Bulgaria, Canada, China, France, Germany, Ireland, Israel, Italy, Japan, Lithuania, Mexico, Netherlands, New Zealand, South Korea, Russia, Singapore, South Africa, Spain, Sweden, Taiwan, Turkey, UK, and USA.

[30] A working paper by Barro and Lee (2010) develops further into a published paper by Barro and Lee (2013).
[31] The source by Gwartney et al. (2015) provides both the raw data of these two variables, and also their chain-linked data that are computed by adjusting the raw data to guarantee cross-time comparability. Then since our sample covers a relatively long term, to avoid inconsistence across time, we use the chain-linked data of these two variables instead of their raw data.
[32] http://nw08.american.edu/~wgp/.

3.3. Model Specifications

Besides the explanatory and control variables mentioned above, there are also some country-specific characteristics in institutions, culture and tastes that may affect ***FBERDperca***. These characteristics are time-invariant, and cannot be captured by the independent variables. Then we include a country effect term to capture these characteristics. Including the country effect term, we will use country fixed-effect (FE) and also random-effect (RE) approach, respectively, to estimate our empirical model.

For the explanatory variables, besides the linear terms of ***PP*** and ***TP***, considering that the effects of ***PP*** and ***TP*** may be non-linear, we also include both variables' quadratic terms, and their interaction term in our first model specification. Then according to the estimation results and relevant test results, we may prefer a model specification where one or more of the linear and non-linear terms of ***PP*** and ***TP*** are dropped.

In addition, to address the possible time lags in the effects of ***PP*** and ***TP***, and reduce the risk of endogeneity caused by reverse causality between the dependent variable and explanatory variables, we will check whether we prefer a model specification where in all the included linear and non-linear terms of ***PP*** and ***TP***, one-period lagged ***PP*** and ***TP*** are used instead of the current ones.

Moreover, to reduce the influence from possible heteroscedasticity, in our empirical model, all the variables except the dummy ***WGD*** are entered as natural logarithms instead of their initial values.

Thus collecting the ideas mentioned above, all the possible model specifications we may use are captured in the following expression:

$$FBERDperca_{i,\ t} = \alpha + \beta[IP]_{i,\ t} + \gamma[Control]_{i,\ t} + \mu_i + \varepsilon_{i,\ t}$$

Here, i denotes country, and t denotes quinquennial period. α is the intercept, μ_i is either a country FE or a country RE term, and $\varepsilon_{i,\ t}$ is the random error term. $[IP]_{i,\ t}$ is a vector that contains the explanatory variable(s) measuring IP protection, including one or more of the linear and non-linear terms of either current or one-period lagged ***PP*** and ***TP***. $[Control]_{i,\ t}$ is a vector that contains the seven control variables.

4. Empirical Results and Discussion

4.1. Descriptive Statistics, Correlation Matrix and Scatter Plots of Variables

Before we run regressions to examine the effects of our explanatory variables on the dependent variable, we check the descriptive statistics of all the logged variables. Table 3 presents these descriptive statistics.

Table 3. Descriptive Statistics of Logged Variables

	FBERDperca	***PP***	***TP***	***PP*** (1-period lagged)	***TP*** (1-period lagged)
Mean	1.64	1.38	1.29	1.27	1.24
Median	2.11	1.43	1.33	1.36	1.31
Maximum	6.16	1.58	1.50	1.58	1.50
Minimum	-4.43	0.18	0.49	0.02	0.17
Std. Dev.	2.34	0.20	0.17	0.30	0.23
Skewness	-0.61	-3.09	-1.68	-2.08	-2.01
Kurtosis	2.60	17.12	7.04	8.00	7.96
Jarque-Bera	6.51	931.29	108.27	165.86	159.35
Probability	0.04	0.00	0.00	0.00	0.00
Sum	154.43	129.76	121.57	119.78	116.74
Sum Sq. Dev.	507.78	3.60	2.83	8.32	5.04
Observations	94	94	94	94	94

	GDPgrow	***FT***	***REGU***	***SEC***	***TER***	***LABOPA***
Mean	0.04	2.08	1.93	3.34	2.44	4.08
Median	0.03	2.09	1.93	3.40	2.59	4.10
Maximum	0.12	2.26	2.17	4.04	3.55	4.35
Minimum	-0.08	1.75	1.54	1.96	-0.78	3.83
Std. Dev.	0.03	0.12	0.14	0.46	0.75	0.10
Skewness	0.06	-0.74	-0.36	-1.03	-1.70	-0.40
Kurtosis	4.38	2.96	2.71	4.20	7.56	3.04
Jarque-Bera	7.52	8.69	2.33	22.32	126.74	2.56
Probability	0.02	0.01	0.31	0.00	0.00	0.28
Sum	3.51	195.75	181.28	313.57	228.98	383.32
Sum Sq. Dev.	0.09	1.34	1.82	19.29	51.72	0.95
Observations	94	94	94	94	94	94

In addition, to check the variability of patent and trade secret protection across countries and across periods, we get the stand deviations of ***PP***, ***TP***, ***PP*** (1-period lagged) and ***TP*** (1-period lagged) in each country across periods, and the stand deviations of these four IP variables in each period across countries. Table 4 and Table 4b present these stand deviations.

Table 4. Cross-period Stand Deviations of IP Variables in Each Country

Variable / Country	***PP***	***TP***	***PP*** (1-perioed lagged)	***TP*** (1-perioed lagged)
Australia (1990-2010)	0.42	0.08	0.75	0.42
Bulgaria (2000-2005)	0.06	0.01	0.43	0.06
Canada (1990-2010)	0.49	0.12	0.55	0.49
France (1990-2010)	0.30	0.02	0.40	0.30
Germany (1990-2010)	0.22	0.01	0.27	0.22
Ireland (1990-2010)	0.97	0.06	1.19	0.97
Israel (2000-2010)	0.00	0.12	0.46	0.00
Italy (1990-2010)	0.26	0.15	0.38	0.26
Japan (1990-2010)	0.30	0.06	0.49	0.30
Mexico (1995-2010)	0.39	0.01	0.94	0.39
Netherlands (1990-2005)	0.18	0.01	0.35	0.18
Korea (1995-2010)	0.18	0.30	0.24	0.18
Russia (2000-2010)	0.00	0.40	0.09	0.00
Singapore (1995-2010)	0.14	0.11	0.87	0.14
Spain (1990-2010)	0.44	0.61	0.66	0.44
Turkey (1990-2010)	1.10	0.11	1.26	1.10
UK (1990-2010)	0.08	0.07	0.26	0.08
Argentina (2000-2010)	0.00	0.02	0.59	0.00
Lithuania (2000-2010)	0.25	0.16	0.54	0.25
NewZealand (1990-1995, and 2005)	0.62	0.20	0.62	0.62
SouthAfrica (2005-2010)	0.06	0.00	0.00	0.06
Sweden (1995 and 2005)	0.06	0.00	0.33	0.06
USA(2010)	0.00	0.00	0.00	0.00
China (2000-2010)	0.50	0.23	0.80	0.50
Taiwan (2000-2010)	0.21	0.10	0.25	0.21
Average	0.29	0.12	0.51	0.29

Table 4b. Cross-country Stand Deviations of IP Variables in Each Period

Period \ Variable	***PP***	***TP***	***PP*** (1-perioed lagged)	***TP*** (1-perioed lagged)
1990 (12 countries)	0.93	0.38	0.85	0.40
1995 (16 countries)	0.58	0.38	1.06	0.64
2000 (21 countries)	0.54	0.71	0.80	0.84
2005 (24 countries)	0.41	0.57	0.52	0.67
2010 (21 countries)	0.39	0.57	0.42	0.57
Average	0.57	0.52	0.73	0.62

In Table 4 and Table 4b, we can see several countries have relatively high cross-period stand deviations in one or more IP variables, but most cross-period stand deviations are lower than cross-country standard deviations. Also, in each of the four IP variables, the average cross-period standard deviation is lower than the average cross-country stand deviation. Then these standard deviations indicate that in this sample, the variabilities of both patent and trade secret protection mainly exist across countries rather than across periods.

Also, to check whether our empirical model will suffer multicollinearity problem, we check the correlations among the independent variables. Table 5 and Table 5b present the correlation matrix of the independent variables including the current ***PP*** and ***TP***, and that of the independent variables including the one-period lagged ***PP*** and ***TP***, respectively.

Table 5. Correlation Matrix of Independent Variables (including the current *PP* and *TP*)

	PP	***TP***	***GDPgrow***	***FT***	***REGU***	***SEC***	***TER***	***LABOPA***
PP	1.0000	0.3553	-0.1330	0.3817	0.2390	0.4140	0.2327	0.0483
TP	0.3553	1.0000	-0.3886	0.5793	0.5496	0.1551	0.3956	0.0469
GDPgrow	-0.1330	-0.3886	1.0000	-0.3008	-0.2451	0.0153	-0.0734	0.0099
FT	0.3817	0.5793	-0.3008	1.0000	0.4386	-0.0345	0.2860	0.0238
REGU	0.2390	0.5496	-0.2451	0.4386	1.0000	0.1213	0.3537	0.4661
SEC	0.4140	0.1551	0.0153	-0.0345	0.1213	1.0000	0.1972	0.1906
TER	0.2327	0.3956	-0.0734	0.2860	0.3537	0.1972	1.0000	0.3095
LABOPA	0.0483	0.0469	0.0099	0.0238	0.4661	0.1906	0.3095	1.0000

Table 5b. Correlation Matrix of Independent Variables (including the one-period lagged *PP* and *TP*)

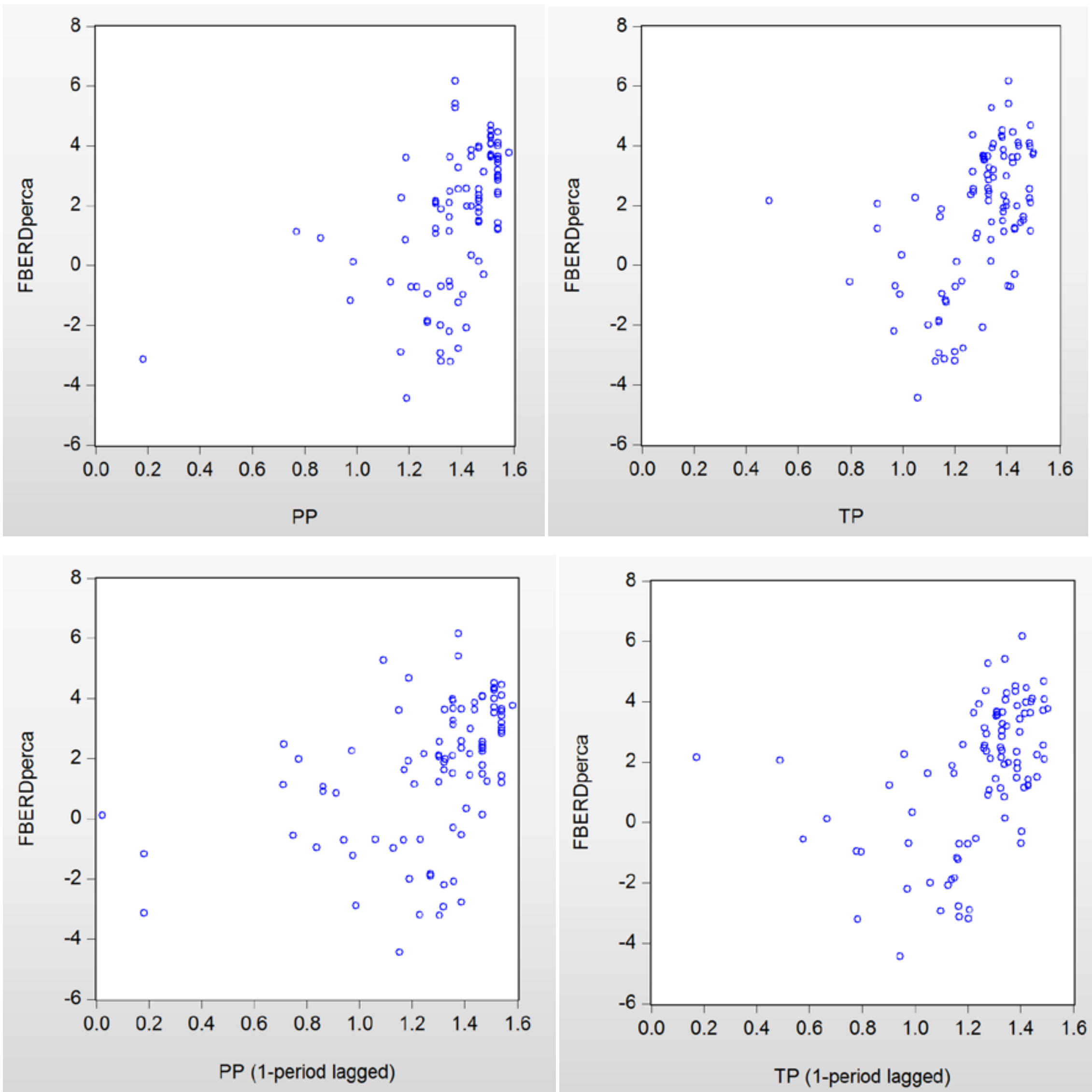
	PP (1-period lagged)	***TP*** (1-period lagged)	***GDPgrow***	***FT***	***REGU***	***SEC***	***TER***	***LABOPA***
PP (1-period lagged)	1.0000	0.3988	-0.0259	0.1760	0.1901	0.4341	0.2623	0.0424
TP (1-period lagged)	0.3988	1.0000	-0.2824	0.5132	0.5608	0.1754	0.3389	0.0142
GDPgrow	-0.0259	-0.2824	1.0000	-0.3008	-0.2451	0.0153	-0.0734	0.0099
FT	0.1760	0.5132	-0.3008	1.0000	0.4386	-0.0345	0.2860	0.0238
REGU	0.1901	0.5608	-0.2451	0.4386	1.0000	0.1213	0.3537	0.4661
SEC	0.4341	0.1754	0.0153	-0.0345	0.1213	1.0000	0.1972	0.1906
TER	0.2623	0.3389	-0.0734	0.2860	0.3537	0.1972	1.0000	0.3095
LABOPA	0.0424	0.0142	0.0099	0.0238	0.4661	0.1906	0.3095	1.0000

We can see in these two tables, all the correlation coefficients have absolute values lower than 0.5 except the correlation coefficient of ***TP*** (1-period lagged) and ***FT***, and that of ***TP*** (1-period lagged) and ***Regu***. Then for the regressions including ***PP*** (1-period lagged) and ***TP*** (1-period lagged), we will run the ones including ***FT*** and ***Regu***, and the ones excluding ***FT*** and ***Regu***, respectively, to check whether the results are invulnerable to the possible multicollinearity caused by the relatively high correlation between ***TP*** (1-period lagged) and ***FT***, and that between ***TP*** (1-period lagged) and ***Regu***.[33]

Moreover, we plot the scatter graphs of the dependent variable ***FBERDperca*** with each of the four main explanatory variables: the current ***PP*** and ***TP***, and also their one-period lagged variables. Figure 1 shows these four scatter graphs.

[33] The results from the regressions excluding ***FT*** and ***Regu*** are presented and discussed in Appendix 2 for this chapter.

Figure 1. Scatter Plots of foreign-sourced R&D investment against IP Protection



We can see all these four scatter graphs do not show clear trends between ***FBERDperca*** and the explanatory variables. Then these graphs indicate that the relation between ***FBERDperca*** and the IP protection is a complicated issue, and thereby needs to be examined carefully by running relevant regressions.

4.2. Regression Results and Discussion

By checking the results from several model specifications and relevant tests, we prefer a model specification that includes a country FE term, the seven control variables, and four one-period lagged explanatory variables: ***PP*** (1-period lagged), ***TP*** (1-period lagged), the quadratic ***TP*** (1-period lagged), and the interaction term of ***PP*** (1-period lagged) and ***TP*** (1-period lagged). The model specification just excludes one explanatory variable: the quadratic ***PP*** (1-period lagged). Table 6 reports the results from this preferred model specification, while the detailed discussion about why to prefer this model specification is presented in the Appendix 1 for this chapter.

Table 6. Effects of Patent and Trade Secret Protection on Foreign-sourced R&D Investment

Dependent Variable: ***FBERDperca***
Method: Panel Least Squares with Country FE
Time Period: 1990-2010
Countries included: 25
Total panel (unbalanced) observations: 94

Regressor	Coefficient	Std Error	t-Statistic
PP (1-period lagged)	-4.873337	1.944855	-2.505758**
TP (1-period lagged)	-10.90855	2.887280	-3.778142***
Quadratic ***TP*** (1-period lagged)	3.228243	1.366716	2.362043**
(1-period lagged ***PP***)* (1-period lagged ***TP***)	4.860687	1.676362	2.899544***
GDPgrow	-7.161242	4.509964	-1.587871
FT	1.112671	1.510180	0.736780
Regu	2.431264	1.282352	1.895941*
Sec	-0.255695	0.353022	-0.724305
Ter	0.011177	0.540949	0.020662
Labopa	-2.607507	2.681988	-0.972229
WGD	0.657265	0.828015	0.793784
Intercept	13.13568	12.54969	1.046694

R^2 =0.942868, Adjusted–R^2 = 0.908391, F-statistic =27.34822

Note: ***, **, and * denote significance at the 1%, 5% and 10% levels, respectively.

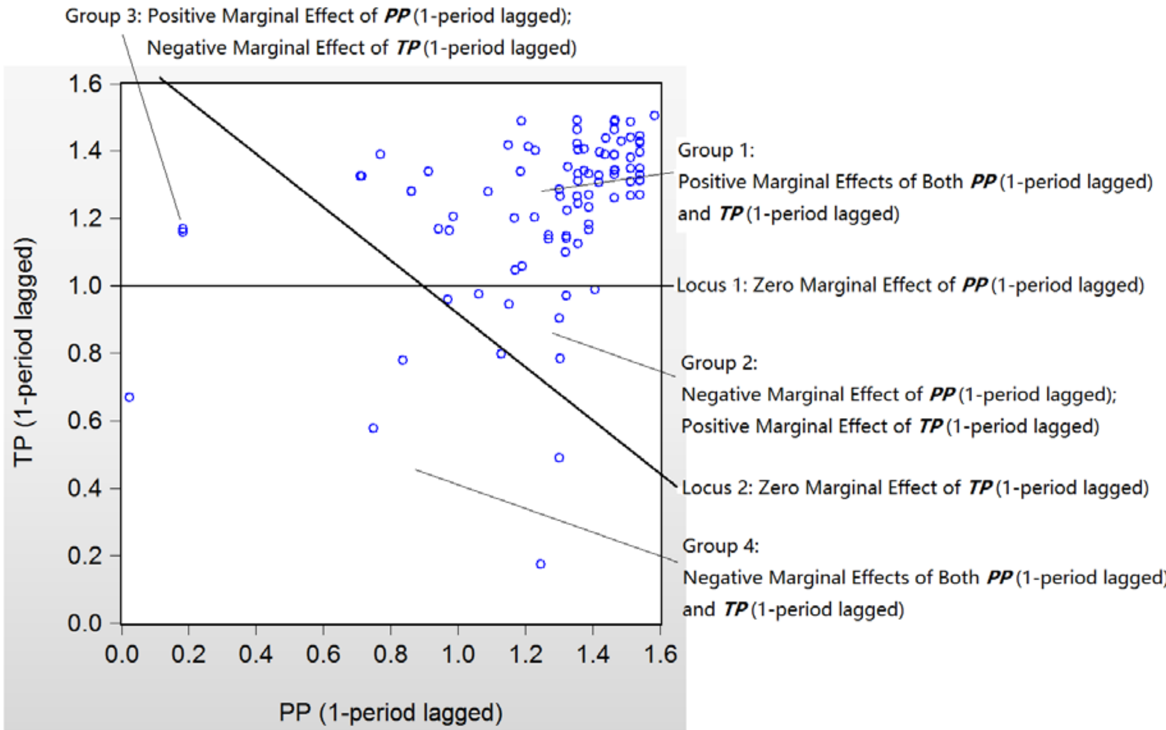
We can see in these results, the coefficients of both ***PP*** (1-period lagged) and ***TP*** (1-period lagged) are significantly negative, while that of the quadratic ***TP*** (1-period lagged) is significantly positive. In addition, there is a significantly positive coefficient of the interaction term of ***PP*** (1-period lagged) and ***TP*** (1-period lagged). This means that for boosting the foreign-sourced R&D investment, patent and trade secret protection are complementary to each other. In the absence of the complementarity between the two regimes, the patent protection alone exhibits a linear negative effect on the foreign-sourced R&D investment. Also, in the absence of the complementarity between the two regimes, the trade secret protection alone exhibits a U-shaped effect on the foreign-sourced R&D investment. Moreover, among the coefficients of the control variables, only the coefficient of ***Regu*** is significant, where it is positively significant. This significantly positive coefficient of ***Regu*** consists with our prediction.

By these results, we check the marginal effects of ***PP*** (1-period lagged) and ***TP*** (1-period lagged), and then find two critical loci: (1) The Locus 1 such that ***TP*** (1-period lagged) = 1.00, on which the marginal effect of ***PP*** (1-period lagged) is zero; and (2) the Locus 2 such that 4.86*(1-period lagged ***PP***) + 6.46*(1-period lagged ***TP***) = 10.91, on which the marginal effect of ***TP*** (1-period lagged) is zero.

Among all the 94 observations, 79 observations have positive marginal effects of both ***PP*** (1-period lagged) and ***TP*** (1-period lagged), since each of these observations has a strength of ***TP*** (1-period lagged) higher than the level at Locus 1, and also a combinative strength of ***PP*** (1-period lagged) and ***TP*** (1-period lagged) higher than the level at Locus 2. Only 7 observations have negative marginal effects of ***PP*** (1-period lagged) while positive ones of ***TP*** (1-period lagged), since each of them has a strength of ***TP*** (1-period lagged) lower than the level at Locus 1, but a combinative strength of ***PP*** (1-period lagged) and ***TP*** (1-period lagged) higher than the level at Locus 2. Only 2 observations have positive marginal effects of ***PP*** (1-period lagged) while negative ones of ***TP*** (1-period lagged), since each of them has a strength of ***TP*** (1-period lagged) higher than the level at Locus 1, but a combinative strength of ***PP*** (1-period lagged) and ***TP*** (1-period lagged) lower than the level at Locus 2. The other 6 observations have negative marginal effects of both ***PP*** (1-period lagged) and ***TP*** (1-period lagged), since each of them has a strength of ***TP*** (1-period lagged) lower than the level at Locus 1, and also a combinative strength of ***PP*** (1-period lagged) and ***TP*** (1-period lagged) lower than the level at Locus 2.

Figure 2 presents Locus 1 and Locus 2, and all the 94 observations located into four groups divided by the two loci, in a coordinate system that has the levels of ***PP*** (1-period lagged) and ***TP*** (1-period lagged) on the horizontal and vertical axes, respectively.

Figure 2. Groups of Observations



In Figure 2, all the 94 observations are located into four groups divided by the two loci: Group 1 where the marginal effects of both ***PP*** (1-period lagged) and ***TP*** (1-period lagged) are positive, Group 2 where the marginal effect of ***PP*** (1-period lagged) is negative while that of ***TP*** (1-period lagged) is positive, Group 3 where the marginal effect of ***PP*** (1-period lagged) is positive while that of ***TP*** (1-period lagged) is negative, and Group 4 where the marginal effects of both ***PP*** (1-period lagged) and ***TP*** (1-period lagged) are negative.

If we locate our 25 sample countries according to the majority of each country's observations, we can see besides Bulgaria, Russia and China, all the other 22 countries are located in Group 1 where the marginal effects of both ***PP*** (1-period lagged) and ***TP*** (1-period lagged) are positive. Only Bulgaria is located in Group 2 where the marginal effect of ***PP*** (1-period lagged) is negative while that of ***TP*** (1-period lagged) is positive. Only Russia and China are located in Group 4 where the marginal effects of both ***PP*** (1-period lagged) and ***TP*** (1-period lagged) are negative. Also, although there are 2 observations in Group 3 where the marginal effect of ***PP*** (1-period lagged) is positive while that of ***TP*** (1-period lagged) is negative, no country has a majority of its observations in this group and then no country is located here.

Then our results indicate that both patent and trade secret protection may have positive or negative effects on the foreign-sourced R&D investment, but mostly, the dominant effects of both regimes on the foreign-sourced R&D investment are their positive effects that stem from the "appropriability" channel: both patent and trade secret protection can increase the appropriability of R&D achievements (Kitch, 1980; Siebeck, 1990; Friedman et al., 1991; Landes and Posner, 2003; Scotchmer, 2004; Allred and Park, 2007a; Lemley, 2008). Also, when patent and trade secret protection work for boosting the foreign-sourced R&D investment, the two regimes are complementary to each other. Only in rare cases, one or both regimes' positive effects from the appriopriability channel become too weak, and thus outweighed by their negative effects stemming from other channels.

As mentioned in Section 2.3, some literature summarizes the three circumstances under which patent and trade secret protection are both crucial and thus complementary to each other (Arora, 1997; Jorda, 2008; Ottoz and Cugno, 2008). The complementarity between the two regimes in our results consists with this series of literature. Although some other literature indicates substitution between the two regimes (Anton and Yao, 2004; Denicolo and Franzoni, 2004; Moser, 2005; Kultti et al., 2007), our results show that for boosting the foreign-sourced R&D investment, the complementarity between the two regimes are much more obvious. This may stem from the fact that MNEs' R&D work tends to be relatively complicated and thus needs both patent and trade secret protection, and then both regimes are crucial for a country to attract foreign MNEs' R&D investment.

Besides the complementarity between patent and trade secret protection, our results show that in the absence of the complementarity between the two regimes, the patent protection alone exhibits a linear negative effect. Then, the sign of the marginal effect of patent protection crucially depends on the strength of trade secret protection. If the strength of trade secret protection is high enough, the positive effect of patent protection is strong enough to outweigh its negative effect, making the net marginal effect of patent protection positive. As the strength of trade secret protection decreases, the positive effect of patent protection weakens. Then if the strength of trade secret protection is low enough, the positive effect of patent protection will be too weak and thus outweighed by its negative effect, making the net marginal effect of patent protection negative.

As for trade secret protection, the issue is a bit more complicated. Since in the absence of the complementarity between patent and trade secret protection, the trade secret protection alone exhibits a U-shaped effect, the sign of the marginal effect of trade secret protection depends not only the strength of patent protection, but also the strength of trade secret protection itself. Jointly, it depends on the combinative strength of patent and trade secret protection. If the combinative strength of patent and trade secret protection is high enough, the positive effect of trade secret protection is strong enough to outweigh its negative effect, making the net marginal effect of trade secret protection positive. As the strength of patent protection and/or that of trade secret protection decreases, the positive effect of trade secret protection weakens. Then if the combinative strength of patent and trade secret protection is low enough, the positive effect of trade secret protection will be too weak and thus outweighed by its negative effect, making the net marginal effect of trade secret protection negative.

Here we try to explain the U-shaped effect of trade secret protection, still based on the basic "appropriability" intuition of trade secret protection (Kitch, 1980; Friedman et al., 1991; Lemley, 2008). A possible explanation is that a country's current strength of trade secret protection affects whether this country could host the MNEs' core-technology development work. Since trade secret laws are highly needed to protect the appropriability of MNEs' newly-developed core technologies, only if a country's current strength of trade secret protection is high enough, MNEs will make much R&D investment in this country to develop core technologies. Then since this country's total foreign-sourced R&D investment contains much investment in core technologies that rely much on trade secret protection, the positive effect of trade secret protection on this country's total foreign-sourced R&D investment is relatively strong. Otherwise, if a country's current strength of trade secret protection is not high enough, MNEs tend to just make some R&D investment in this country to adapt or customize completed technologies for the local market, or to develop non-core technologies,[34] while keeping the MNEs' core-technology development work in their home countries. Trade secret laws are not so needed to protect the appropriability of adaption/customization achievements or that of newly-developed non-core technologies. Then since in the country whose current strength of trade secret protection is not high enough, the total foreign-sourced R&D investment contains much investment in adaptions/customizations or non-core technologies that rely lightly on trade secret protection, the positive effect of trade secret protection on this country's total foreign-sourced R&D investment is relatively weak.

Moreover, we should discuss the channels for patent and trade secret protection to exhibit negative effects on the foreign-sourced R&D investment.

For the negative effect of patent protection, a channel is that facing weaker patent protection and thus weaker legal barriers to imitation, more R&D investment is needed for enhancing de-facto barriers to imitation. This channel is supported by the theoretical work by Reed and Defillippi (1990). These authors' work suggests that a firm may reinvest in its "competence characteristics of tacitness, complexity and specificity" that "can create causal ambiguity", in order to enhance de-facto barriers to the imitation of the firm's competence-based advantages. Along with this theoretical support, some empirical or case studies also

[34] This trend is supported by some empirical evidences that developed countries host much foreign-sourced R&D investment that is made for developing core technologies, while developing countries tend to host the foreign-sourced R&D investment made for adaption/customization or for developing non-core technologies (Wortmami, 1990; Florida and Kenney, 1994; Asakawa, 1996; Kumar, 1996; Reddy, 1997; Kuemmerle, 1999; Sun, 2003; Sun et al., 2006; Bardhan and Kroll, 2006; Zhao, 2006). In these evidences, it seems that a country's economic development would affect the type(s) of foreign-sourced R&D investment into the country. However, our results indicate that a country's trade secret protection, rather than its economic development, really affects the type(s) of foreign-sourced R&D investment into the country. The relation between economic development and type(s) of foreign-sourced R&D investment just stems from the high positive correlation between a country's strength of trade secret protection and its economic development level (the correlation coefficient of ***TP*** (1-period lagged) and the per capita GDP from our sample is 0.7031813).

support this channel (Zander and Kogut, 1995; González-Álvarez and Nieto-Antolín, 2007; Keupp et al., 2010).[35]

As for the negative effect of trade secret protection, there is a channel that weaker trade secret protection allows more knowledge spillover among competitors, and then some knowledge leaking from competitors may assist with a firm's R&D work (Lokshin et al., 2006; Samila and Sorensen, 2011; Png, 2012; Lippoldt and Schultz, 2014; Png and Samila, 2015). Also, there is a sub-channel derived from this channel. The sub-channel stems from the fact that in many circumstances, the MNEs may not need weaker trade secret protection to allow more knowledge spillover, but just need weaker trade secret protection to allow more labour mobility. Since trade secret laws, especially the laws on non-compete covenants, may forbid some labour mobility to prevent secret leakage, weaker trade secret protection may relax the restrictions on labour mobility, allowing more human resources qualified for R&D work to move from domestic firms to MNEs (Samila and Sorensen, 2011; Png, 2012; Png and Samila, 2015).[36]

5. Concluding Remarks

Based on an unbalanced panel dataset for 25 countries during the period between 1990 and 2010, this chapter examines empirically the effects of both patent and trade secret

[35] As mentioned in Section 1 and Section 2.1, much theoretical literature predicts an inverted-U-shaped effect of patent protection on R&D, and thus indicates another channel for the negative effect of patent protection on R&D: if the current patent protection has already been quite strong, strengthening patent protection further will reduce R&D investment, since too strong patent protection greatly hampers "inventing around" activities (e.g., Gallini, 1992; Cadot and Lippman, 1995; Horowitz and Lai, 1996; Shapiro, 2001; O'Donoghue and Zweimuller, 2004). However, it is obviously improper to relate this channel to our results, since in our results, negative marginal effects of patent protection do not exist in the observations that have relatively strong patent protection, but exist in those observations that have relatively weak trade secret protection and also tend to have relatively weak patent protection.

[36] The existing theoretical literature and case studies also indicate another channel for the negative effect of trade secret protection on R&D: weaker trade secret protection spurs more R&D efforts to renew a technology more quickly, and thereby to make the leaked information of outdated technology valueless (McGaughey et al., 2000; Lippoldt and Schultz, 2014). However, this channel mainly exist in the situation that patent protection can substitute trade secret protection, and most R&D work tends to rely on patent protection rather than trade secret protection. Then it is improper to relate this channel to our results where patent and trade secret protection complement each other.

protection in a country, on the foreign-sourced R&D investment into the country. Our results indicate that both patent and trade secret protection may have positive or negative effects on the foreign-sourced R&D investment, but mostly, the dominant effects of both regimes on the foreign-sourced R&D investment are their positive effects that stem from the "appropriability" channel: both patent and trade secret protection can increase the appropriability of R&D achievements. Also, when patent and trade secret protection work for boosting the foreign-sourced R&D investment, the two regimes are complementary to each other.

Only in rare cases, one or both regimes' positive effects from the appriopriability channel become too weak, and thus outweighed by their negative effects stemming from other channels. For patent protection, its negative effect tends to become dominant if the strength of trade secret protection is quite low, since if the trade secret protection is quite weak and thus cannot give sufficient complementarity for the patent protection, the positive effect of patent protection will become too weak and thus outweighed by its negative effect. As for trade secret protection, since it alone exhibits a U-shaped effect in the absence of the complementarity between patent and trade secret protection, the negative effect of trade secret protection tends to become dominant if the combinative strength of patent and trade secret protection is quite low. In this situation, the patent protection is quite weak and thus cannot give sufficient complementarity for the trade secret protection. Also, the trade secret protection itself is quite weak, and thus makes the country's foreign-sourced R&D investment dominated by the investment in adaptions/customizations or non-core technologies that rely lightly on trade secret protection. Both factors tend to make the positive effect of trade secret protection too weak and thus outweighed by its negative effect.

6. Limitations

The first limitation of this chapter comes from the representation of our sample. Our sample is relatively small, covering just 25 countries with 94 observations. The sample countries include 17 OECD countries and 8 trade partners of the OECD. Then although some countries in the sample were developing or newly industrialized countries in their sample periods, a majority of the countries, 13 out of 25, were developed countries. This is obviously disproportional to the countries in the whole world from the sample periods till today, since developing countries are always much more than developed ones. Then the representation of the sample is somewhat questionable. Then it is needed for further research to get more-convincing results, by using larger and better-representative sample(s).

Then second limitation comes from the unbalanced structure of the panel data in our sample. The countries with missing observations may suffer additional country effects caused by "sample selection", and these additional country effects may lead to an inconsistent FE/RE estimator. However, we can argue that this should not be a serious problem in our empirical results. Our preferred model specification includes a country FE term, and then even if there are additional country effects caused by sample selection, the additional country effects should be captured by the country FE term. Indicated by Wooldridge (2002), if the additional country effects caused by sample selection just correlate with regressor(s), these additional effects will not lead to an inconsistent FE estimator, since the country FE term capturing these additional effects is allowed to correlate with regressor(s). Only if the additional country effects caused by sample selection correlate with the random error term, these additional effects may lead to an inconsistent FE estimator. To prove that in our preferred model specification, the additional country effects caused by sample selection, if exist, should not correlate with the random error term, we do a test suggested by Nijman and Verbeek (1992). In this test, we denote the sample selection indicator by $S_{i,\ t}$ such that $S_{i,\ t}$ = 1 if for the country *i* in period *t*, the data of all the variables are available, while $S_{i,\ t}$ = 0 if for the country *i* in period *t*, the data of one or more variables are missing. Then we add $S_{i,\ t-1}$ in our preferred model specification, and run the regression by country FE approach again (the first period, 1990, is lost in this regression). The results show that the coefficient of $S_{i,\ t-1}$ is insignificant. Alternatively, we add $S_{i,\ t+1}$ instead, and the country FE regression results show that the coefficient of $S_{i,\ t+1}$ is insignificant (the last period, 2010, is lost in this regression). Thus the insignificant coefficients of both $S_{i,\ t-1}$ and $S_{i,\ t+1}$ indicate that the additional country effects caused by sample selection, if exist, are not likely to correlate with the random error term.

The third limitation could be the possible endogeneity of the explanatory variables in regressions. Nevertheless, we have tried our best in the empirical work to reduce the risk to suffer endogeneity. Firstly, to reduce the risk of endogeneity caused by reverse causality between the dependent variable and explanatory variables, we replace the current explanatory variables with the one-period lagged ones and then check the results. The results show that comparing with the effects of the current explanatory variables, the effects of the one-period lagged explanatory variables exhibit a similar trend, but become significantly stronger. This indicates that the effects of the one-period lagged explanatory variables should not come from the reverse causality between the dependent variable and explanatory variables. Then our empirical model is not likely to suffer the endogeneity caused by reverse causality between the dependent variable and explanatory variables. Secondly, to reduce the risk of endogeneity caused by another issue, the omission of any independent variable that is correlated with explanatory variable(s) and also affects the dependent variable, our empirical model has tried to include all the independent variables that may affect our dependent variable, and also includes a country effect term that captures some time-invariant country-specific characteristics in institutions, culture and tastes. An exception is that our main empirical model excludes the independent variable of domestic-sourced R&D investment, although this variable may also affect our dependent variable. The reason why we exclude the independent variable of domestic-sourced R&D investment is to avoid the “simultaneity bias”, a bias comes from the possibility that the domestic-sourced and foreign-sourced R&D investments affect each other, while both R&D investments are affected by the IP protection. Despite excluding the variable of domestic-sourced R&D investment in our main empirical model, we can include this variable and then run the regressions as a robust check. The results show that the coefficient of this variable and also that of its quadratic term, if included, are never significant, and including this variable hardly changes our main results. Although we have tried our best to include all the possible independent variables, we may still omit some independent variable(s) and such omission may cause endogeneity. It is a pity that due to insufficient observations, we cannot do our empirical work by the dynamic system GMM estimation technique developed by Blundell and Bond (1998), a technique that can greatly reduce the risk of endogeneity.

Another limitation comes from our measurement for patent and trade secret protection. It is a pity that when we examine the effects of both IP regimes on our dependent variable, due to data insufficiency, we cannot specifically examine the effect of each IP index's each component on our dependent variable. Especial attention should be paid to an obvious weakness in our use of the patent rights index developed by Ginarte and Park (1997). This patent rights index contains five categories, and its first category “coverage” contains eight components. These eight components in the “coverage” category measure the patent coverages on eight product groups, respectively. Among these eight product groups, some product groups such as pharmaceuticals, chemicals and software tend to be much more R&D-intensive than some others such as food and plant & animal varieties. However, when computing the overall score in the patent rights index, the eight sub-scores respective for the eight product groups’ regarding patent coverages are equally weighed. This means an unit change in the sub-score regarding to a highly R&D-intensive product group, and that in the sub-score regarding to a lowly R&D-intensive group lead to the same change in the patent rights index’s overall score. Then it could be uncertain how a change in the index’s overall score accurately reflects the R&D-related change in patent protection, and thus challenge the validity of our work in this chapter.

Appendix 1 for Chapter 3 –

Choice of Model Specification

We will run regressions in several model specifications. At first, we run the country FE regressions (1)~(4) of ***FBERDperca*** on the selected variables from ***PP***, ***TP*** and their quadratic terms and interaction term, and also the control variables.[37] In addition, we run the RE regressions (1b)~(4b) respectively corresponding to the FE ones (1)~(4). Table 7 and Table 7b report the results from the FE regressions and those from the RE ones, respectively.

[37] For all the country FE regressions we run in our empirical work, we do the Redundant Fixed Effects-Likelihood Ratio tests, and all the test results indicate that the country FE/RE regressions are preferred to their corresponding pooled OLS regressions.

Table 7. Results from the Country FE Regressions of *FBERDperca* on *PP* and *TP*

Dependent Variable: ***FBERDperca***				
Regressor	(1)	(2)	(3)	(4)
PP	1.650698**	-5.003385	0.625475	-4.022557
Quadratic PP			0.464585	-0.084574
TP	-2.274975	-8.856673	-10.07751*	-15.28287*
Quadratic TP			3.780215	3.603905
PP*TP		5.341019		4.596725
GDPgrow	-14.09380***	-13.77774***	-14.45704***	-13.95741***
FT	-0.746501	-0.763080	-0.513096	-0.648900
Regu	2.628499*	2.649897*	2.931946**	2.914623**
Sec	-0.243972	-0.193487	-0.244652	-0.222020
Ter	1.067348**	0.863184	0.793422	0.699502
Labopa	-1.648147	-2.682594	-1.724786	-2.427372
WGD	0.873024	0.806919	0.794282	0.714223
Intercept	4.242954	16.87032	8.334810	17.90571
R^2	0.932888	0.934033	0.935553	0.936195
Adjusted R^2	0.895976	0.896019	0.896662	0.895897
Periods included	5	5	5	5
Years	1990-2010	1990-2010	1990-2010	1990-2010
Countries covered	25	25	25	25
N	94	94	94	94

Note: ***, **, and * denote significance at the 1%, 5% and 10% levels, respectively.

Table 7b. Results from the Country RE Regressions of *FBERDperca* on *PP* and *TP*

Dependent Variable: ***FBERDperca***				
Regressor	(1b)	(2b)	(3b)	(4b)
PP	1.612190**	-7.417475	-1.308511	-4.835318
Quadratic PP			1.387157	1.169100
TP	-0.472706	-9.690826	-13.30410**	-17.63332**
Quadratic TP			5.986339**	6.223445**
PP*TP		7.214497		3.175232
GDPgrow	-13.59749***	-13.03951***	-14.40580***	-14.03736***
FT	0.763422	0.824965	1.409249	1.712946
Regu	2.539251**	2.589135**	2.983062**	2.971670**
Sec	-0.044352	0.004996	-0.039054	0.004759
Ter	0.747923**	0.588898	0.357054	0.267830
Labopa	-0.260021	-1.493567	-0.779371	-1.027478
WGD	0.840619	0.784480	0.779767	0.745425
Intercept	-6.606157	9.829661	2.034896	7.281754
R^2	0.363309	0.380480	0.415684	0.422814
Adjusted R^2	0.295092	0.305839	0.337301	0.337305
Periods included	5	5	5	5
Consistence of RE in Hausman Test	Not rejected	Not rejected	Not rejected	Rejected**
Years	1990-2010	1990-2010	1990-2010	1990-2010
Countries covered	25	25	25	25
N	94	94	94	94

Note: ***, **, and * denote significance at the 1%, 5% and 10% levels, respectively

In the results from the FE regressions (1)~(4) and their corresponding RE regressions (1b)~(4b), we can see only in the FE regression (1) and RE regression (1b), ***PP*** gets a significantly positive coefficient. In the FE regressions (2)~(4) and RE regressions (2b)~(4b) that include the quadratic ***PP*** or the interaction term of ***PP*** and ***TP***, or both, the coefficient of ***PP*** turns to insignificant. In these six regressions, except the insignificantly negative coefficient of the quadratic ***PP*** in the FE regression (4), the quadratic ***PP*** and the interaction term of ***PP*** and ***TP*** always get insignificantly positive coefficients. As for ***TP***, only in the FE regressions (3)~(4) and RE regressions (3b)~(4b), the coefficient of ***TP*** is significant. In these four regressions, ***TP*** always gets a significantly negative coefficient, while the quadratic ***TP*** gets a significantly positive coefficient in the RE regressions (3b)~(4b), but just gets a insignificantly positive one in the FE regressions (3)~(4). Generally, ***PP*** and ***TP*** never both get significant coefficients in the same regression.

Also, to address the possible time lags in the effects of ***PP*** and ***TP***, and reduce the risk of endogeneity caused by reverse causality between the dependent variable and explanatory variables, we replace the current ***PP*** and ***TP*** in all their linear and non-linear terms, with their one-period lagged variables. Then we run the country FE regressions (5)~(9) of ***FBERDperca*** on the selected variables from ***PP*** (1-period lagged), ***TP*** (1-period lagged) and their quadratic terms and interaction term, and also the control variables. In addition, we run the RE regressions (5b)~(9b) respectively corresponding to the FE ones (5)~(9). Table 8 and Table 8b report the results from the FE regressions and those from the RE ones, respectively.

Table 8. Results from the Country FE Regressions of *FBERDperca* on *PP* (1-period lagged) and *TP* (1-period lagged)

Dependent Variable: ***FBERDperca***					
Regressor	(5)	(6)	(7)	(8)	(9)
PP (1-period lagged)	0.580626	-5.357489***	-2.190174	-4.927787**	-4.873337**
Quadratic ***PP*** (1-period lagged)			1.555872*	0.115971	
TP (1-period lagged)	-0.693885	-5.506509***	-6.322122**	-10.73966***	-10.90855***
Quadratic ***TP*** (1-period lagged)			3.439069**	3.225433**	3.228243**
(1-period lagged ***PP***)*(1-period lagged ***TP***)		5.260149***		4.723609**	4.860687***
GDPgrow	-12.94499***	-5.603866	-12.21162***	-7.217619	-7.161242
FT	1.120658	1.062544	1.512353	1.139712	1.112671
Regu	2.620591*	2.240275*	1.866691	2.371968*	2.431264*
Sec	-0.084183	-0.124079	-0.225458	-0.254377	-0.255695
Ter	1.125600**	0.347270	0.353246	0.005616	0.011177
Labopa	-2.078768	-2.184705	-3.627686	-2.685613	-2.607507
WGD	0.628443	0.549306	0.687113	0.655516	0.657265
Intercept	0.869255	8.986594	12.51642	13.40975	13.13568
R^2	0.927574	0.937372	0.937876	0.942879	0.942868
Adjusted R^2	0.887739	0.901281	0.900388	0.906803	0.908391
Periods included	5	5	5	5	5
Years	1990-2010	1990-2010	1990-2010	1990-2010	1990-2010
Countries covered	25	25	25	25	25
N	94	94	94	94	94

Note: ***, **, and * denote significance at the 1%, 5% and 10% levels, respectively.

Table 8b. Results from the Country RE Regressions of *FBERDperca* on *PP* (1-period lagged) and *TP* (1-period lagged)

Dependent Variable: ***FBERDperca***					
Regressor	(5b)	(6b)	(7b)	(8b)	(9b)
PP (1-period lagged)	0.826582*	-4.845214**	-1.956013	-3.959831**	-3.749763**
Quadratic ***PP*** (1-period lagged)			1.514465*	0.396013	
TP (1-period lagged)	-0.079797	-4.870222***	-7.905714***	-11.08286***	-11.75186***
Quadratic ***TP*** (1-period lagged)			4.455379***	4.187839***	4.268114***
(1-period lagged ***PP***)* (1-period lagged ***TP***)		4.914385***		3.522714*	3.981464***
GDPgrow	-14.13950***	-6.753683	-12.58391***	-8.997656**	-8.954374**
FT	2.386930	2.362896*	3.077094**	2.730451**	2.678237**
Regu	2.651370**	2.218312*	2.014497	2.262208*	2.417753**
Sec	0.065294	-0.039515	-0.123789	-0.184848	-0.192323
Ter	0.686405**	0.340634	0.103646	0.033627	0.045189
Labopa	-0.603022	-1.210311	-1.791780	-1.748440	-1.612992
WGD	0.689994	0.643230	0.818914	0.803533	0.814961
Intercept	-8.322229	1.228973	1.909588	5.380359	5.003796
R^2	0.345323	0.412319	0.453000	0.471672	0.470564
Adjusted R^2	0.275179	0.341514	0.379622	0.393401	0.399543
Consistence of RE in Hausman Test	Not rejected	Not rejected	Not rejected	Not rejected	Rejected*
Periods included	5	5	5	5	5
Years	1990-2010	1990-2010	1990-2010	1990-2010	1990-2010
Countries covered	25	25	25	25	25
N	94	94	94	94	94

Note: ***, **, and * denote significance at the 1%, 5% and 10% levels, respectively.

Among the FE regressions (5)~(8), the coefficient of ***PP*** (1-period lagged) is insignificant in the FE regressions (5) and (7) that exclude the interaction term of ***PP*** (1-period lagged) and ***TP*** (1-period lagged), but turns to significantly negative in the FE regressions (6) and (8) that include the interaction term. In both the regressions (6) and (8), the interaction term of ***PP*** (1-period lagged) and ***TP*** (1-period lagged) gets a significantly positive coefficient. In the FE regression (7) that includes the quadratic ***PP*** (1-period lagged) but excludes the interaction term of ***PP*** (1-period lagged) and ***TP*** (1-period lagged), the coefficient of the quadratic ***PP*** (1-period lagged) is significantly positive but that of ***PP*** (1-period lagged) itself turns to insignificant. Also, in the regression (8) that includes both the quadratic ***PP*** (1-period lagged) and the interaction term of ***PP*** (1-period lagged) and ***TP*** (1-period lagged), the significance of the positive coefficient of the quadratic ***PP*** (1-period lagged) disappears. Then we argue that in the regression (7), the significance of the positive coefficient of the quadratic ***PP*** (1-period lagged) could be fake, since it just appears due to omitted variable bias here: the coefficient of the quadratic ***PP*** (1-period lagged) mistakenly reflects the positive effect of the omitted interaction term of ***PP*** (1-period lagged) and ***TP*** (1-period lagged). This argument is reinforced by the fact that the adjusted R^2 from the regression (7) is lower than those from the regressions (6) and (8) that include the interaction term of ***PP*** (1-period lagged) and ***TP*** (1-period lagged). Also, to support this argument, we run a Wald test for the coefficient of the quadratic ***PP*** (1-period lagged) in the regression (8), and then the test result shows that the null hypothesis that "the coefficient of the quadratic ***PP*** (1-period lagged) is zero" is not rejected even at the 10% level. Then this Wald test result, combined with the insignificance (indicated by t test) of the coefficient of the quadratic ***PP*** (1-period lagged) in the regression (8), strongly supports that the coefficient of the quadratic ***PP*** (1-period lagged) is insignificant.

As for ***TP*** (1-period lagged), we can see that among the FE regressions (5)~(8), ***TP*** (1-period lagged) always gets a negative coefficient, but just in the FE regressions (6)~(8) that includes the quadratic ***TP*** (1-period lagged) or the interaction term of ***PP*** (1-period lagged) and ***TP*** (1-period lagged), or both, the negative coefficient of ***TP*** (1-period lagged) becomes significant. The quadratic ***TP*** (1-period lagged), if included, always gets a significantly positive coefficient. Then these results indicate that ***TP*** (1-period lagged) exhibits a U-shaped effect.

Therefore rather than the FE regressions (5)~(8), we prefer the FE regression (9) that excludes the quadratic ***PP*** (1-period lagged), while includes all the other four explanatory variables: ***PP*** (1-period lagged), ***TP*** (1-period lagged), the quadratic ***TP*** (1-period lagged), and the interaction term of ***PP*** (1-period lagged) and ***TP*** (1-period lagged). This preference is reinforced by the fact that the adjusted R^2 from the FE regression (9) is higher than all those from the FE regressions (5)~(8). In the results from the FE regression (9) we prefer, the coefficients of both ***PP*** (1-period lagged) and ***TP*** (1-period lagged) are significantly negative, while that of the quadratic ***TP*** (1-period lagged) is significantly positive. In addition, there is a significantly positive coefficient of the interaction term of ***PP*** (1-period lagged) and ***TP*** (1-period lagged). This means that for boosting the foreign-sourced R&D investment, patent and trade secret protection are complementary to each other. In the absence of the complementarity between the two regimes, the patent protection alone exhibits a linear negative effect on the foreign-sourced R&D investment. Also, in the absence of the complementarity between the two regimes, the trade secret protection alone exhibits a U-shaped effect on the foreign-sourced R&D investment.

When it comes to the results from the RE regressions (5b)~(8b), we can see except a minor difference that the positive coefficient of ***PP*** (1-period lagged) is significant in the RE regression (5b), the trend of the IP variables' coefficients here is the same as that in the results from the FE regressions (5)~(8). Then similar to our preferring the FE regression (9), here rather than the RE regressions (5b)~(8b), we prefer the RE regression (9b) that is corresponding to the FE regression (9). This preference is reinforced by the fact that the adjusted R^2 from the RE regression (9b) is higher than all those from the RE regressions (5b)~(8b). In the results from the RE regression (9b) we prefer here, the trend of the IP variables' coefficients is totally the same as that in the results from the FE regression (9). However, since in the RE regression (9b), the consistence of RE is rejected in Hausman test, we prefer the FE regression (9) to its corresponding RE regression (9b). Therefore, the FE regression (9) is preferred among all these FE and RE regressions that use the one-period lagged ***PP*** and ***TP***.

Comparing the regressions using the one-period lagged ***PP*** and ***TP*** with those using the current ***PP*** and ***TP***, we can see the signs of the lagged IP variables' coefficients are mostly the same as those of the current IP variables' coefficients. However, the significance of the lagged IP variables' coefficients tends to be stronger and more convincing, since only by using the lagged IP variables, the two IP regimes' variables can both have significant coefficients in the same regression. Also, we can see mostly, replacing the current IP variables with the one-period lagged IP variables increases a regression's adjusted R^2. Then these results indicate that the effects of both patent and trade secret protection tend to have time lags.

Therefore, for the reason that the effects of both patent and trade secret protection tend to have time lags, and also the reason that comparing with the regressions using the current ***PP*** and ***TP***, the regressions using the one-period lagged ***PP*** and ***TP*** are less likely to suffer endogeneity caused by reverse causality between the dependent variable and explanatory variables, we should prefer the regressions using the one-period lagged ***PP*** and ***TP*** to those using the current ones. Then the FE regression (9) should be not only preferred among all the regressions using the one-period lagged ***PP*** and ***TP***, but also preferred to all those regressions using the current ***PP*** and ***TP***. Therefore the model specification of the FE regression (9) is our preferred specification, among all the model specifications we use to run regressions. Then our detailed discussion refers to the results from the FE regression (9).

Appendix 2 for Chapter 3 –

Additional Regression Results as Robust Check

To check the robustness of our preferred results, we run several other regressions that exclude the variable(s) of one IP protection mechanism, or some control variables.

Firstly, we run the country FE regressions (10)~(13) that include the variable(s) of ***PP*** (1-period lagged), but exclude those of ***TP*** (1-period lagged), and also the corresponding RE regressions (10b)~(13b). Table 9 reports the results from these FE and RE regressions.

Table 9. Results from the Regressions of *FBERDperca* Including the Variable(s) of Only One IP Regime -- *PP* (1-period lagged)

Dependent Variable: ***FBERDperca***						
Model type / Regressor	Country FE			Country RE		
	(10)	(11)	(12)	(10b)	(11b)	(12b)
PP (1-period lagged)	0.459691	-2.601100	-2.663720*	0.825885*	-2.437998	-2.448537*
Quadratic ***PP*** (1-period lagged)		1.753224**	1.781721**		1.797334**	1.823102**
GDPgrow	-13.33459***	-10.98148**	-10.58498**	-14.20492***	-11.28559***	-11.05908***
FT	1.379543	1.549134	1.669645	2.449128*	2.815897*	2.972188**
Regu	2.202171*	1.508626	1.532655	2.606221**	1.902033	1.908552
Sec	-0.057031	-0.077341		0.071145	0.043683	
Ter	1.082511**	0.722703	0.651648	0.670802**	0.480062	0.456056
Labopa	-2.218679	-3.329636	-3.231904	-0.563471	-1.448304	-1.463396
WGD	0.685805	0.581472		0.696767	0.625100	
Intercept	1.028319	8.298869	7.540518	-8.601771	-2.857616	-2.961709
R^2	0.926964	0.931594	0.930975	0.345621	0.381722	0.378303
Adjusted R^2	0.888649	0.893970	0.896462	0.284033	0.315478	0.327700
Consistence of RE in Hausman test	NA	NA	NA	Not rejected	Not rejected	Not rejected
Periods included	5	5	5	5	5	5
Years	1990-2010	1990-2010	1990-2010	1990-2010	1990-2010	1990-2010
Countries covered	25	25	25	25	25	25
N	94	94	94	94	94	94

Note: ***, **, and * denote significance at the 1%, 5% and 10% levels, respectively.

We can see in both the FE regression (10) and RE regression (10b) that excludes the quadratic ***PP*** (1-period lagged), ***PP*** (1-period lagged) gets a positive coefficient, while its positive coefficient is only significant in the RE regression (10b). In both the FE regression (11) and RE regression (11b) that include the quadratic ***PP*** (1-period lagged), the quadratic ***PP*** (1-period lagged) gets a significantly positive coefficient, while the coefficient of ***PP*** (1-period lagged) turns to a negative one that is insignificant but very close to the 10% significance level[38]. If we drop ***Sec*** and ***WGD*** whose coefficients are very insignificant[39], and then run the FE regression (12) and RE regression (12b), we can see in the results from both the regressions (12) and (12b), the negative coefficient of ***PP*** (1-period lagged) turns to significant, and the coefficient of the quadratic ***PP*** (1-period lagged) is still significantly positive. Also, we can see in each specification, dropping ***Sec*** and ***WGD*** increases rather than decreases the adjusted R^2. Then the results from the FE regression (12) and RE regression (12b) that exclude ***Sec*** and ***WGD*** are convincing, and support the robustness of our preferred results, since here ***PP*** (1-period lagged) still gets a significantly negative coefficient, while the significantly positive coefficient of the quadratic ***PP*** (1-period lagged) may just mistakenly reflect the positive effect of the omitted interaction term of ***PP*** (1-period lagged) and ***TP*** (1-period lagged). Also, the results from all the six regressions here generally consist with all the previous regressions that include both ***PP*** (1-period lagged) and ***TP*** (1-period lagged), since here the coefficient of ***PP*** (1-period lagged) still changes from positive to negative when we add the quadratic ***PP*** (1-period lagged).

Secondly, we run the country FE regressions (14)~(15) that include the variable(s) of ***TP*** (1-period lagged), but exclude those of ***PP*** (1-period lagged), and also the corresponding RE regressions (14b)~(15b). Table 10 reports the results from these FE and RE regressions.

[38] Here for the coefficient of ***PP*** (1-period lagged), the p-value of t-statistic is 0.1056 from the FE regression (11) and 0.1065 from the RE regression (11b).

[39] Here for the coefficient of ***Sec***, the p-value of t-statistic is 0.8365 from the FE regression (11) and 0.8993 from the RE regression (11b), and for the coefficient of ***WGD***, the p-value of t-statistic is 0.5147 from the FE regression (11) and 0.4784 from the RE regression (11b).

Table 10. Results from the Regressions of *FBERDperca* Including the Variable(s) of Only One IP Regime -- *TP* (1-period lagged)

Dependent Variable: ***FBERDperca***				
Model type / Regressor	Country FE		Country RE	
	(14)	(15)	(14b)	(15b)
TP (1-period lagged)	-0.291695	-6.640828**	0.367795	-8.582414***
Quadratic ***TP*** (1-period lagged)		3.568017**		4.986794***
GDPgrow	-12.02508***	-13.07206***	-12.62319***	-13.63945***
FT	1.273395	1.333574	2.212811	2.697826**
Regu	2.395202*	2.560125*	2.474092*	2.594056**
Sec	0.024246	-0.117718	0.238625	0.082001
Ter	1.354813***	0.932506*	0.907318**	0.377113
Labopa	-2.681706	-3.196011	-1.179997	-1.553165
WGD	0.725837	0.844672	0.807677	1.008161
Intercept	2.729610	8.114302	-5.934097	-0.619829
R^2	0.925876	0.932665	0.321019	0.407209
Adjusted R^2	0.886991	0.895631	0.257115	0.343695
Consistence of RE in Hausman test	NA	NA	Not rejected	Not rejected
Periods included	5	5	5	5
Years	1990-2010	1990-2010	1990-2010	1990-2010
Countries covered	25	25	25	25
N	94	94	94	94

Note: ***, **, and * denote significance at the 1%, 5% and 10% levels, respectively.

We can see in the results from both the FE regression (15) and RE regression (15b) that include both ***TP*** (1-period lagged) and its quadratic term, ***TP*** (1-period lagged) always exhibits a U-shaped effect: the coefficient of ***TP*** (1-period lagged) is significantly negative, while that of the quadratic ***TP*** (1-period lagged) is significantly positive. This consists with our preferred results.

Thirdly, we run the FE regressions (16)~(19) that exclude some control variables, and also their corresponding RE regressions (16b)~(19b). Table 11 and Table 11b report the results from the FE regressions and those from the RE ones, respectively.

Table 11. Results from the Country FE Regressions of *FBERDperca* Excluding Some Control Variables

Dependent Variable: ***FBERDperca***				
Regressor	(16)	(17)	(18)	(19)
PP (1-period lagged)	-5.621473***	-5.357702***	-6.811964***	-6.763431***
Quadratic ***PP*** (1-period lagged)	0.709544		0.208814	
TP (1-period lagged)	-9.430285***	-10.34734***	-9.704190***	-10.04025***
Quadratic ***TP*** (1-period lagged)	3.045656**	3.040755**	2.087074	2.117847*
(1-period lagged ***PP***)* (1-period lagged ***TP***)	4.328982**	5.211859***	6.034040***	6.322626***
GDPgrow	-8.486631*	-8.192301*		
Sec	-0.304380	-0.308660		
Ter	0.111488	0.173171		
Labopa	-3.866616	-3.395849		
WGD	0.716067	0.734469		
Intercept	24.29290	22.83013**	8.971699***	9.171032***
R^2	0.939048	0.938524	0.932755	0.932703
Adjusted R^2	0.903923	0.904712	0.902285	0.903714
Periods included	5	5	5	5
Years	1990-2010	1990-2010	1990-2010	1990-2010
Countries covered	25	25	25	25
N	94	94	94	94

Note: ***, **, and * denote significance at the 1%, 5% and 10% levels, respectively.

Table 11b. Results from the Country RE Regressions of *FBERDperca* Excluding Some Control Variables

Dependent Variable: ***FBERDperca***				
Regressor	(16b)	(17b)	(18b)	(19b)
PP (1-period lagged)	-4.634523**	-4.414034**	-6.612845***	-6.532263***
Quadratic ***PP*** (1-period lagged)	0.555063		0.240664	
TP (1-period lagged)	-10.19926***	-11.03043***	-11.00109***	-11.43685***
Quadratic ***TP*** (1-period lagged)	3.852686***	3.918554***	3.129667**	3.201210***
(1-period lagged ***PP***)* (1-period lagged ***TP***)	3.777923*	4.472989***	5.825328***	6.141213***
GDPgrow	-10.43537**	-10.33115**		
Sec	-0.273562	-0.279093		
Ter	0.145052	0.168078		
Labopa	-2.510865	-2.226633		
WGD	0.928141	0.944647		
Intercept	18.22272*	17.49799*	8.917126***	9.145096***
R^2	0.422529	0.419237	0.364260	0.363085
Adjusted R^2	0.352954	0.357013	0.328139	0.334460
Consistence of RE in Hausman test	Not rejected	Rejected*	Rejected***	Rejected***
Periods included	5	5	5	5
Years	1990-2010	1990-2010	1990-2010	1990-2010
Countries covered	25	25	25	25
N	94	94	94	94

Note: ***, **, and * denote significance at the 1%, 5% and 10% levels, respectively.

The FE regressions (16)~(17) and RE regressions (16b)~(17b) exclude ***FT*** and ***Regu*** that may cause multicollinearity, as we discussed in Section 4.1, while the FE regressions (18)~(19) and RE regressions (18b)~(19b) exclude all the control variables. We can see except a minor deviation that the positive coefficient of the quadratic ***TP*** (1-period lagged) from the FE regression (18) is insignificant but still very close to the 10% significance level,[40] all these results show a trend of the IP variables' coefficients as the same as that in our preferred results: there are significantly negative coefficients of ***PP*** (1-period lagged) and ***TP*** (1-period lagged), significantly positive coefficients of the quadratic ***TP*** (1-period lagged) and the interaction term of ***PP*** (1-period lagged) and ***TP*** (1-period lagged), and an insignificant coefficient of the quadratic ***PP*** (1-period lagged), if included.

Also, since both ***Sec*** and ***Ter*** measure the aspects of human resource, and thus have some similar characteristics, although these two variable do not exhibit a high correlation in our sample (their correlation coefficient is 0.1972), we still check the results from the regressions that include only one of these two variables. Table 12 reports the results from the country FE regressions (20)~(23) that include only one of ***Sec*** and ***Ter***, and Table 12b reports the results from the corresponding RE regressions (20b)~(23b).

[40] Here for the coefficient of ***TP*** (1-period lagged), the p-value of t-statistic is 0.1088 from the FE regression (18).

Table 12. Results from the Country FE Regressions of *FBERDperca* Including Only One of *Sec* and *Ter*

Dependent Variable: ***FBERDperca***				
Regressor	(20)	(21)	(22)	(23)
PP (1-period lagged)	-4.935087**	-4.887021***	-4.989326**	-4.922862**
Quadratic ***PP*** (1-period lagged)	0.117005		0.142228	
TP (1-period lagged)	-10.75059***	-10.93352***	-10.34023***	-10.54506***
Quadratic ***TP*** (1-period lagged)	3.229107**	3.235671**	3.069534**	3.071992**
(1-period lagged ***PP***)*(1-period lagged ***TP***)	4.729759**	4.875489***	4.668775**	4.836736***
GDPgrow	-7.210285	-7.145506	-6.983749	-6.913039
FT	1.139271	1.111302	1.307882	1.275751
Regu	2.373707*	2.435818*	2.365529*	2.438295*
Sec	-0.253701	-0.254362		
Ter			-0.066810	-0.060442
Labopa	-2.676034	-2.586875	-2.207366	-2.108422
WGD	0.655209	0.656680	0.764133	0.766971
Intercept	13.38474	13.08058	10.31419	9.957989
R^2	0.942879	0.942867	0.942369	0.942351
Adjusted R^2	0.908410	0.909943	0.907591	0.909129
Periods included	5	5	5	5
Years	1990-2010	1990-2010	1990-2010	1990-2010
Countries covered	25	25	25	25
N	94	94	94	94

Note: ***, **, and * denote significance at the 1%, 5% and 10% levels, respectively.

Table 12b. Results from the Country RE Regressions of *FBERDperca* Including Only One of *Sec* and *Ter*

Dependent Variable: ***FBERDperca***				
Regressor	(20b)	(21b)	(22b)	(23b)
PP (1-period lagged)	-4.106446**	-3.923199**	-3.913545**	-3.684790**
Quadratic ***PP*** (1-period lagged)	0.367872		0.465324	
TP(1-period lagged)	-11.11919***	-11.76724***	-10.74474***	-11.49951***
Quadratic ***TP*** (1-period lagged)	4.118517***	4.202978***	4.139972***	4.212477***
(1-period lagged ***PP***)* (1-period lagged ***TP***)	3.689828*	4.128137***	3.319319*	3.868434**
GDPgrow	-8.769652**	-8.708489**	-9.060059**	-8.986118**
FT	2.600956*	2.557760**	2.934742**	2.857501**
Regu	2.285263*	2.437994**	2.215438*	2.393632**
Sec	-0.187804	-0.193348		
Ter			0.014075	0.027795
Labopa	-1.767575	-1.608454	-1.544556	-1.404395
WGD	0.789277	0.799305	0.887186	0.902808
Intercept	5.886595	5.407322	3.447402	3.096110
R^2	0.471928	0.470797	0.469819	0.468518
Adjusted R^2	0.401089	0.407038	0.398697	0.404485
Consistence of RE in Hausman Test	Not rejected	Not rejected	Rejected*	Rejected**
Periods included	5	5	5	5
Years	1990-2010	1990-2010	1990-2010	1990-2010
Countries covered	25	25	25	25
N	94	94	94	94

Note: ***, **, and * denote significance at the 1%, 5% and 10% levels, respectively.

We can see among all these FE and RE regressions including only one of ***Sec*** and ***Ter***, the results show a trend of the IP variables' coefficients that is totally the same as that in our preferred results: there are significantly negative coefficients of ***PP*** (1-period lagged) and ***TP*** (1-period lagged), significantly positive coefficients of the quadratic ***TP*** (1-period lagged) and the interaction term of ***PP*** (1-period lagged) and ***TP*** (1-period lagged), and an insignificant coefficient of the quadratic ***PP*** (1-period lagged), if included.

Chapter 4

Effects of Patent and Trade Secret Protection on R&D Investment: Manufacturing Vs. Service Sector

1. Introduction

The extent to which legal protection of intellectual property (IP) rights affects R&D activities is of interest both to academics and policy makers. Within this debate, two legal protection regimes, namely patent protection and trade secret protection, have attracted most of the attention.

The effect of patent protection on general R&D has been widely investigated both theoretically (Gallini, 1992; Cadot and Lippman, 1995; Horowitz and Lai, 1996; Shapiro, 2001; O'Donoghue and Zweimuller, 2004), and empirically (Varsakelis, 2001; Kanwar and Evenson, 2003; Park, 2005). However, as for how patent protection affects the R&D investment in different sectors, the existing empirical evidence is limited to the manufacturing sector (Park, 2005; Allred and Park, 2007a & 2007b; Qian, 2007). In spite of the increased importance of the service sector for advanced economies, relatively little evidence is available for services, and there is no work providing a comparative analysis of the manufacturing sector and service sector.

Trade secret protection, and its effect on R&D in general, have been investigated theoretically (e.g., Kitch, 1980; Friedman et al., 1991; Lemley, 2008; Lippoldt and Schultz, 2014), and indirectly hinted by some empirical evidence (Lokshin et al., 2006; Samila and Sorensen, 2011; Png, 2012; Png and Samila, 2015). However, empirical investigations that directly focus on this issue are relatively rare, and the only two are provided by Png (2017) and the Chapter 3 of this thesis, respectively, while the latter just focuses on the foreign-sourced R&D investment. However, an analysis of how trade secret protection affects the R&D investment in different sectors is, to our knowledge, currently unavailable.

At the micro level, empirical findings indicate that, manufacturing firms are relatively more likely to patent their innovations, while service firms are more likely to keep their innovations secret (Hall et al., 2013; Morikawa, 2014). It is thus interesting to understand, given that different sectors seem to prefer different forms of protection, how the R&D investment in a country's manufacturing sector and that in its services sector, respectively, are affected by the country's legal provisions in terms of patent and trade secret protection. Our work aims at filling in this gap.

We examine this issue empirically, based on an unbalanced panel dataset covering 21 countries for the five quinquennial periods from 1990 to 2010.[41] In our empirical model, each country's strength of patent protection is measured by a patent rights index that is constructed by Ginarte and Park (1997). Also, an index constructed by Lippoldt and Schultz (2014) is used to measure the trade secret protection in each country.

Our results show that on the one hand, patent protection positively affects both the levels of R&D investment in manufacturing and in services. On the other hand, trade secret protection has no significant effect on the R&D investment in manufacturing, while our results weakly indicate a U-shaped effect of trade secret protection on the R&D investment in services.

The remainder of this chapter is structured as follows. Section 2 reviews some empirical evidence about the difference between manufacturing sector and service sector in legal IP protection's effect on R&D. Section 3 describes the empirical strategy. Section 4 presents and discusses the empirical results. Section 5 provides concluding remarks. Section 6

[41] We don't have enough data about the R&D investment from a specific source (domestic/foreign) into a specific sector (manufacturing/service). Then in this chapter's empirical work, the R&D investment in a country's manufacturing/service sector just refers to the total R&D investment that business enterprises perform in this country's manufacturing/service sector, regardless of the R&D investment's source (domestic/foreign).

discusses some limitations of this chapter. Moreover, in two appendices for this chapter, we present some additional empirical results that help us check the robustness of our main results, or supplement the main results.

2. Difference Between Manufacturing Sector and Service Sector in Legal IP Protection's Effect on R&D: Hint From Empirical Evidence

For the effects of patent and trade secret protection on the R&D investment in the manufacturing or service sector, we can still refer to the literature we reviewed in Section 2 of our Chapter 3. Then as the same as that for the foreign-sourced R&D investment, the existing literature we reviewed cannot help us predict unambiguous effects of both patent and trade secret protection on the manufacturing/service R&D investment, and also cannot help us unambiguously predict that when patent and trade secret protection work for boosting the manufacturing/service R&D investment, what interaction between the two regimes exists. These effects and interaction need to be examined by our empirical work.

In addition, we also try to find some literature that refers to the difference between manufacturing sector and service sector. Some empirical studies focus on how patent and trade secret protection affect the R&D investment in manufacturing industries (Park, 2005; Allred and Park, 2007a & 2007b; Qian, 2007). However, to our knowledge, there is no empirical study focusing on how these two regimes affect the R&D investment in service industries. Nevertheless, some empirical evidence gives a hint about the possible difference, between the effects of the two regimes on the manufacturing R&D investment and those on the service R&D investment. This evidence comes from the analysis of manufacturing and service firms' attitudes towards patents and secrecy.

In a sample of 11,151 manufacturing firms and 8,446 knowledge-intensive-business-service (KIBS) firms in the UK for the period from 1998 to 2006, Hall et al. (2013) find that manufacturing firms prefer patents to secrecy for protecting product innovations, while they prefer secrecy for protecting process innovations. In contrast, KIBS firms prefer secrecy to patents for protecting both product and process innovations.

Morikawa (2014) analyses a sample of 1,567 manufacturing firms and 1,860 service firms in Japan for the fiscal year of 2011. The investigation shows that among the manufacturing firms, the percentage of firms holding patents is much higher than that among the service firms (39.2% vs. 9.8%), while the percentage of firms holding trade secrets is not so different from that among the service firms (33.0% vs. 32.6%). Restricting attention to the firms that engage in R&D, the percentage of firms holding patents among manufacturing firms is sizably larger than that among service firms (60.4% vs. 34.8%), but the percentage of firms holding trade secrets is lower (39.3% vs. 49.6%).

In summary, these two investigations indicate that manufacturing firms are relatively more likely to patent their innovations, while service firms are more likely to keep their innovations secret. Given these findings, we can predict that the effect of patent protection on the manufacturing R&D investment should be stronger, or at least not weaker than that on the service R&D investment. Symmetrically, the effect of trade secret protection on the manufacturing R&D investment should be weaker, or at least not stronger than that on the service R&D investment.

3. Empirical Strategy

3.1. Measurement of Variables

Dependent Variables:

Two dependent variables will be used to measure the volume of R&D investment into the manufacturing sector, and that into the service sector, respectively.

Since trade secrets are essential to the operation of business enterprises, but not to that of governments, academic institutions and other non-profit institutions, we focus on the R&D investment performed by business enterprises. Also, we express R&D investment in per capita terms to account for heterogeneity in population size. Our dependent variables are thus the per capita value of the R&D investment performed by business enterprises in the manufacturing sector, and that performed in the service sector, denoted as ***MBERDperca*** and ***SBERDperca***, respectively.

Explanatory Variables:

Similar to our Chapter 3, our two explanatory variables are the country-level strength of patent protection and that of trade secret protection, denoted as ***PP*** and ***TP***, respectively. We still use the patent rights index constructed by Ginarte and Park (1997) to measure ***PP***, and the trade secret protection index constructed by Lippoldt and Schultz (2014) to measure ***TP***. Details on the construction of these two indexes can be found in the Section 3.1 of our Chapter 3.

Control Variables:

In addition to the two explanatory variables ***PP*** and ***TP***, the empirical model also includes the same seven control variables used in our Chapter 3. These are the per capita real GDP, the rate of completing secondary education as the highest level in the population aged 15+, the rate of completing tertiary education as the highest level in the population aged 25+, the index of freedom to trade internationally, the index of market regulation, the labour participation rate in the population aged 15+, and the "West Germany dummy" (the dummy to distinct the observations of Germany by 1990 that refer only to the former West Germany, with those after 1990 that refer to the reunified Germany), denoted as ***GDPperca***, ***Sec***, ***Ter***, ***FT***, ***Regu***, ***labopa*** and ***WGD***, respectively.

The rationale for including ***GDPgrow***, ***Sec***, ***Ter***, ***labopa*** and ***WGD*** is the same as discussed in our Chapter 3.

However, the effects of ***FT*** and ***Regu*** on ***MBERDperca*** or ***SBERDperca***, are expected to be somewhat different. This is because ***FT*** and ***Regu*** refer to a country's regulation on the cross-border movement of capital, goods and services. For instance, on the one hand, a higher ***FT*** means it's easier for the country to import high-tech goods/services, and this reduces the demand for domestically developed high-tech goods/services, and thus the need for internal R&D investment (both domestic-sourced and foreign-sourced). On the other hand, a higher ***FT*** means it's easier for the country to import the materials, tools or intermediate goods needed for R&D work, and this boosts the R&D investment made in the country. Then the overall effect of ***FT*** on ***MBERDperca*** or ***SBERDperca*** is theoretically ambiguous. Similar to that on foreign-sourced R&D investment, ***Regu*** theoretically exhibits a positive effect on ***MBERDperca*** or ***SBERDperca***, but the intuition here is also different. A higher ***Regu*** means the country has lighter regulations on credit market, labour market and other business activities, and therefore the R&D projects' costs, including the costs in labour, finance and relevant operation activities, are lower. This boosts the country's R&D investment.

3.2. Data Sources

The data of ***MBERDperca*** and ***SBERDperca***are provided by two sources: the OECD, and the Eurostat office of the European Union (EU). Similar to our Chapter 3, the data in national currency units at current prices are converted into purchasing-power-parity (PPP) international dollars at 2005 constant prices. The conversion uses the GDP deflators from the WEO Database (Oct. 2015 edition), and also the PPP conversion factors from the 2005 ICP.

The data sources for all the other variables are the same as those presented in the Section 3.2 of our Chapter 3.

Our sample is an unbalanced panel dataset including 70 observations covering 21 countries for the five quinquennial periods during 1990 to 2010. The countries in our sample are Australia, Bulgaria, Canada, China, Germany, Ireland, Israel, Italy, Japan, Lithuania, Mexico, Netherlands, New Zealand, South Korea, Singapore, South Africa, Spain, Sweden, Taiwan, Turkey, and USA.

3.3. Model Specifications

Similar to our Chapter 3, all the possible model specifications we may use for this chapter's empirical work are captured in the following two expression:

$$MBERDperca_{i,\ t} = \alpha + \beta[IP]_{i,\ t} + \gamma[Control]_{i,\ t} + \mu_i + \varepsilon_{i,\ t}\ ;$$
$$SBERDperca_{i,\ t} = \alpha + \beta[IP]_{i,\ t} + \gamma[Control]_{i,\ t} + \mu_i + \varepsilon_{i,\ t}\ .$$

Here, i denotes country, and t denotes quinquennial period. α is the intercept, μ_i is either a country FE or a country RE term, and $\varepsilon_{i,\ t}$ is the random error term. $[IP]_{i,\ t}$is a vector that contains the explanatory variable(s) measuring IP protection, including one or more of the linear terms, quadratic terms and interaction term of ***PP*** and ***TP***.[42]$[\ Control]_{i,\ t}$is a vector that contains the seven control variables.

Also, to reduce the influence from possible heteroscedasticity, in all the possible model specifications, all the variables except the dummy ***WGD*** are entered as natural logarithms instead of their initial values.

[42] In the main empirical work of this chapter, we just use the current ***PP*** and ***TP*** but not their one-period lagged variables. To address the possible time lags in the effects of ***PP*** and ***TP***, and reduce the risk of the endogeneity caused by reverse causality between the dependent variable, ***MBERDperca*** or ***SBERDperca***, and the variables of the current ***PP*** and ***TP***, we also replace the current ***PP*** and ***TP*** in all their linear and non-linear terms, with their one-period lagged variables, and then run the relevant regressions. However, when using the one-period lagged ***PP*** and ***TP***, the sample size will be reduced to 69, because there is missing data of the one-period lagged ***TP*** in one observation of the initial sample. Despite the sample reduction, the results from the regressions that use the one-period lagged ***PP*** and ***TP*** are very similar, to those from the regressions that use the current ***PP*** and ***TP***, namely, the trends in the effects of ***PP*** and ***TP*** on ***MBERDperca*** or ***SBERDperca*** do not exhibit difference, when we change from using the current ***PP*** and ***TP*** to using the one-period lagged ones. This indicates that there is no serious endogeneity caused by reverse causality between ***MBERDperca*** or ***SBERDperca*** and the variables of the current ***PP*** and ***TP***. However, because several countries' values of ***PP*** and ***TP*** change significantly across time, while the other countries' are relatively time-consistent, it's unclear that, whether or not the similarity between the effects of the current ***PP*** and ***TP*** and those of the one-period lagged ***PP*** and ***TP*** is caused by the relatively consistent levels of ***PP*** and ***TP*** across time, and then we cannot clearly see whether or not the effects of ***PP*** and ***TP*** have time lags.

4. Empirical Results and Discussion

4.1. Descriptive Statistics, Correlation Matrix and Scatter Plots of Variables

Before we run regressions to examine the effects of our explanatory variables on each dependent variable, we check the descriptive statistics of all the logged variables. Table 1 presents these descriptive statistics.

Table 1. Descriptive Statistics of Logged Variables

	MBERDperca	*SBERDperca*	*PP*	*TP*	*GDPgrow*	*FT*
Mean	4.83	3.38	1.36	1.32	0.04	2.11
Median	5.32	3.71	1.43	1.35	0.04	2.11
Maximum	6.52	6.42	1.58	1.51	0.12	2.26
Minimum	1.07	-2.99	0.18	0.80	-0.08	1.75
Std. Dev.	1.49	1.76	0.23	0.14	0.03	0.10
Skewness	-1.03	-1.14	-2.58	-1.28	-0.19	-0.85
Kurtosis	3.01	5.01	12.39	4.65	5.37	3.66
Jarque-Bera	12.27	26.94	334.92	27.09	16.88	9.73
Probability	0.00	0.00	0.00	0.00	0.00	0.01
Sum	338.23	236.29	95.43	92.63	2.58	147.44
Sum Sq. Dev.	153.08	213.71	3.54	1.43	0.06	0.74
Observations	70	70	70	70	70	70
	Regu	*Sec*	*Ter*	*Labopa*		
Mean	1.94	3.37	2.55	4.08		
Median	1.95	3.42	2.66	4.09		
Maximum	2.17	4.04	3.55	4.35		
Minimum	1.57	1.98	-0.53	3.83		
Std. Dev.	0.15	0.42	0.63	0.10		
Skewness	-0.45	-0.97	-1.82	-0.46		
Kurtosis	2.46	4.01	9.59	2.90		
Jarque-Bera	3.21	13.93	165.41	2.54		
Probability	0.20	0.00	0.00	0.28		
Sum	135.73	236.18	178.58	285.47		
Sum Sq. Dev.	1.54	12.04	27.35	0.74		
Observations	70	70	70	70		

In addition, to check the variability of patent and trade secret protection across countries and across periods, we get the stand deviations of ***PP*** and ***TP*** in each country across periods, and the stand deviations of these two IP variables in each period across countries. Table 2 and Table 2b present these stand deviations.

Table 2. Cross-period Stand Deviations of IP Variables in Each Country

Country \ Variable	***PP***	***TP***
Australia (1990-2005)	0.08	0.46
Bulgaria (1995 and 2005)	0.01	0.49
Canada (1990-2005)	0.13	0.52
Germany (1990-2005)	0.00	0.23
Ireland (1990-2005)	0.05	1.03
Israel (1995-2010)	0.20	0.43
Italy (1995-2010)	0.15	0.14
Japan (1990-2010)	0.06	0.30
Mexico (1995-2005)	0.01	0.31
Netherlands (1990-2005)	0.01	0.18
Korea (1995-2010)	0.30	0.18
Singapore (1995-2010)	0.11	0.14
Spain (1990-2005)	0.65	0.45
Turkey (1990-2005)	0.10	1.16
Lithuania (2000-2005)	0.17	0.26
New Zealand (1990-1995, and 2005)	0.20	0.62
South Africa (2005)	0.00	0.00
Sweden (1995 and 2005)	0.00	0.06
USA (1990-2005)	0.20	0.09
China (2000)	0.00	0.00
Taiwan (2000-2010)	0.12	0.26
Average	0.12	0.35

Table 2b. Cross-country Stand Deviations of IP Variables in Each Period

Period \ Variable	***PP***	***TP***
1990 (10 countries)	0.43	1.02
1995 (17 countries)	0.47	0.67
2000 (17 countries)	0.58	0.57
2005 (20 countries)	0.51	0.41
2010 (6 countries)	0.36	0.34
Average	0.47	0.60

In Table 2 and Table 2b, we can see several countries have relatively high cross-period stand deviations in one or both IP variables, but most cross-period stand deviations are lower than cross-country standard deviations. Also, in each of both IP variables, the average cross-period standard deviation is lower than the average cross-country stand deviation. Then these standard deviations indicate that in this sample, the variabilities of both patent and trade secret protection mainly exist across countries rather than across periods.

Also, to check whether our empirical model will suffer multicollinearity problem, we check the correlations among the independent variables. Table 3 presents the correlation matrix of all the independent variables.

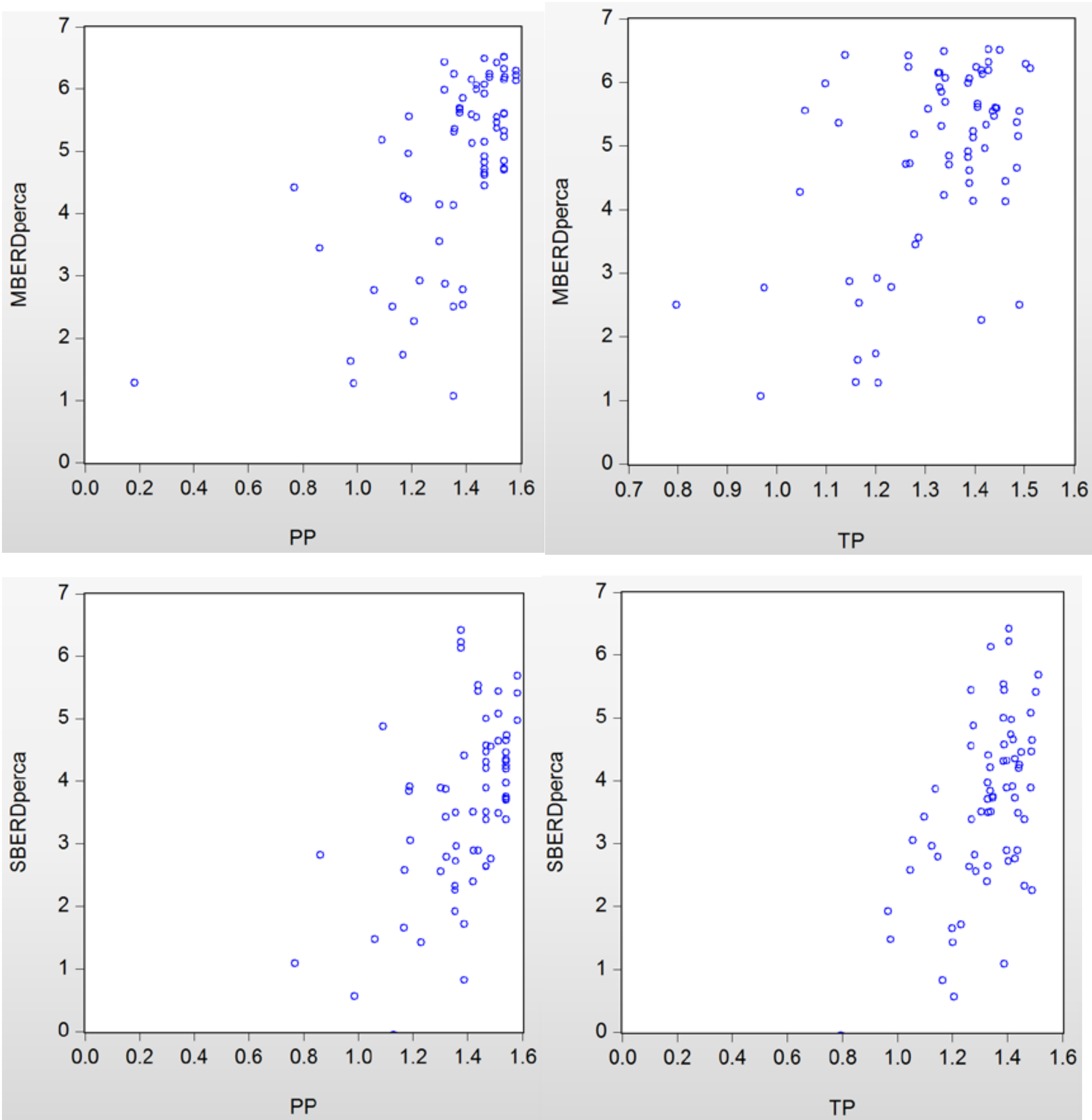
Table 3. Correlation Matrix of Independent Variables

	PP	***TP***	***GDPgrow***	***FT***	***REGU***	***SEC***	***TER***	***LABOPA***
PP	1.0000	0.4676	-0.0712	0.4580	0.3197	0.5848	0.3025	0.1024
TP	0.4676	1.0000	-0.1523	0.4485	0.5405	0.2907	0.5492	0.2066
GDPgrow	-0.0712	-0.1523	1.0000	-0.1191	-0.1096	-0.0160	-0.0067	-0.1045
FT	0.4580	0.4485	-0.1191	1.0000	0.3820	0.1135	0.2643	0.1393
REGU	0.3197	0.5405	-0.1096	0.3820	1.0000	0.2998	0.4278	0.5844
SEC	0.5848	0.2907	-0.0160	0.1135	0.2998	1.0000	0.3791	0.3591
TER	0.3025	0.5492	-0.0067	0.2643	0.4278	0.3791	1.0000	0.4181
LABOPA	0.1024	0.2066	-0.1045	0.1393	0.5844	0.3591	0.4181	1.0000

We can see in Table 3, besides the correlation coefficient of ***PP*** and ***Sec***, the one of ***TP*** and ***Regu***, the one of ***TP*** and ***Ter***, and the one of ***Labopa*** and ***Regu***, all the other correlation correlations have absolute values lower than 0.5. Then we will run the regressions including ***Sec, Ter*** and ***Regu***, and the ones excluding these three variables, respectively, to check whether the results are invulnerable to the possible multicollinearity caused by the relatively high correlation between ***PP***, ***TP*** or ***Labopa*** and one or more of ***Sec, Ter*** and ***Regu***.

Moreover, in the following Figure 1, we plot each of the dependent variables ***MBERDperca*** and ***SBERDperca*** against each of the two main explanatory variables: ***PP*** and ***TP***.

Figure 1. Scatter Plots of sectoral R&D investment against IP protection



We can see all these four scatter graphs do not show clear trends between ***MBERDperca*** or ***SBERDperca*** and the explanatory variables. Then these graphs indicate that the relation between ***MBERDperca*** or ***SBERDperca*** and the IP protection is a complicated issue, and thereby needs to be examined carefully by running relevant regressions.

4.2. Regression Results and Discussion

We start off by analyzing the effects of patent and trade secret protection on R&D investment in the manufacturing sector. Regressions (1)~(5) in Table 4 report the coefficients of ***PP***, ***TP***, their quadratic terms and interaction term, and the control variables for the fixed effect model. Results for the random effect model are reported in Table 4b.

Table 4. Manufacturing (FE)

Dependent Variable: ***MBERDperca***					
Regressor	(1)	(2)	(3)	(4)	(5)
PP	1.595144***	1.126786	2.363538*	-1.752516	1.607561***
Quadratic ***PP***			-0.357262	-0.875483	
TP	0.115090	-0.345720	8.002701	10.06789	
Quadratic ***TP***			-3.088502	-5.889023	
PP*TP		0.360459		4.011244	
GDPgrow	-2.349962	-2.308737	-2.017069	-1.122759	-2.416208
FT	-1.699179*	-1.669274*	-1.905331*	-1.852904*	-1.717372*
Regu	-1.459777**	-1.447235**	-1.384079**	-1.161416*	-1.447318**
Sec	-0.418748	-0.394853	-0.493675	-0.314114	-0.427538
Ter	0.563468*	0.549265*	0.607400**	0.501821	0.578773**
Labopa	-0.313382	-0.393736	-0.010258	-0.477512	-0.338231
WGD	0.286768	0.289685	0.247785	0.229000	0.290731
Intercept	10.25044*	11.03748	4.099027	6.625592	10.49432*
R^2	0.976928	0.976940	0.977414	0.978116	0.976917
Adjusted R^2	0.960201	0.959201	0.958989	0.959190	0.961153
Periods included	5	5	5	5	5
Years	1990-2010	1990-2010	1990-2010	1990-2010	1990-2010
Countries covered	21	21	21	21	21
N	70	70	70	70	70

Note: ***, **, and * denote significance at the 1%, 5% and 10% levels, respectively.

Table 4b. Manufacturing (RE)

Dependent Variable: ***MBERDperca***					
Regressor	(1b)	(2b)	(3b)	(4b)	(5b)
PP	1.149532***	0.453519	1.137966	-2.956373	1.253939***
Quadratic ***PP***			0.097017	-0.526490	
TP	1.172945	0.465452	19.78058**	19.18120**	
Quadratic ***TP***			-7.468070**	-9.336616**	
PP*TP		0.536462		4.164033	
GDPgrow	-0.956950	-0.939065	-0.319523	0.396950	-1.582764
FT	-0.038856	-0.002223	-0.324410	-0.341145	-0.122022
Regu	-1.488508***	-1.472410***	-1.379669**	-1.187099**	-1.293218**
Sec	0.171022	0.195555	0.127236	0.265370	0.118922
Ter	0.502494***	0.492283**	0.457207**	0.403198**	0.643958***
Labopa	0.820824	0.677587	1.602525	1.049217	0.576345
WGD	0.523416	0.525808	0.529442	0.502340	0.575377
Intercept	-0.655239	0.671191	-14.74464*	-9.882142	1.371499
R^2	0.420670	0.421417	0.448316	0.458221	0.403831
Adjusted R^2	0.333770	0.323352	0.343686	0.344162	0.325645
Consistence of RE in Hausman test	Rejected***	Rejected***	Rejected***	Rejected***	Rejected***
Periods included	5	5	5	5	5
Years	1990-2010	1990-2010	1990-2010	1990-2010	1990-2010
Countries covered	21	21	21	21	21
N	70	70	70	70	70

Note: ***, **, and * denote significance at the 1%, 5% and 10% levels, respectively.

We can see in all the RE regressions (1b)~(5b), the consistency of RE is rejected in Hausman test. We accordingly focus on the FE regressions (1)~(5).

Comparing the results among the regressions (1)~(4), the coefficients of the quadratic ***PP***, ***TP*** and its quadratic term, and the interaction term of ***PP*** and ***TP*** are all insignificant. In contrast, the coefficient of ***PP*** is significantly positive in the regressions (1) and (3) that do not include the interaction term of ***PP*** and ***TP***, while turns to insignificant in (2) and (4) where the interaction term is included. Since in both of these two regressions, (2) and (4), the coefficient of the interaction term itself is insignificantly positive, we argue that the interaction term may pick some positive effect from ***PP***, making the coefficient of ***PP*** turn from significantly positive to insignificant in these two regressions. To support this argument, we run Wald tests to rule out the possibility that in these two regressions, (2) and (4), the coefficient of ***PP***, and that of the interaction term of ***PP*** and ***TP*** would be both individually insignificant but jointly significant. The Wald test results show that in both of these two regressions, the null hypothesis that "the coefficients of ***PP*** and the interaction term ***PP********TP*** are jointly zero" is rejected at the 10% level but not rejected at the 5% level. Then these Wald test results indicate that in these two regressions, the coefficient of ***PP*** and that of the interaction term could hardly be jointly significant, supporting our argument that the insignificance of ***PP***'s coefficient may be caused by that some positive effect of ***PP*** is picked by the interaction term. Therefore, the insignificant coefficients of ***PP*** in these two regressions, (2) and (4), are less preferred than the significantly positive coefficients of ***PP*** in the regressions (1) and (3) that exclude the interaction term of ***PP*** and ***TP***.

To sum up, on the manufacturing R&D investment, the results indicate that patent protection has a positive effect, while trade secret protection has no significant effect.

Therefore rather than the FE regressions (1)~(4), we prefer the FE regression (5), a model specification that includes ***PP***, but excludes all the other explanatory variables since they turn to have no significant effect on the dependent variable. This preference is reinforced by the fact that the adjusted R^2 from the FE regression (5) is higher than all those from the FE regressions (1)~(4).

In addition, to check whether our results for manufacturing R&D are invulnerable to possible multicolinearity, we run the regressions excluding ***Sec*, *Ter*** and ***Regu*** that may cause multicolinearity. Regressions (6)~(11) in Table 5 report the results for the fixed effect model. Results for the random effect model are reported in Table 5b.

Table 5. Manufacturing (FE, excluding *Sec*, *Ter* and *Regu*)

Dependent Variable: ***MBERDperca***						
Regressor	(6)	(7)	(8)	(9)	(10)	(11)
PP	1.412526***	-2.500316	1.912135	-5.815663*	-4.328164	1.473238***
Quadratic ***PP***			-0.235802	-1.320549*		
TP	0.335506	-3.740910	7.336941	12.46185	13.67037	
Quadratic ***TP***			-2.719904	-8.675429	-7.611802	
PP*TP		3.082903		7.861048**	4.567715*	
GDPgrow	-0.493397	-0.592976	-0.132180	0.926111	-0.235219	-0.565828
FT	-1.727086**	-1.559544*	-1.857961**	-1.984545**	-1.534877*	-1.838727**
Labopa	0.953089	-0.114909	1.297374	-0.085928	-0.346221	1.058028
WGD	0.308987	0.282610	0.296589	0.168369	0.274466	0.323287
Intercept	2.226855	11.35413	-3.592137	4.353783	2.467767	2.397731
R^2	0.971052	0.972161	0.971370	0.975189	0.973241	0.970929
Adjusted R^2	0.953549	0.954264	0.951818	0.957201	0.954967	0.954411
Periods included	5	5	5	5	5	5
Years	1990-2010	1990-2010	1990-2010	1990-2010	1990-2010	1990-2010
Countries covered	21	21	21	21	21	21
N	70	70	70	70	70	70

Note: ***, **, and * denote significance at the 1%, 5% and 10% levels, respectively.

Table 5b. Manufacturing (RE, excluding *Sec*, *Ter* and *Regu*)

Dependent Variable: ***MBERDperca***						
Regressor	(6b)	(7b)	(8b)	(9b)	(10b)	(11b)
PP	1.274756***	-0.771367	0.956790	-4.099267	-3.132265	1.568345***
Quadratic ***PP***			0.252974	-0.640401		
TP	1.676979**	-0.508065	24.38718***	23.65791***	23.95992***	
Quadratic ***TP***			-9.179324**	-11.64897***	-10.91323***	
PP*TP		1.615550		5.443201*	3.656106	
GDPgrow	0.508177	0.446332	1.074399	1.802021	1.377839	0.029322
FT	-0.210024	-0.180952	-0.455217	-0.697612	-0.426517	-0.436910
Labopa	1.544412	1.076840	2.367155**	1.668772	1.752570	1.904548**
WGD	0.320664	0.308080	0.375325	0.286127	0.342039	0.383569
Intercept	-5.206194	-0.617364	-21.86356***	-14.49030*	-16.37576*	-4.415642
R^2	0.338865	0.342571	0.385317	0.403830	0.399278	0.291053
Adjusted R^2	0.275900	0.268345	0.304703	0.314404	0.320495	0.235667
Consistence of RE in Hausman test	Rejected***	Rejected***	Rejected***	Rejected***	Rejected***	Rejected***
Periods included	5	5	5	5	5	5
Years	1990-2010	1990-2010	1990-2010	1990-2010	1990-2010	1990-2010
Countries covered	21	21	21	21	21	21
N	70	70	70	70	70	70

Note: ***, **, and * denote significance at the 1%, 5% and 10% levels, respectively.

It is still that in all the RE regressions (6b)~(11b), the consistency of RE is rejected in Hausman test. Then we accordingly focus on the FE regressions (6)~(11).

Comparing the results from the FE regressions (6)~(10) with the those from the FE regressions (1)~(4) that include ***Sec, Ter*** and ***Regu***, we find only two differences. Firstly, here in the FE regression (8) that include the quadratic ***PP***, the positive coefficient of ***PP*** turns to insignificant. However, it is not strange that if ***PP*** just exhibits a linear positive effect, its coefficient may turns to insignificant when the quadratic ***PP*** is included. Secondly, in the FE regression (9) that include both the quadratic ***PP*** and the interaction term of ***PP*** and ***TP***, both ***PP*** and its quadratic term get significantly negative coefficients, while the interaction term of ***PP*** and ***TP*** get a significantly positive coefficient. However, the case here that both ***PP*** and its quadratic term have significantly negative coefficients is not normally meaningful, and then we just argue that the significantly negative coefficients of ***PP*** and its quadratic term, and the significantly positive coefficient of the interaction term of ***PP*** and ***TP*** just appear because the interaction term picks some positive effect from ***PP*** and its quadratic term. To confirm this argument, we drop the quadratic ***PP*** and run the FE regression (10). In the results from the regression (10), the coefficient of ***PP*** is still negative but turns to insignificant, while the coefficient of the interaction term of ***PP*** and ***TP*** is still significantly positive. This confirms our argument that the negative coefficient of ***PP*** is caused by the interaction term's picking positive effect from ***PP***. Then the significance of the negative coefficient of ***PP*** in the regression (9) is fake, and the quadratic ***PP*** and the interaction term of ***PP*** and ***TP*** that will disorder our results should be excluded. Since in the results from the FE regressions (6) and (11) that exclude both the quadratic ***PP*** and the interaction term of ***PP*** and ***TP***, ***PP*** still gets a significantly positive coefficient, and also, the coefficients of ***TP*** and its quadratic term, if included, are never significant among all these FE regressions, we still conclude that ***PP*** exhibits a positive effect while ***TP*** exhibits no significant effect on the dependant variable.

Therefore, since the results from the regressions excluding ***Sec, Ter*** and ***Regu*** still show that on the manufacturing R&D investment, patent protection exhibits a positive effect, while trade secret protection has no significant effect, consistent with our main results from the regressions including all the control variables, we can say our main results are invulnerable to the possible multicolinearity caused by ***Sec, Ter*** and ***Regu***. Then we still prefer the FE regression (5) that includes ***PP*** and all the seven control variables, while excluding the other four explanatory variables.

A positive effect of patent protection here is consistent with most previous empirical findings (Varsakelis, 2001; Kanwar and Evenson, 2003; Park, 2005; Allred and Park, 2007a). This positive effect obviously comes from the "appropriability" channel: stronger patent protection increases the appropriability of R&D achievements (Siebeck, 1990; Landes and Posner, 2003; Scotchmer, 2004; Allred and Park, 2007a).

As for trade secret protection, the insignificant effect of trade secret protection on the manufacturing R&D investment seems inconsistent with some previous findings: some empirical investigations (Hall et al., 2013; Morikawa, 2014), and also case studies (Arora, 1997; Jorda, 2008; Ottoz and Cugno, 2008) indicate that trade secret laws are needed for protecting many manufacturing innovations. However, the investigation by Hall et al. (2013) finds that secrecy is preferred to patents for protecting process innovations, but opposite for protecting product innovations. Also, in Jorda (2008) and Ottoz and Cugno (2008), all the cases that need trade secret protection are process innovations, while in Arora (1997), the cases that need trade secret protection are the product innovations in organic dyestuffs. All these findings indicate that trade secret protection is important for some manufacturing innovations, but not for the others. A possible explanation of our finding is that, as the strength of trade secret protection changes, the manufacturing R&D investment may just flow between different kinds of innovations, keeping the total volume of manufacturing R&D investment roughly unchanged.

Moreover, we check the effects of the control variables. Among all the control variables' coefficients from our preferred model specification, the FE regression (5) that includes ***PP*** but excludes all the other explanatory variables, there are three control variables getting significant coefficients: ***FT***, ***Regu*** and ***Ter***. Both ***FT*** and ***Regu*** get significantly negative coefficients, while ***Ter*** gets a significantly positive coefficient. The significantly negative coefficient of ***FT*** is not strange, since we did not predict an unambiguous effect of ***FT***, but mentioned that this effect is theoretically ambiguous. Then the results here show that the dominant effect of ***FT*** is its negative effect from the channel that easier export of technological products to the country decreases the foreign investors' incentive to make R&D investment for market entry. Also, the significantly positive coefficient of ***Ter*** consists with our prediction. Only the significantly negative coefficient of ***Regu*** is contrary to our prediction. A possible cause is that lighter regulations on credit and labour market lead to lower costs of labour and finance, and then the cheaper labour and loans enable the manufacturing firms to achieve extensive growth more easily, thereby decreasing rather than increasing the firms' incentive to engage for instance in labour or capital saving innovations.

Besides examining the effects of patent and trade secret protection on the manufacturing R&D investment, we also run regressions to examine the two regimes' effects on R&D investment in the service sector. Tables 6 and 6b are the analogous of 5 and 5b for the service sector. Country FE regressions (12)~(17) of ***SBERDperca*** on ***PP***, ***TP***, their quadratic terms and interaction term, and the control variables are shown in Table 6. RE regressions (12b)~(17b) are displayed in Table 6b.

Table 6. Services (FE)

Dependent Variable: ***SBERDperca***						
Regressor	(12)	(13)	(14)	(15)	(16)	(17)
PP	3.434012***	-2.447895	2.612381	1.384278	3.271404***	3.307436***
Quadratic ***PP***			0.323035	0.168414		
TP	-1.173213	-6.960329	-37.16648*	-36.55029	-38.16945*	
Quadratic ***TP***			14.20276	13.36718	14.62624*	
PP*TP		4.526847		1.196830		
GDPgrow	-1.980382	-1.462651	-2.602887	-2.336053	-2.392508	-1.305076
FT	-2.121674	-1.746116	-1.808384	-1.792742	-1.959022	-1.936219
Regu	0.115541	0.273050	-0.134344	-0.067908	-0.117040	-0.011461
Sec	0.247257	0.547339	0.466795	0.520371	0.441831	0.336868
Ter	1.300625***	1.122262**	1.184430**	1.152929**	1.202599**	1.144606**
Labopa	-1.645258	-2.654388	-2.005989	-2.145403	-1.756329	-1.391949
WGD	-0.058173	-0.021541	0.013098	0.007493	-0.011998	-0.098564
Intercept	7.122637	17.00667	30.96823*	31.72208*	30.55958*	4.636559
R^2	0.953214	0.954500	0.956662	0.956707	0.956538	0.952375
Adjusted R^2	0.919295	0.919501	0.921308	0.919265	0.923107	0.919850
Periods included	5	5	5	5	5	5
Years	1990-2010	1990-2010	1990-2010	1990-2010	1990-2010	1990-2010
Countries covered	21	21	21	21	21	21
N	70	70	70	70	70	70

Note: ***, **, and * denote significance at the 1%, 5% and 10% levels, respectively.

Table 6b. Services (RE)

Dependent Variable: ***SBERDperca***						
Regressor	(12b)	(13b)	(14b)	(15b)	(16b)	(17b)
PP	3.195434***	-2.526782	1.664411	-3.507268	3.251887***	3.199663***
Quadratic ***PP***			0.771986	0.012970		
TP	0.037162	-5.685805	3.078119	1.773371	3.517896	
Quadratic ***TP***			-1.338950	-3.456606	-1.420730	
PP*TP		4.383985		5.205136		
GDPgrow	-0.700887	-0.427078	-1.048107	-0.115602	-0.609393	-0.721507
FT	-0.964463	-0.513793	-0.772991	-0.717290	-1.129940	-0.974694
Regu	0.947728	1.067259	0.883210	1.086236	0.919213	0.948434
Sec	0.554876	0.794222	0.595401	0.792917	0.527789	0.552457
Ter	0.864129***	0.793449***	0.829967***	0.773524**	0.871072***	0.869517***
Labopa	-0.646496	-1.673829	-0.878330	-1.506369	-0.499537	-0.655671
WGD	-0.113483	-0.069190	-0.049635	-0.062079	-0.112220	-0.111531
Intercept	-2.284548	7.482420	-2.685565	3.315515	-4.572080	-2.188841
R^2	0.712018	0.719074	0.718525	0.724014	0.715126	0.712344
Adjusted R^2	0.668821	0.671459	0.665141	0.665911	0.666843	0.674619
Consistence of RE in Hausman test	Not rejected	Not rejected	Not rejected	Not rejected	Rejected*	Not rejected
Periods included	5	5	5	5	5	5
Years	1990-2010	1990-2010	1990-2010	1990-2010	1990-2010	1990-2010
Countries covered	21	21	21	21	21	21
N	70	70	70	70	70	70

Note: ***, **, and * denote significance at the 1%, 5% and 10% levels, respectively.

Now among the RE regressions (12b)~(17b), the messages from the Hausman tests are inconsistent: the consistence of RE is not rejected in the RE regressions (12b)~(15b) and (17b), but rejected in the RE regression (16b). Then we should check both the FE and RE regression results carefully.

In the results from the FE regressions (12)~(17), we can see the coefficient of ***PP*** is always significantly positive if both the quadratic ***PP*** and the interaction term of ***PP*** and ***TP*** are excluded, but turns to insignificant if one or both of the quadratic ***PP*** and the interaction term are included. In the results from both the regressions (14) and (15) that include both ***PP*** and its quadratic term, both ***PP*** and its quadratic term get insignificantly positive coefficients. This means the effect of ***PP*** should be neither U-shaped nor inverted-U-shaped, and then the quadratic ***PP*** should not be included since it may just pick some positive effect from ***PP***, making the coefficient of ***PP*** insignificant. Also, since the interaction term of ***PP*** and ***TP***, if included, always gets an insignificantly positive coefficient, we argue that the interaction term may also pick some positive effect from ***PP***, making the coefficient of ***PP*** insignificant. To support this argument, we run Wald tests to rule out the possibility that in the regressions (13) and (15) that include both ***PP*** and the interaction term of ***PP*** and ***TP***, the coefficient of ***PP*** and that of the interaction term of ***PP*** and ***TP*** would be both individually insignificant but jointly significant. The Wald test results show that in both of these two regressions, the null hypothesis that "the coefficients of ***PP*** and the interaction term ***PP********TP*** are jointly zero" are not rejected even at the 10% level. Then these Wald test results indicate that in these two regressions, the coefficient of ***PP*** and that of the interaction term are not jointly significant, supporting our argument that the insignificance of ***PP***'s coefficient in the regressions (13) and (15) may be caused by that some positive effect of ***PP*** is picked by the interaction term. Then both the quadratic ***PP*** and the interaction term of ***PP*** and ***TP*** should be excluded, since they may disorder our results. Therefore, since ***PP*** always gets a significantly positive coefficient if both the quadratic ***PP*** and the interaction term of ***PP*** and ***TP*** are excluded, we can conclude that ***PP*** exhibits a positive effect on the dependent variable.

As for ***TP***, in the results from the FE regression (14) that includes ***PP***, ***TP*** and their quadratic terms, the coefficient of ***TP*** is significantly negative, while that of the quadratic ***TP*** is insignificantly positive but very close to the 10% significance level.[43] In the results from the FE regression (16) that drops the quadratic ***PP*** while keeping the other three explanatory variables, the positive coefficient of the quadratic ***TP*** turns to significant, and also, ***TP*** still gets a significantly negative coefficient. Since our discussion before indicated that the quadratic ***PP*** and the interaction term of ***PP*** and ***TP*** should be excluded, these results from the FE regression (16) that just include ***PP***, ***TP*** and the quadratic ***TP*** tends to be convincing. This means ***TP*** tends to exhibit a U-shaped effect, but this effect may be relatively weak. The fact that dropping the variables of ***TP*** will decrease the regression's adjusted R^2, as it is showed from the regression (16) to the (17), reinforces the existence of the effect of ***TP***.

Therefore, among all the FE regressions (12)~(17), we prefer the FE regression (16) where ***PP*** exhibits a positive effect, while ***TP*** exhibits a U-shaped effect that may be relative weak. This preference is reinforced by the fact that the adjusted R^2 from the regression (16) is higher than those from all the other five FE regressions.

When it comes to the RE regressions (12b)~(17b), there is something different. The RE regression results still show that ***PP*** always gets a significantly positive coefficient if both the quadratic ***PP*** and the interaction of ***PP*** and ***TP*** are excluded, but these results show the variables of ***TP*** never get significant coefficients. This means ***PP*** exhibits a positive effect but ***TP*** exhibits no significant effect, and then among all the RE regressions (12b)~(17b), we should prefer the regression (17b) that includes ***PP*** while excluding all the other explanatory variables. This preference is reinforced by the fact that the adjusted R^2 from the RE regression (17b) is higher than those from all the other five RE regressions.

Now we compare the results from the RE regressions with those from the FE ones. In the RE regression (17b) we prefer among all the six RE regressions, the consistence of RE is not rejected in Hausman test. Then due to the RE regression's higher efficiency than its

[43] Here for the quadratic ***TP***, the p-value of t-statistic is 0.1094.

corresponding FE one's, this RE regression (17b) is preferred to its corresponding FE regression (17). However, in the RE regression (16b) corresponding to the FE regression (16) we prefer among all the six FE regressions, the consistence of RE is rejected in Hausman test. Then we should prefer the FE regression (16) to its corresponding RE regression (16b). Thus we can see the choice between the FE regression (16) and the RE regression (17b) is ambiguous. This means we are unsure that whether the U-shaped effect of ***TP*** is convincing or not, since it is only showed by the FE regression (16) but not by the RE regression (17b).

Therefore, from all these FE and RE regression results together, we can just conclude that patent protection exhibits a positive effect on the service R&D investment, while our results weakly indicate a U-shaped effect of trade secret protection on the service R&D investment.

In addition, to check whether our results for service R&D are invulnerable to possible multicolinearity, we run the regressions excluding ***Sec, Ter*** and ***Regu*** that may cause multicolinearity. Regressions (18)~(22) in Table 7 report the results for the fixed effect model. Results for the random effect model are reported in Table 7b.

Table 7. Services (FE, excluding *Sec*, *Ter* and *Regu*)

Dependent Variable: ***SBERDperca***					
Regressor	(18)	(19)	(20)	(21)	(22)
PP	4.337114***	-1.475985	3.167751	2.550929	4.214799***
Quadratic ***PP***			0.518197	0.431614	
TP	0.559928	-5.496185	-39.23772*	-38.82866	-41.24539*
Quadratic ***TP***			15.56786*	15.09250	16.42428*
PP*TP		4.580103		0.627458	
GDPgrow	1.517978	1.370038	0.212979	0.297450	0.642545
FT	-4.061932***	-3.813024***	-3.703731**	-3.713835**	-3.941042***
Labopa	2.225942	0.639275	1.112687	1.002274	1.615158
WGD	-0.471434	-0.510621	-0.449933	-0.460167	-0.481272
Intercept	-3.849714	9.710191	25.67335	26.30758	24.81006
R^2	0.941705	0.943458	0.946493	0.946511	0.946166
Adjusted R^2	0.906456	0.907109	0.909952	0.907731	0.911558
Periods included	5	5	5	5	5
Years	1990-2010	1990-2010	1990-2010	1990-2010	1990-2010
Countries covered	21	21	21	21	21
N	70	70	70	70	70

Note: ***, **, and * denote significance at the 1%, 5% and 10% levels, respectively.

Table 7b. Services (RE, excluding *Sec*, *Ter* and *Regu*)

Dependent Variable: ***SBERDperca***					
Regressor	(18b)	(19b)	(20b)	(21b)	(22b)
PP	3.985793***	1.325057	1.997807	1.005428	4.086864***
Quadratic ***PP***			1.036929	0.868901	
TP	2.338184**	-0.380151	12.75332	12.08318	12.94304
Quadratic ***TP***			-4.397068	-4.672910	-4.302171
PP*TP		2.093513		1.059202	
GDPgrow	1.438803	1.454084	1.059587	1.201971	1.773670
FT	-1.839133	-1.618183	-1.629339	-1.708967	-2.097135*
Labopa	1.953208	1.476930	1.877624	1.724500	2.428121
WGD	-0.588594	-0.604762	-0.505969	-0.517912	-0.570013
Intercept	-9.385848	-4.486437	-14.74260	-12.83477	-17.32870
R^2	0.638151	0.637132	0.646783	0.648895	0.642122
Adjusted R^2	0.603689	0.596163	0.600459	0.596229	0.601716
	Rejected**	Rejected***	Rejected***	Rejected**	Rejected***
Periods included	5	5	5	5	5
Years	1990-2010	1990-2010	1990-2010	1990-2010	1990-2010
Countries covered	21	21	21	21	21
N	70	70	70	70	70

Note: ***, **, and * denote significance at the 1%, 5% and 10% levels, respectively.

We can see here in all the RE regressions (18b)~(22b), the consistency of RE is rejected in Hausman test. Then we accordingly focus on the FE regressions (18)~(22).

In the results from the FE regressions (18)~(22), ***PP*** still gets a significantly positive coefficient when both the quadratic ***PP*** and the interaction term of ***PP*** and ***TP*** are excluded. Also, the results still support a U-shaped effect of ***TP***. This support is even a bit stronger than that from the previous FE regressions including all the control variables, since here in both the FE regressions (20) and (22) that include both ***TP*** and its quadratic term, ***TP*** exhibits a U-shaped effect: ***TP*** gets a significantly negative coefficient, while the quadratic ***TP*** gets a significantly positive coefficient.

Therefore, these results from the regressions of service R&D investment excluding ***Sec, Ter*** and ***Regu*** still indicate a positive effect of ***PP***, and provide even stronger support for a U-shaped effect of ***TP***. This confirms that our main results from the regressions of service R&D investment including all the control variables are invulnerable to the possible multicolinearity caused by ***Sec, Ter*** and ***Regu***.

Then from all our results for service R&D, we can conclude that patent protection exhibits a positive effect on the service R&D investment. Also, our results weakly indicate a U-shaped effect of trade secret protection on the service R&D investment.

Checking the marginal effects of trade secret protection by the results from the FE regression (16), the one we prefer among the FE regressions including all the control variables, we find that if the strength of trade secret protection (measured by ***TP***) exceeds a threshold, trade secret protection exhibits a positive marginal effect, but if otherwise, trade secret protection exhibits a negative marginal effect. Specifically, the results from the FE regression (16) show that among all the 70 observations, 47 observations have ***TP*** higher than a threshold that is ***TP***=1.30, and thereby get positive marginal effects of ***TP***, while the other 23 observations have ***TP*** lower than the threshold of ***TP***=1.30, and thereby get negative marginal effects of ***TP***.

Also, we check the effects of the control variables. Among all the control variables' coefficients in the results from both the FE regression (16) we prefer among the FE regressions including all the control variables, and the RE regression (17b) we prefer among the RE regressions including all the control variables, only ***Ter*** gets a significant coefficient. The coefficient of ***Ter*** is significantly positive, consistent with our prediction.

The positive effect of patent protection on the service R&D investment obviously still comes from the "appropriability" channel: stronger patent protection increases the appropriability of R&D achievements.

Also, still based on the basic "appropriability" intuition for trade secret protection (Kitch, 1980; Friedman et al., 1991; Lemley, 2008), we try to give an explanation for the U-shaped effect of trade secret protection on the service R&D investment. When a country's current strength of trade secret protection is relatively low, it tends to have active start-up and spin-off activities in the service sector, since weak trade secret protection allows much labour mobility and knowledge spillover among firms, especially those from mature firms to start-up firms, and thereby spurs start-ups and spin-offs (Samila and Sorensen, 2011; Png, 2012; Png and Samila, 2015).[44] In this situation, much of R&D investment in the service sector is made by the start-up firms, but each start-up firm's R&D investment is limited in both quantity and quality: a start-up firm's R&D work is usually completed with the help of the technicians and knowledge flowing from mature firm(s), and thus tends to develop products/processes similar to the mature firm(s)'. Then the start-up firms' R&D work is not so innovative, and thus rarely needs trade secret laws to protect the appropriability of R&D achievements. Strengthening the country's trade secret protection will discourage start-ups and spin-offs, since it decreases the labour mobility and knowledge spillover from mature firms to start-up firms. Therefore, strengthening trade secret protection will lead to fewer start-up firms, and then since the quantity of each start-up firm's lowly-innovative R&D

[44] This point is supported by the empirical evidence that comparing with manufacturing industries, knowledge-intensive service industries such as IT services are more active in the start-up and spin-off activities that benefit from inter-firm labour mobility and knowledge flow through labour mobility (Lehtoranta, 2010).

investment is limited, fewer start-up firms means a smaller total amount of the lowly-innovative R&D investment made by start-up firms.[45] At first, this negative effect on the start-up firms' lowly-innovative R&D investment is dominant in the effect of trade secret protection on the total service R&D investment, but when the trade secret protection is strengthened further, the situation will change. When the strength of trade secret protection becomes high enough, some firms with enough R&D ability are willing to invest in the highly-innovative R&D work: the R&D work that needs trade secret laws to protect the appropriability of its innovative achievements. Then strengthening the trade secret protection further spurs these firms with enough R&D ability to make more highly-innovative R&D investment, since stronger trade secret protection increases the appropriability of the innovative R&D achievements. Gradually, these innovative firms become stronger and stronger, and then the positive effect on these firms' highly-innovative R&D investment becomes dominant in the effect of trade secret protection on the total service R&D investment.

Moreover, comparing our results for the manufacturing sector with those for the service sector, we can see the effect of patent protection on the manufacturing R&D investment and that on the service R&D investment act in the same pattern. As for trade secret protection, our results weakly indicate that the effect of trade secret protection on the service R&D investment tends to be stronger than that on the manufacturing R&D investment. These results are consistent with the findings by Hall et al. (2013) and Morikawa (2014), which indicate that service firms are relatively more likely to keep their innovations secret, while manufacturing firms are more likely to patent their innovations.

Finally, we check how the relative composition of manufacturing sector and service sector relates to our discussion. Checking the compositions of GDP, the data show that in most of

[45] This intuition for the negative effect of trade secret protection on R&D is essentially the same as that applied to our results in Chapter 3: weaker trade secret protection allows more inter-firm labour mobility and knowledge flow through labour mobility. However, its manifestations are slightly different in the two chapters: in Chapter 3 we focus on the R&D human resources flowing from domestic firms to MNEs, while here we focus on the inter-firm labour mobility and knowledge flow that spur start-ups and spin-offs.

our sample countries, the part contributed by the service sector is significantly larger than that contributed by the manufacturing sector.[46] However, the sectoral compositions of country-level R&D investment exhibit an opposite trend: in most of the sample countries, the volume of manufacturing R&D investment is significantly larger than that of service R&D investment. These sectoral compositions of R&D investment indicate that, the effects of patent and trade secret protection on the total R&D investment in a country tend to act in the same pattern as those on the manufacturing R&D investment: patent protection exhibits a positive effect, while trade secret protection has no significant effect. This is confirmed by running the regressions of the total R&D investment on patent and trade secret protection. The regression results for the total R&D investment are presented in Appendix 2.

5. Concluding Remarks

Using an unbalanced panel dataset covering 21 countries for 1990 to 2010, this chapter examines empirically how a country's legal regimes of both patent and trade secret protection affect the R&D investment in the manufacturing sector and service sector. The results show that on the one hand, patent protection positively affects both the R&D investment in manufacturing and that in services. On the other hand, trade secret protection has no significant effect on the R&D investment in manufacturing, while our results weakly indicate a U-shaped effect of trade secret protection on the R&D investment in services. In the U-shaped effect of trade secret protection, specifically, if the strength of trade secret protection exceeds a threshold, the marginal effect of trade secret protection on the service R&D investment is positive; otherwise, this marginal effect turns to negative.

[46] This is measured by the value added achieved in the manufacturing sector and that in the service sector. The data provided by the WDI Database show that in most of our sample countries, the part of GDP constituted by the value added in the service sector is significantly larger than that constituted by the value added in the manufacturing sector (data from https://data.worldbank.org/indicator/NV.IND.MANF.ZS?view=chart, and https://data.worldbank.org/indicator/NV.SRV.TETC.ZS?view=chart, in the WDI Database).

The positive effects of patent protection on both the R&D investment in manufacturing and that in services obviously come from the appropriability channel: stronger patent protection increases the appropriability of R&D achievements.

Also, still based on the basic appropriability intuition, we try to give an explanation for the U-shaped effect of trade secret protection on the service R&D investment. In a country, weak trade secret protection leads to an environment where benefited from the inter-firm labour mobility and knowledge flow allowed by weak trade secret protection, there are active start-up and spin-off activities in the service sector, and active R&D activities in the start-up service firms, but the start-up service firms' R&D work tends to be lowly-innovative, and thus rarely needs trade secret laws to protect the appropriability of R&D achievements. In this environment, strengthening trade secret protection will discourage start-ups and spin-offs, since it decreases the labour mobility and knowledge flow from mature firms to start-up firms. Then strengthening trade secret protection will lead to fewer start-up firms, and thus a smaller total amount of the lowly-innovative R&D investment made by the start-up firms. At first, this negative effect on the start-up firms' lowly-innovative R&D investment is dominant in the effect of trade secret protection on the total service R&D investment, but when the trade secret protection is strengthened further, the situation will change. When the strength of trade secret protection becomes high enough, some firms with enough R&D ability begin to invest in the highly-innovative R&D work that needs trade secret laws to protect the appropriability of its innovative achievements. Then strengthening the trade secret protection further spurs these firms with enough R&D ability to make more highly-innovative R&D investment, since stronger trade secret protection increases the appropriability of the innovative R&D achievements. Gradually, these innovative firms become stronger and stronger, and then the positive effect on these firms' highly-innovative R&D investment becomes dominant in the effect of trade secret protection on the total service R&D investment.

Comparing the findings in this chapter with those in Chapter 3 about foreign-sourced R&D investment, we can see an obvious difference: patent and trade secret protection are complementary to each other for boosting the foreign-sourced R&D investment, but there is no interaction between the two regimes for boosting the manufacturing/service R&D investment that's mainly domestic-sourced. We give an explanation for this difference: the innovations developed by the foreign-sourced R&D investment, especially the strategic foreign-sourced R&D investment into core technologies, are more complicated than those by the domestic-sourced R&D investment, and thereby more likely to need both patent and trade secret protection.

Finally, our results may have some policy implications. To increase the total volume of R&D investment in manufacturing, a country should strengthen patent protection rather than trade secret protection. As for the service sector, to boost the R&D investment in services, a developed country whose current trade secret protection is relatively strong can strengthen trade secret protection further. However, a developing country whose current trade secret protection is relatively weak should be aware that strengthening trade secret protection may backfire. Also, our findings indicate that it's feasible for a country to boost the service R&D investment by strengthening patent protection, especially by extending the patent coverage on service innovations.

6. Limitations

Similar to our Chapter 3, the work in this chapter has four limitations in the sample data and empirical model: (1) developed countries are over-represented in our sample; (2) the unbalanced structure of the panel dataset may harm the reliability of empirical results; (3) there is possible endogeneity of the explanatory variables in regressions; and (4) it is a pity that when we examine the effects of both IP regimes on our dependent variables, due to data insufficiency, we cannot specifically examine the effect of each IP index's each component on our dependent variables.

Also, the work in these two chapters together has another limitation: due to lack of data, we have not examined the effects of patent and trade secret protection on the R&D investment from a specific source (domestic/foreign) into a specific sector (manufacturing/service).

Moreover, our policy implications should be taken with caution: our findings suggest that it may be possible to boost R&D investment by adjusting IP protection regimes, but are silent regarding the productivity of R&D investment. Empirical evidence shows that, in some circumstances, the productivity of R&D investment is low (e.g., Atzeni and Carboni, 2006). Then even if the country successfully increases the volume of R&D investment by adjusting its IP protection regimes, the benefit of more R&D investment may be too low to exceed the cost of IP regime adjustment.

Appendix 1 for Chapter 4 –

Additional Regression Results as Robust Check

To check the robustness of our main results, we run several other regressions that exclude the variable(s) of one IP protection regime, use alternative dependent variables, or exclude one or more of the control variables.

We start from the regressions that exclude the variable(s) of one IP protection regime. Firstly, we run the country FE regressions (23)~(24) for manufacturing R&D that include the variable(s) of ***PP***, but exclude those of ***TP***, and also the corresponding RE regressions (23b)~(24b). Table 8 reports the results from these FE and RE regressions.

Table 8. Manufacturing
(including only the variable(s) of *PP* but not those of *TP*)

Dependent Variable: ***MBERDperca***				
Regressor \ Model type	Country FE		Country RE	
	(23)	(24)	(23b)	(24b)
PP	1.607561***	2.414009*	1.253939***	0.848933
Quadratic ***PP***		-0.388191		0.202126
GDPgrow	-2.416208	-2.196229	-1.582764	-1.729024
FT	-1.717372*	-1.917007**	-0.122022	-0.109323
Regu	-1.447318**	-1.409560**	-1.293218**	-1.328439**
Sec	-0.427538	-0.470568	0.118922	0.113036
Ter	0.578773**	0.614915**	0.643958***	0.624895***
Labopa	-0.338231	-0.052044	0.576345	0.428559
WGD	0.290731	0.261789	0.575377	0.576012
Intercept	10.49432*	9.361457	1.371499	2.256329
R^2	0.976917	0.977178	0.403831	0.407653
Adjusted R^2	0.961153	0.960632	0.325645	0.318801
Consistence of RE in Hausman test	NA	NA	Rejected***	Rejected***
Periods included	5	5	5	5
Years	1990-2010	1990-2010	1990-2010	1990-2010
Countries covered	21	21	21	21
N	70	70	70	70

Note: ***, **, and * denote significance at the 1%, 5% and 10% levels, respectively.

Among these FE and RE regressions including only the variable(s) of ***PP*** but not those of ***TP***, we can see in the results from both the FE regression (23) and RE regression (23b) that include ***PP*** but not its quadratic term, ***PP*** gets a significantly positive coefficient. Also, in the results from the FE regression (24) that includes both ***PP*** and its quadratic term, the coefficient of ***PP*** is still significantly positive, while that of the quadratic ***PP*** is insignificant. Then these results indicate that patent protection exhibits a positive effect on the manufacturing R&D investment, consistent with our main results.

Secondly, we run the country FE regressions (25)~(26) for manufacturing R&D that include the variable(s) of ***TP***, but exclude those of ***PP***, and also the corresponding RE regressions (25b)~(26b). Table 9 reports the results from these FE and RE regressions.

Table 9. Manufacturing (including only the variable(s) of *TP* but not those of *PP*)

Dependent Variable: ***MBERDperca***				
Model type / Regressor	Country FE		Country RE	
	(25)	(26)	(25b)	(26b)
TP	0.945087	1.440543	1.509859*	9.249979
Quadratic ***TP***		-0.195429		-3.089455
GDPgrow	-1.710391	-1.704014	-0.419432	-0.175806
FT	0.793504	0.794726	1.266698*	1.202345
Regu	-1.541081**	-1.538085**	-1.414841**	-1.361310**
Sec	0.412712	0.411245	0.688676**	0.686100**
Ter	0.830080**	0.831752**	0.594444**	0.592739**
Labopa	-1.572355	-1.572585	-0.097782	0.089549
WGD	0.512130	0.511820	0.606025	0.604002
Intercept	7.856043	7.539629	-0.659929	-6.141003
R^2	0.966480	0.966481	0.339293	0.343920
Adjusted R^2	0.943589	0.942180	0.252643	0.245508
Consistence of RE in Hausman test	NA	NA	Not rejected	Not rejected
Periods included	5	5	5	5
Years	1990-2010	1990-2010	1990-2010	1990-2010
Countries covered	21	21	21	21
N	70	70	70	70

Note: ***, **, and * denote significance at the 1%, 5% and 10% levels, respectively.

In the results from these FE and RE regressions including only the variable(s) of ***TP*** but not those of ***PP***, we can see ***TP*** and its quadratic term always get insignificant coefficients expect that in the RE regression (25b). In this RE regression (25b) that includes ***TP*** but not its quadratic term, ***TP*** gets a significantly positive coefficient, and the consistence of RE is not rejected in Hausman test. However, we argue that the significantly positive coefficient of ***TP*** in this RE regression here is not so convincing for two reasons: 1) the significantly positive coefficient of ***TP*** here may just mistakenly reflect the positive effect of the omitted ***PP***; and 2) the consistence of RE here is not convincing since in all our main regressions that include the variables of both ***PP*** and ***TP***, the consistence of RE is strongly rejected (at 1% significance level) in Hausman test. Then these results still show that trade secret protection tends to have no significant effect on the manufacturing R&D investment, roughly consistent with our main results.

Thirdly, we run the country FE regressions (27)~(28) for service R&D that include the variable(s) of ***PP***, but exclude those of ***TP***, and also the corresponding RE regressions (27b)~(28b). Table 10 reports the results from these FE and RE regressions.

Table 10. Services
(including only the variable(s) of *PP* but not those of *TP*)

Dependent Variable: ***SBERDperca***				
Model type / Regressor	Country FE		Country RE	
	(27)	(28)	(27b)	(28b)
PP	3.307436***	2.419607	3.199663***	1.634981
Quadratic ***PP***		0.427365		0.751209
GDPgrow	-1.305076	-1.547254	-0.721507	-1.009889
FT	-1.936219	-1.716438	-0.974694	-0.604105
Regu	-0.011461	-0.053030	0.948434	0.886232
Sec	0.336868	0.384240	0.552457	0.627085
Ter	1.144606**	1.104816**	0.869517***	0.800261***
Labopa	-1.391949	-1.707016	-0.655671	-0.948329
WGD	-0.098564	-0.066701	-0.111531	-0.062807
Intercept	4.636559	5.883743	-2.188841	-1.014448
R^2	0.952375	0.952602	0.712344	0.714941
Adjusted R^2	0.919850	0.918238	0.674619	0.672183
Consistence of RE in Hausman test	NA	NA	Not rejected	Not rejected
Periods included	5	5	5	5
Years	1990-2010	1990-2010	1990-2010	1990-2010
Countries covered	21	21	21	21
N	70	70	70	70

Note: ***, **, and * denote significance at the 1%, 5% and 10% levels, respectively.

Among these FE and RE regressions including only the variable(s) of ***PP*** but not those of ***TP***, we can see in the results from both the FE regression (27) and RE regression (27b) that include ***PP*** but not its quadratic term, ***PP*** gets a significantly positive coefficient. Then these results indicate that patent protection exhibits a positive effect on the service R&D investment, consistent with our main results.

Fourthly, we run the country FE regressions (29)~(30) for service R&D that include the variable(s) of ***TP***, but exclude those of ***PP***, and also the corresponding RE regressions (29b)~(30b). Table 11 reports the results from these FE and RE regressions.

Table 11. Services
(including only the variable(s) of *TP* but not those of *PP*)

Dependent Variable: ***SBERDperca***				
Model type / Regressor	Country FE		Country RE	
	(29)	(30)	(29b)	(30b)
TP	0.613596	-53.52177*	1.157128	-11.76745
Quadratic ***TP***		21.35326*		5.219004
GDPgrow	-0.603520	-1.300377	1.611767	1.036108
FT	3.244553**	3.111041**	2.972962**	3.096035**
Regu	-0.059490	-0.386943	1.688935	1.502819
Sec	2.037217***	2.197539***	2.012181***	2.015925***
Ter	1.874585***	1.691796***	0.831576**	0.884486***
Labopa	-4.355564	-4.330354	-2.266945	-2.859014
WGD	0.426983	0.460856	0.052776	0.073094
Intercept	1.967998	36.54059*	-7.424210	2.811667
R^2	0.918530	0.925781	0.555001	0.560696
Adjusted R^2	0.862892	0.871972	0.496641	0.494801
Consistence of RE in Hausman test	NA	NA	Not rejected	Not rejected
Periods included	5	5	5	5
Years	1990-2010	1990-2010	1990-2010	1990-2010
Countries covered	21	21	21	21
N	70	70	70	70

Note: ***, **, and * denote significance at the 1%, 5% and 10% levels, respectively.

Among these FE and RE regressions including only the variable(s) of ***TP*** but not those of ***PP***, we can see in the results from the FE regression (30) that includes both ***TP*** and its quadratic term, ***TP*** gets a significantly negative coefficient, while the quadratic ***TP*** gets a significantly positive coefficient. However, the significance of the coefficients of both ***TP*** and its quadratic term disappears in the RE regression (30b) corresponding to the FE regression (30). Then these results still weakly indicate a U-shaped effect of trade secret protection on the service R&D investment, consistent with our main results.

Therefore, all these results from the regressions that include only one IP regime's variable(s) still indicate positive effects of patent protection on both the manufacturing and service R&D investments, while weakly indicate a U-shaped effect of trade secret protection on the service R&D investment. However, as for the effect of trade secret protection on the manufacturing R&D investment, there is a minor deviation in the results from the regressions that include only the variable(s) of ***TP*** but not those of ***PP*** here: the FE regression results still show no significant coefficients of both ***TP*** and its quadratic term, but in the RE regression (25b) that includes ***TP*** but not its quadratic term, ***TP*** gets a significantly positive coefficient, and the consistence of RE is not rejected in Hausman test. Nevertheless, we can argue that the significantly positive coefficient of ***TP*** in the RE regression (25b) here is not convincing for two reasons: 1) the significantly positive coefficient of ***TP*** here may just mistakenly reflect the positive effect of the omitted ***PP***; and 2) the consistence of RE here is not convincing since in all our main regressions that include the variables of both ***PP*** and ***TP***, the consistence of RE is strongly rejected (at 1% significance level) in Hausman test. Then these results still show that trade secret protection tends to have no significant effect on the manufacturing R&D investment, roughly consistent with our main results.

Anyway, the significantly positive coefficient of ***TP*** in the RE regression (25b) for manufacturing R&D here slightly challenges our main results' suggestion on sectoral comparison: the effect of trade secret protection on the service R&D investment tends to be stronger than that on the manufacturing R&D investment. Then to check the robustness of our main results more carefully, we use each country's ratio of manufacturing R&D investment to total GDP, and that of service R&D investment to total GDP, as the dependent variables alternative to ***MBERDperca*** and ***SBERDperca***, respectively. These two ratios are denoted by ***MBERD/GDP*** (manufacturing R&D-GDP ratio) and ***SBERD/GDP*** (service R&D-GDP ratio). Then we run the regressions of ***MBERD/GDP*** and those of ***SBERD/GDP***, respectively. In these regressions, the control variable ***GDPgrow*** correlated with ***MBERD/GDP*** and ***SBERD/GDP*** is excluded.

Firstly, we run the FE regressions (31)~(34) for the manufacturing R&D-GDP ratio, and the corresponding RE regressions (31b)~(34b). Table 12 and Table 12b report the results from the FE regressions and those from the RE regressions, respectively.

Table 12. Manufacturing R&D-GDP ratio (FE)

Dependent Variable: ***MBERD/GDP***				
Regressor	(31)	(32)	(33)	(34)
PP	-3.689723	1.025426***		
Quadratic ***PP***	-1.199218*			
TP	11.52624	10.96936	0.819570	5.958337
Quadratic ***TP***	-7.193429	-4.204887		-2.029139
PP*TP	5.566330			
FT	-1.224554	-1.047161	0.529354	0.542139
Regu	-1.299722**	-1.589854***	-1.713963***	-1.684626***
Sec	-0.031115	-0.203007	0.357142	0.340477
Ter	0.130188	0.167257	0.318255	0.339397
Labopa	-0.885201	-0.239777	-1.112158	-1.130998
WGD	0.218507	0.240483	0.399753	0.398402
Intercept	2.555185	-2.552501	3.027760	-0.182283
R^2	0.960760	0.956934	0.948879	0.949050
Adjusted R^2	0.928749	0.925712	0.916015	0.914255
Periods included	5	5	5	5
Years	1990-2010	1990-2010	1990-2010	1990-2010
Countries covered	21	21	21	21
N	70	70	70	70

Note: ***, **, and * denote significance at the 1%, 5% and 10% levels, respectively.

Table 12b. Manufacturing R&D-GDP ratio (RE)

Dependent Variable: ***MBERD/GDP***				
Regressor	(31b)	(32b)	(33b)	(34b)
PP	-2.423829	0.847812**		
Quadratic ***PP***	-0.854871			
TP	8.048690	8.841672	0.948499	3.156666
Quadratic ***TP***	-4.930187	-3.280185		-0.884818
PP*TP	3.906818			
FT	-0.415102	-0.215186	0.855376	0.825040
Regu	-1.529235***	-1.725589***	-1.705738***	-1.690460***
Sec	0.326151	0.246717	0.624452**	0.618779**
Ter	0.118054	0.132228	0.197455	0.199995
Labopa	0.767894	1.340056	0.357795	0.376484
WGD	0.467689	0.503962	0.563366	0.561589
Intercept	-5.485306	-10.58384	-4.519462	-5.898438
R^2	0.297424	0.277344	0.210332	0.210265
Adjusted R^2	0.164177	0.168946	0.121176	0.106693
Consistence of RE in Hausman test	Rejected**	Rejected**	Not rejected	Not rejected
Periods included	5	5	5	5
Years	1990-2010	1990-2010	1990-2010	1990-2010
Countries covered	21	21	21	21
N	70	70	70	70

Note: ***, **, and * denote significance at the 1%, 5% and 10% levels, respectively.

Among these FE and RE regressions of the manufacturing R&D-GDP ratio, we can see in the results from both the FE regression (32) and RE regression (32b) that excludes the quadratic ***PP*** and the interaction term of ***PP*** and ***TP***, ***PP*** gets a significantly positive coefficient. As for ***TP***, both ***TP*** and its quadratic term, if included, always get insignificant coefficients, even in the FE regressions (33)~(34) and RE regressions (33b)~(34b) that exclude the variable(s) of ***PP***. Then these results indicate that on the manufacturing R&D investment, patent protection exhibits a positive effect, while trade secret protection has no significant effect, consistent with our main results.

Secondly, we run the FE regressions (35)~(38) for the service R&D-GDP ratio, and the corresponding RE regressions (35b)~(38b). Table 13 and Table 13b report the results from the FE regressions and those from the RE regressions, respectively.

Table 13. Services R&D-GDP ratio (FE)

Dependent Variable: ***SBERD/GDP***				
Regressor	(35)	(36)	(37)	(38)
PP	-1.168646	2.660563***		
Quadratic ***PP***	-0.298620			
TP	-34.36092*	-36.23683*	0.395129	-49.23839**
Quadratic ***TP***	11.47068	13.95355*		19.59873**
PP*TP	3.447228			
FT	-1.162934	-1.265036	2.982035**	2.858550**
Regu	-0.135393	-0.299581	-0.262118	-0.545476
Sec	0.856829	0.708580	1.957730***	2.118699***
Ter	0.711699*	0.774976**	1.425808***	1.221606**
Labopa	-2.350306	-1.675913	-4.170242*	-3.988268*
WGD	-0.037674	-0.050857	0.345833	0.358878
Intercept	26.56689*	23.25312	-1.601784	29.40287
R^2	0.942391	0.941664	0.897760	0.907919
Adjusted R^2	0.895394	0.899370	0.832034	0.845035
Periods included	5	5	5	5
Years	1990-2010	1990-2010	1990-2010	1990-2010
Countries covered	21	21	21	21
N	70	70	70	70

Note: ***, **, and * denote significance at the 1%, 5% and 10% levels, respectively.

Table 13b. Services R&D-GDP ratio (RE)

Dependent Variable: ***SBERD/GDP***				
Regressor	(35b)	(36b)	(37b)	(38b)
PP	-2.573998	2.782327***		
Quadratic ***PP***	-0.296759			
TP	-11.45760	-10.22374	0.198073	-22.95589*
Quadratic ***TP***	1.933616	3.816959		9.352413*
PP*TP	4.610845			
GDPgrow	-0.596974	-1.223615	1.272525	0.222892
FT	-0.894144	-1.128543	2.148264*	2.447246**
Regu	0.621112	0.458360	1.216610	0.974942
Sec	0.842127*	0.627546	1.899863***	1.896391***
Ter	0.520077*	0.594310**	0.539728*	0.606900**
Labopa	-1.765933	-1.011503	-1.876120	-2.939709*
WGD	-0.081510	-0.101891	0.029481	0.050467
Intercept	9.099163	2.938149	-9.359570	8.745760
R^2	0.704629	0.696518	0.487458	0.517292
Adjusted R^2	0.642445	0.645081	0.420239	0.444886
Consistence of RE in Hausman test	Not rejected	Not rejected	Not rejected	Not rejected
Periods included	5	5	5	5
Years	1990-2010	1990-2010	1990-2010	1990-2010
Countries covered	21	21	21	21
N	70	70	70	70

Note: ***, **, and * denote significance at the 1%, 5% and 10% levels, respectively.

Among these FE and RE regressions of the service R&D-GDP ratio, we can see in the results from both the FE regression (36) and RE regression (36b) that exclude the quadratic ***PP*** and the interaction term of ***PP*** and ***TP***, ***PP*** gets a significantly positive coefficient. As for ***TP***, in the results from the FE regression (36), ***TP*** gets a significantly negative coefficient while its quadratic term gets a significantly positive one, but the significance of the coefficients of both ***TP*** and its quadratic term disappears in the RE regression (36b) corresponding to the FE regression (36). However, if excluding the variable(s) of ***PP***, both FE and RE regression results, presented as the results from the FE regression (38) and its corresponding RE regression (38b), show that ***TP*** gets a significantly negative coefficient while its quadratic term gets a significantly positive one. Then these results still weakly indicate a U-shaped effect of trade secret protection on the service R&D investment, consistent with our main results.

Also, comparing the results for service R&D-GDP ratio with those for manufacturing R&D-GDP ratio, we can see an obvious trend that the effect of trade secret protection on the service R&D investment tends to be stronger than that on the manufacturing R&D investment.

Moreover, since both ***Sec*** and ***Ter*** measure the aspects of human resource, and thus have some similar characteristics, although these two variable do not exhibit a high correlation in our sample (their correlation coefficient is 0.3791), we still check the results from the regressions that include only one of these two variables.

Firstly, we run the regressions including only one of ***Sec*** and ***Ter*** for manufacturing R&D. We run the FE regressions (39)~(43) that include ***Sec*** but not ***Ter***, and their corresponding RE regressions (39b)~(43b). Table 14 and Table 14b report the results from the FE regressions and those from the RE regressions, respectively. Also, we run the FE regressions (44)~(48) that include ***Ter*** but not ***Ser***, and their corresponding RE regressions (44b)~(48b). Table 15 and Table 15b report the results from the FE regressions and those from the RE regressions, respectively.

Table 14. Manufacturing (FE, including *Sec* but not *Ter*)

Dependent Variable: ***MBERDperca***					
Regressor	(39)	(40)	(41)	(42)	(43)
PP	1.761166***	-0.788803	2.226937	-3.820016	1.891365***
Quadratic ***PP***			-0.212231	-1.015224	
TP	0.752166	-1.821144	5.780755	9.403053	
Quadratic ***TP***			-1.958274	-6.386722	
PP*TP		1.945134		5.927166	
GDPgrow	-0.686693	-0.690461	-0.405977	0.501691	-0.848747
FT	-2.208114**	-1.977518**	-2.356272**	-2.162982**	-2.454385***
Regu	-1.156907*	-1.130422*	-1.095501*	-0.840604	-0.997795*
Sec	-0.274719	-0.165367	-0.313990	-0.094815	-0.312244
Labopa	1.303057	0.649584	1.561309	0.467229	1.449647
WGD	0.205825	0.232574	0.178409	0.168470	0.219391
Intercept	3.964874	9.066866	-0.187708	4.646662	4.527528
R^2	0.974630	0.975004	0.974818	0.976522	0.974063
Adjusted R^2	0.957304	0.956882	0.955448	0.957370	0.957389
Periods included	5	5	5	5	5
Years	1990-2010	1990-2010	1990-2010	1990-2010	1990-2010
Countries covered	21	21	21	21	21
N	70	70	70	70	70

Note: ***, **, and * denote significance at the 1%, 5% and 10% levels, respectively.

Table 14b. Manufacturing (RE, including *Sec* but not *Ter*)

Dependent Variable: ***MBERDperca***					
Regressor	(39b)	(40b)	(41b)	(42b)	(43b)
PP	1.231694***	-1.507903	0.763068	-5.023667	1.491651***
Quadratic ***PP***			0.316604	-0.612829	
TP	2.018708***	-0.792040	22.15477**	20.88847**	
Quadratic ***TP***			-8.132712**	-10.69189***	
PP*TP		2.097835		5.953381*	
GDPgrow	0.406267	0.413646	0.828581	1.669229	-0.073931
FT	-0.271061	-0.057113	-0.401845	-0.419604	-0.499689
Regu	-1.268886**	-1.222804**	-1.194341**	-0.946420	-0.701839
Sec	0.284578	0.389166	0.252099	0.431233	0.265062
Labopa	1.938105*	1.321266	2.537141**	1.599795	2.118777**
WGD	0.422252	0.447998	0.461520	0.436388	0.484377
Intercept	-5.584275	-0.322758	-19.96208**	-12.17194	-4.600165
R^2	0.377218	0.382806	0.413048	0.432859	0.311805
Adjusted R^2	0.295542	0.290227	0.313564	0.325298	0.234105
Consistence of RE in Hausman test	Rejected***	Rejected***	Rejected***	Rejected***	Rejected***
Periods included	5	5	5	5	5
Years	1990-2010	1990-2010	1990-2010	1990-2010	1990-2010
Countries covered	21	21	21	21	21
N	70	70	70	70	70

Note: ***, **, and * denote significance at the 1%, 5% and 10% levels, respectively.

Table 15. Manufacturing (FE, including *Ter* but not *Sec*)

Dependent Variable: ***MBERDperca***					
Regressor	(44)	(45)	(46)	(47)	(48)
PP	1.352061***	-0.503529	1.873181	-3.209248	1.370882***
Quadratic ***PP***			-0.257365	-0.973135	
TP	0.286880	-1.634549	5.181934	9.171735	
Quadratic ***TP***			-1.905685	-6.075631	
PP*TP		1.471689		5.177352	
GDPgrow	-1.944416	-1.870582	-1.665440	-0.676220	-2.092979
FT	-1.342310	-1.303357	-1.444888	-1.593380*	-1.369847
Regu	-1.590532***	-1.508863**	-1.556606**	-1.188217*	-1.565536***
Ter	0.495848*	0.453615	0.517326*	0.423341	0.531579**
Labopa	0.052644	-0.360701	0.312053	-0.442349	0.008473
WGD	0.437780	0.414507	0.428639	0.319489	0.456134
Intercept	7.106162	11.05202	2.812898	6.677747	7.563880
R^2	0.976126	0.976360	0.976357	0.977759	0.976054
Adjusted R^2	0.959822	0.959220	0.958169	0.959615	0.960660
Periods included	5	5	5	5	5
Years	1990-2010	1990-2010	1990-2010	1990-2010	1990-2010
Countries covered	21	21	21	21	21
N	70	70	70	70	70

Note: ***, **, and * denote significance at the 1%, 5% and 10% levels, respectively.

Table 15b. Manufacturing (RE, including *Ter* but not *Sec*)

Dependent Variable: ***MBERDperca***					
Regressor	(44b)	(45b)	(46b)	(47b)	(48b)
PP	1.260851***	1.381441	1.280668	-1.439057	1.491651***
Quadratic ***PP***			0.071546	-0.388714	
TP	1.161914	1.253056	20.44900**	20.36707**	
Quadratic ***TP***			-7.740080**	-9.177149**	
PP* TP		-0.095497		2.888589	
GDPgrow	-0.998652	-1.057287	-0.300391	0.176932	-0.073931
FT	-0.139780	-0.191855	-0.428330	-0.534387	-0.499689
Regu	-1.424997***	-1.438241**	-1.330687**	-1.164210**	-0.701839
Ter	0.518083***	0.521611***	0.467686**	0.441492**	0.265062
Labopa	0.822583	0.802406	1.665328	1.298288	2.118777**
WGD	0.464930	0.464688	0.485720	0.433099	0.484377
Intercept	-0.165410	-0.067871	-15.01909*	-11.58492	-4.600165
R^2	0.416812	0.418510	0.446755	0.452449	0.311805
Adjusted R^2	0.340328	0.331286	0.352985	0.348603	0.234105
Consistence of RE in Hausman test	Rejected***	Rejected***	Rejected***	Rejected***	Rejected***
Periods included	5	5	5	5	5
Years	1990-2010	1990-2010	1990-2010	1990-2010	1990-2010
Countries covered	21	21	21	21	21
N	70	70	70	70	70

Note: ***, **, and * denote significance at the 1%, 5% and 10% levels, respectively.

We can see here in all the RE regressions (39b)~(48b), the consistency of RE is rejected in Hausman test. Then we accordingly focus on the FE regressions (39)~(48).

Among all the FE regressions (39)~(48) that include only one of ***Sec*** and ***Ter***, the results show that ***PP*** gets a significantly positive coefficient if the quadratic ***PP*** and the interaction term of ***PP*** and ***TP*** are excluded, while both ***TP*** and its quadratic term, if included, always get insignificant coefficients. Then these results from the regressions including only one of ***Sec*** and ***Ter*** still show that on the manufacturing R&D investment, patent protection exhibits a positive effect, while trade secret protection has no significant effect, consistent with our main results.

Secondly, we run the regressions including only one of ***Sec*** and ***Ter*** for service R&D. We run the FE regressions (49)~(50) that include ***Sec*** but not ***Ter***, the FE regressions (51)~(52) that include ***Ter*** but not ***Sec***, and also the FE regressions (53) that excludes both ***Sec*** and ***Ter*** as robust check. Also, we run the RE regressions (49b)~(53b) corresponding to the FE regressions (49)~(53). Table 16 and Table 16b report the results from the FE regressions and those from the RE regressions, respectively.

Table 16. Services (FE, excluding one or both of *Sec* and *Ter*)

Dependent Variable: ***SBERDperca***					
Regressor	(49)	(50)	(51)	(52)	(53)
PP	-3.365782	3.591051***	3.797545	3.531941***	4.112470***
Quadratic ***PP***	-0.152640		0.330188		
TP	-38.07775	-43.53228*	-35.06569	-35.32280	-38.88461*
Quadratic ***TP***	12.22372	17.27602*	13.67632	13.43176	15.37314*
PP*TP	5.598644		-0.734981		
GDPgrow	1.396106	1.030293	-3.075802	-2.771362	0.732777
FT	-2.505143	-2.999725*	-2.222678	-2.335303*	-3.821404***
Regu	0.669152	0.477689	-0.023508	0.034955	0.830259
Sec	1.024208	0.779940			
Ter			1.282942**	1.279386***	
Labopa	0.025130	1.622541	-2.203655	-2.119571	1.348795
WGD	-0.131574	-0.173838	-0.142414	-0.169374	-0.485097
Intercept	27.17551	21.58848	31.63568*	31.84383*	22.90886
R^2	0.950681	0.949150	0.956005	0.955922	0.947131
Adjusted R^2	0.910447	0.912284	0.920115	0.923965	0.911025
Periods included	5	5	5	5	5
Years	1990-2010	1990-2010	1990-2010	1990-2010	1990-2010
Countries covered	21	21	21	21	21
N	70	70	70	70	70

Note: ***, **, and * denote significance at the 1%, 5% and 10% levels, respectively.

Table 16b. Services (RE, excluding one or both of *Sec* and *Ter*)

Dependent Variable: ***SBERDperca***					
Regressor	(49b)	(50b)	(51b)	(52b)	(53b)
PP	-7.556999	3.375073***	0.854154	3.628093***	3.909417***
Quadratic ***PP***	-0.110915		0.322734		
TP	5.404518	9.091435	5.519200	5.855823	12.45132
Quadratic ***TP***	-6.157566	-3.004395	-3.207202	-2.401822	-4.370662
PP*TP	8.613955		1.693188		
GDPgrow	2.329469	1.861492	-0.800817	-0.745571	1.806286
FT	-0.695905	-1.349889	-1.430669	-1.608002	-2.034933
Regu	1.516985	1.282038	1.195543	1.115817	1.557547*
Sec	1.122288**	0.730219			
Ter			0.868096***	0.906985***	
Labopa	-0.440722	1.486254	-0.867860	-0.403775	1.725741
WGD	-0.186493	-0.291979	-0.290544	-0.293845	-0.557574
Intercept	-1.659609	-16.26953	-1.068482	-4.496972	-16.60947
R^2	0.693224	0.671474	0.710513	0.707658	0.658723
Adjusted R^2	0.635043	0.622195	0.655610	0.663807	0.613966
Consistence of RE in Hausman test	Not rejected	Rejected**	Rejected*	Rejected**	Rejected**
Periods included	5	5	5	5	5
Years	1990-2010	1990-2010	1990-2010	1990-2010	1990-2010
Countries covered	21	21	21	21	21
N	70	70	70	70	70

Note: ***, **, and * denote significance at the 1%, 5% and 10% levels, respectively.

Among the FE regressions (49)~(52) and RE regressions (49b)~(52b) that include only one of ***Sec*** and ***Ter***, we can see in the results from the FE regressions (50) & (52) and RE regressions (50b) & (52b) that exclude the quadratic ***PP*** and the interaction term of ***PP*** and ***TP***, ***PP*** gets a significantly positive coefficient. Then these results still indicate a positive effect of patent protection on the service R&D investment, consistent with our main results.

As for ***TP***, among the FE regressions (50) & (52) and RE regressions (50b) & (52b) that exclude the quadratic ***PP*** and the interaction term of ***PP*** and ***TP***, we can see in the results from the FE regression (50) that includes ***Sec*** but not ***Ter***, ***TP*** exhibits a U-shaped effect: ***TP*** gets a significantly negative coefficient, while the quadratic ***TP*** gets a significantly positive coefficient. However, the significance of the coefficients of ***TP*** and its quadratic term disappears in the RE regression (50b) corresponding to the FE regression (50). When it comes to the FE regression (52) and RE regression (52b) that include ***Ter*** but not ***Sec***, we can see the significance of the coefficients of ***TP*** and its quadratic term totally disappears, although in the FE regression (52), the coefficients of ***TP*** and its quadratic term are still close to the 10% significance level.[47] In the FE regression (53) that excludes both ***Sec*** and ***Ter***, the significance of the negative coefficient of ***TP*** and the positive coefficient of the quadratic ***TP*** returns. Then since in the FE regression (52) and RE regression (52b), ***Ter*** gets a positive and strongly significant coefficient, and the correlation between ***Ter*** and ***TP*** is relatively high (the two variables' correlation coefficient is 0.5492), we can argue that the significance of the coefficients of ***TP*** and its quadratic term totally disappears just due to the multicolinearity caused by the high correlation between ***TP*** and ***Ter***: the significance of the coefficients of ***TP*** and its quadratic term cannot survive in a regression including ***Ter*** but not ***Sec***, since ***Ter***, which is highly correlated with ***TP***, exhibits a quite strong effect that tends to be stronger when ***Sec*** is absent. Anyway, the insignificance of the coefficients of ***TP*** and its quadratic term in both the FE and RE regressions including ***Ter*** but not ***Sec*** weakens the support for the U-shaped effect of trade secret protection, but we can still keep our main conclusion for this issue: our results weakly indicate a U-shaped effect of trade secret protection on the service R&D investment.

[47] Here, for ***TP*** and its quadratic term, the p-values of t-statistics are 0.1004 and 0.1121, respectively.

Appendix 2 for Chapter 4 –

Effect of IP Protection on Total R&D Investment

As mentioned in the last paragraph of Section 4.2, here we run the regressions of the per capita value of the total R&D investment in each country, denoted as ***BERDperca***, on our IP variable(s) and control variables. Table 17 reports the results from the FE regressions (54)~(58) of ***BERDperca***, and Table 17b reports the results from the corresponding RE regressions (54b)~(58b).

Table 17. Total R&D Investment (FE)

Dependent Variable: ***BERDperca***					
Regressor	(54)	(55)	(56)	(57)	(58)
PP	1.740040***	1.179746	1.956994	1.291771	1.756181***
Quadratic ***PP***			-0.116306	-0.200059	
TP	0.149610	-0.401655	-4.835157	-4.501387	
Quadratic ***TP***			1.980405	1.527795	
PP* TP		0.431215		0.648284	
GDPgrow	-0.794978	-0.745661	-0.770739	-0.626203	-0.881094
FT	-1.599290*	-1.563516*	-1.633198*	-1.624725*	-1.622940**
Regu	-0.672008	-0.657005	-0.694845	-0.658859	-0.655813
Sec	-0.305065	-0.276480	-0.289736	-0.260716	-0.316492
Ter	0.605745**	0.588755**	0.600036**	0.582973**	0.625641**
Labopa	-0.005440	-0.101567	0.070566	-0.004950	-0.037743
WGD	0.317055	0.320545	0.313791	0.310755	0.322206
Intercept	6.811473	7.752999	9.593406	10.00174	7.128501
R^2	0.979654	0.979671	0.979755	0.979774	0.979634
Adjusted R^2	0.964903	0.964034	0.963238	0.962281	0.965725
Periods included	5	5	5	5	5
Years	1990-2010	1990-2010	1990-2010	1990-2010	1990-2010
Countries covered	21	21	21	21	21
N	70	70	70	70	70

Note: ***, **, and * denote significance at the 1%, 5% and 10% levels, respectively.

Table 17b. Total R&D Investment (RE)

Dependent Variable: ***BERDperca***					
Regressor	(54)	(55)	(56)	(57)	(58)
PP	1.403473***	0.383508	0.926963	-1.097303	1.492210***
Quadratic ***PP***			0.284234	-0.013664	
TP	0.962142	-0.065180	11.74015	11.48057	
Quadratic ***TP***			-4.346460	-5.272854	
PP* TP		0.784931		2.041154	
GDPgrow	0.115321	0.158412	0.288308	0.664056	-0.405038
FT	-0.405556	-0.342093	-0.477740	-0.472243	-0.489812
Regu	-0.661784	-0.638539	-0.607215	-0.512831	-0.511056
Sec	0.152678	0.192427	0.137654	0.211240	0.105033
Ter	0.534337***	0.517691***	0.498372***	0.468168**	0.651877***
Labopa	0.689333	0.489464	0.936903	0.679359	0.488703
WGD	0.489095	0.493938	0.506026	0.494711	0.530065
Intercept	-0.700704	1.162921	-7.962668	-5.692955	1.022900
R^2	0.563737	0.565593	0.573368	0.576843	0.552548
Adjusted R^2	0.498297	0.491965	0.492455	0.487758	0.493865
Consistence of RE in Hausman test	Rejected***	Rejected***	Rejected***	Rejected***	Rejected***
Periods included	5	5	5	5	5
Years	1990-2010	1990-2010	1990-2010	1990-2010	1990-2010
Countries covered	21	21	21	21	21
N	70	70	70	70	70

Note: ***, **, and * denote significance at the 1%, 5% and 10% levels, respectively.

We can see in the results from all these FE and RE regressions for total R&D investment, ***PP*** always gets a significantly positive coefficient if the quadratic ***PP*** and the interaction term of ***PP*** and ***TP*** are excluded, while both ***TP*** and its quadratic term never get significant coefficients. Then these results indicate that on the total R&D investment in a country, patent protection exhibits a positive effect, while trade secret protection has no significant effect. This supports our argument that since in most countries, the manufacturing R&D investment dominates the total R&D investment, the effects of patent and trade secret protection on each country's total R&D investment act in a pattern similar to those on the country's manufacturing R&D investment.

Bibliography –

References for Chapter 2:

Cebrién, M. (2009), “The Structure of Payments as a Way to Alleviate Contractual Hazards in International Technology Licensing”, Industrial and Corporate Change 18(6), 1135-1160.

Chen, F., Li, F. and Meng, Q. (2016), “Integration and autonomy in Chinese technology-sourcing cross-border M&As: from the perspective of resource similarity and resource complementarity”, Technology Analysis and Strategic Management, accepted on 04 Nov. 2016 and published online on 29 Nov. 2016, at: http://www.tandfonline.com/doi/abs/10.1080/09537325.2016.1261102.

Ernst, D. (2005), “Complexity and internationalisation of innovation—why is chip design moving to Asia?”, International Journal of Innovation Management 9(1), 47-73.

Gallini, N.T. (1984), “Deterrence through Market Sharing: A Strategic Incentive for Licensing”, American Economic Review 74(5), 931-941.

Gallini, N.T. and Winter, R.A. (1985), “Licensing in the Theory of Innovation”, The RAND Journal of Economics 16(2), 237-252.

Gallini, N.T. and Wright, B.D. (1990), "Technology Transfer under Asymmetric Information", The RAND Journal of Economics 21(1), 147-160.

Gao, L. and Yang, X. (2003), "Investigation on the development of chip industry in China", China Computer World, April 15, 2003. http://tech.sina.com.cn/other/2003-04-15/1436178184.shtml (in Chinese).

González-Álvarez, N., and Nieto-Antolín, M. (2007), "Appropriability of innovation results: An empirical study in Spanish manufacturing firms", Technovation 27 (5): 280-295.

Kamien, M.I. and Tauman, Y. (1986), "Fees versus Royalties and the Private Value of a Patent", Quarterly Journal of Economics 101(3), 471-491.

Kanwar, S. (2012), "Intellectual property protection and technology licensing: The case of developing countries", Journal of Law and Economics 55(3), 539-564.

Katz, M.L. and Shapiro, C. (1985), "On the Licensing of Innovations", The RAND Journal of Economics 16(4), 504-520.

Katz, M.L. and Shapiro, C. (1986), "How to License Intangible Property", The Quarterly Journal of Economics 101(3), 567-590.

Keupp, M.M., Beckenbauer, A., and Gassmann, O. (2010), "Enforcing Intellectual Property Rights in Weak Appropriability Regimes", Management International Review 50 (1):109–130.

Li, J.-P., Li, M., Zhao, X., Li, J.-J., Su, H., Huang, M.(eds.)(2013), *Report on the Group of Twenty (G20) National Innovation Competitiveness Development (2011-2013)* (in Chinese), Social Sciences Academic Press, Beijing, China.

Macho-Stadler, I., Martinez-Giralt, X. and Perez-Castrillo, J.D. (1996), "The role of information in licensing contract design", Research Policy 25(1), 43–57.

Ministry of Industry and Information Technology of China (2013), *2012 Statistical Bulletin of China's Electronic Information Industry*, at: http://www.miit.gov.cn/n11293472/n11293832/n11294132/n12858387/15173031.html (in Chinese).

Nocke, V. and Yeaple, S. (2007), "Cross-border mergers and acquisitions vs. greenfield foreign direct investment: the role of firm heterogeneity", Journal of International Economics 72 (2), 336–365.

Raff, H., Ryan, M. and Stähler, F. (2009), "The choice of market entry mode: Greenfield investment, M&A and joint venture", International Review of Economics & Finance 18(1), 3–10.

Reed, R. and Defillippi, R.J. (1990), "Causal Ambiguity, Barriers to Imitation, and Sustainable Competitive Advantage", The Academy of Management Review 15 (1), 88-102.

Rockett, K. (1990), "The Quality of Licensed Technologies", International Journal of Industrial Organization 8(4), 559–574.

Taylor, C.T. and Silberston, A. (1973), *The economic impact of the patent system: a study of the British experience*, Cambridge University Press, Cambridge, UK.

"The 2012 Annual Financial Report of the Semiconductor Manufacturing International Corporation (SMIC)",
at: http://www.smics.com/attachment/20130429173201001642069_en.pdf.

“The cost of chip production in mainland China is about 20% lower than that in Europe and Northern America” (2004, Sep. 23), retrieved from: http://news.ccidnet.com/art/1366/20040923/158204_1.html (in Chinese).

Yang, G. and Maskus, K.E. (2001), “Intellectual Property Rights and Licensing: An Econometric Investigation”, Review of World Economics 53(1), 169–187.

Zander, U., and Kogut, B. (1995). “Knowledge and the Speed of the Transfer and Imitation of Organizational Capabilities: An Empirical Test”, Organization Science 6 (1):76 – 92.

References for Chapter 3 & Chapter 4:

AlIred, B.B. and Park, W.G. (2007a), "The influence of patent protection on firm innovation investment in manufacturing industries", Journal of International Management 13(2), 91-109.

Allred, B.B. and Park, W.G. (2007b), "Patent rights and innovative activities: Evidence from national and firm-level data", Journal of International Business Studies 38 (6), 878-900.

Anton, J. J. and Yao, D.A. (2004), "Little patents and big secrets: Managing intellectual property", The RAND Journal of Economics 35 (1), 1-22.

Arora, A. (1997), “Patents, Licensing, and Market Structure in Chemical Industry”, Research Policy 26 (4–5), 391–403.

Asakawa, K. (1996), “External-internal linkages and overseas autonomy-control tension: the management dilemma of the Japanese R&D in Europe”, IEEE Transactions on Engineering Management 43 (1), 24–32.

Atzeni, G.E. and Carboni, O.A. (2006), "ICT productivity and firm propensity to innovative investment: Evidence from Italian microdata", Information Economics and Policy 18 (2), 139-156.

Bardhan, A.D. and Kroll, C.A. (2006), "Competiveness and an emerging sector: the Russian software industry and its global linkages", Industry and Innovation 13 (1), 65–95.

Barro, R. and Lee, J.-W. (2010), "A New Data Set of Educational Attainment in the World, 1950-2010", National Bureau of Economic Research (NBER) Working Paper No. 15902, Cambridge, MA, USA, at: http://www.nber.org/papers/w15902.

Barro, R. and Lee, J.-W. (2013), "A New Data Set of Educational Attainment in the World, 1950-2010", Journal of Development Economics 104, 184-198, with the Updated *Barro-Lee Educational Attainment Dataset* at: http://www.barrolee.com/.

Blundell, R. and Bond, S. (1998), "Initial conditions and moment restrictions in dynamic panel data models", Journal of Econometrics 87, 115–143.

Cadot, O. and Lippman, S.A. (1995), "Barriers to imitation and the incentive to innovate", INSEAD Working Paper No. 95/23/EPS, Fontainebleau, France, at: https://flora.insead.edu/fichiersti_wp/Inseadwp1995/95-23.pdf.

Carmel, E. (2003), "The new software exporting nations: Success factors", The Electronic Journal of Information Systems in Developing Countries 13(4), 1-12.

Denicolo, V. and Franzoni, L. (2004), "Patents, Secrets, and the First Inventor Defense", Journal of Economics and Management Strategy 13 (3), 517-538.

Eurostat Office of European Union (EU), Eurostat Database, at: http://ec.europa.eu/eurostat/data/database.

Florida, R. and Kenney, M. (1994), "The Globalization of Japanese R&D: The Economic Geography of Japanese R&D Investment in the United States", Economic Geography 70 (4), 344-70.

Friedman, D.D., Landes, W.M. and Posner, R.A. (1991), “Some Economics of Trade Secret Law”, Journal of Economic Perspectives 5 (1), 61-72.

Gallini, N.T. (1992), “Patent Policy and Costly Imitation”, The RAND Journal of Economics 23 (1), 52-63.

González-Álvarez, N., and Nieto-Antolín, M. (2007), “Appropriability of innovation results: An empirical study in Spanish manufacturing firms”, Technovation 27 (5), 280-295.

Ginarte, J.C. and Park, W.G. (1997), “Determinants of patent rights: A cross-national study”, Research Policy 26 (3), 283-301.

Gwartney, J., Lawson, R. and Hall, J. (2012), “Economic Freedom of the World: 2012 Annual Report”, Fraser Institute Publishing, Vancouver, BC, Canada, at: http://www.freetheworld.com/release_2012.html.

Gwartney, J., Lawson, R. and Hall, J. (2015), “Economic Freedom of the World: 2015 Annual Report”, with the whole*2015 Economic Freedom Dataset*, Fraser Institute Publishing, Vancouver, BC, Canada, at: http://www.freetheworld.com/release_2015.html.

Hall, B.H., Helmers, C., Rogers, M. and Sena, V. (2013), "The importance (or not) of patents to UK firms", Oxford Economic Papers 65 (3), 603-629.

Horowitz, A.W. and Lai, E.L.-C. (1996), “Patent length and the rate of innovation”, International Economic Review 37 (4), 785–801.

IMF, *World Economic Outlook (WEO) Database (Oct. 2015 edition)*, at: http://www.imf.org/external/pubs/ft/weo/2015/02/weodata/index.aspx.

International Labour Organization (ILO), *ILOSTAT Database*, at: http://www.ilo.org/ilostat/faces/oracle/webcenter/portalapp/pagehierarchy/Page137.jspx?_afrLoop=107913286693878&clean=true#!%40%40%3F_afrLoop%3D107913286693878%26clean%3Dtrue%26_adf.ctrl-state%3Dfak2pd8zr_309.

Jorda, K.F. (2008), "Patent and Trade Secret Complementariness: An Unsuspected Synergy", Washburn Law Journal 48, 1-32.

Kanwar, S. and Evenson, R. (2003), "Does intellectual property protection spur technological change?", Oxford Economic Papers 55 (2), 235–264.

Keupp, M.M., Beckenbauer, A., and Gassmann, O. (2010), "Enforcing Intellectual Property Rights in Weak Appropriability Regimes", Management International Review 50 (1):109–130.

Kitch, E.W. (1980), "The Law and Economics of Rights in Valuable Information", Journal of Legal Studies 9 (4), 683-723.

Kuemmerle, W. (1999), "Foreign direct investment in industrial research in the pharmaceutical and electronics industries-results from a survey of multinational firms", Research Policy 28 (2–3), 179- 193.

Kultti, K., Takalo T. and Toikka J. (2007), "Secrecy versus patenting", The RAND Journal of Economics 38 (1), 22-42.

Kumar, N. (1996), "Intellectual Property Protection, Market Orientation and Location of Overseas R&D Activities by Multinational Enterprises", World Development24 (4), 673-688.

Kumar, N. (2001), “Determinants of location of overseas R&D activity of multinational enterprises: the case of US and Japanese corporations”, Research Policy 30 (1), 159–174.

Landes, W.M. and Posner, R.A. (2003), *The Economic Structure of Intellectual Property Law*, Harvard University Press: Cambridge.

Lehtoranta, O. (2010), "Knowledge flows from incumbent firms to newcomers: The growth performance of innovative SMEs and services start-ups", VTT Working Paper No. 143, VTT Technical Research Centre of Finland Ltd., Finland, at: http://www.vtt.fi/inf/pdf/workingpapers/2010/W143.pdf.

Lemley, M.A. (2008), “The Surprising Virtues of Treating Trade Secrets as IP rights”, Stanford Law Review 61 (2), 311-353.

Lippoldt, D. and Schultz, M.F. (2014), “Uncovering Trade Secrets - An Empirical Assessment of Economic Implications of Protection for Undisclosed Data”, OECD Trade Policy Paper No. 167, OECD publishing, at: http://dx.doi.org/10.1787/5jxzl5w3j3s6-en.

Lokshin, B., Belderbos, R. and Carree, M. (2006), “Internal and External R&D: Complements or Substitutes? Evidence from a Dynamic Panel Data Model”, Hitotsubashi University Research Unit for Statistical Analysis in Social Sciences (Hi-Stat) Discussion Paper No. d06-163, Kunitachi, Tokyo, Japan, at: http://hermes-ir.lib.hit-u.ac.jp/rs/handle/10086/13583?mode=full.

McGaughey, S. L., Liesch, P. W. and Poulson, D. (2000), “An unconventional approach to intellectual property protection: the case of an Australian firm transferring shipbuilding technologies to China”, Journal of World Business 35 (1), 1-20.

Morikawa, M. (2014), "Innovation in the Service Sector and the Role of Patents and Trade Secrets", Research Institute of Economy, Trade and Industry (RIETI) Discussion Paper 14-E-030, Tokyo, Japan, at: http://www.rieti.go.jp/jp/publications/dp/14e030.pdf.

Moser, P. (2005), "How Do Patent Laws Influence Innovation? Evidence from Nineteenth-Century World's Fairs", American Economic Review 95 (4), 1214-1236.

Nijman, T. and Verbeek, M. (1992), “Nonresponse in Panel Data: The Impact on Estimates of a Life Cycle Consumption Function”, Journal of Applied Econometrics 7, 243–257.

O’Donoghue, T. and Zweimuller, J. (2004), “Patents in a model of endogenous growth”, Journal of Economic Growth 9 (1), 81–123.

OECD, *OECD.Stat*, at: http://stats.oecd.org/.

Ottoz, E. and Cugno, F. (2008), “Patent–Secret Mix in Complex Product Firms”, American Law and Economics Review 10 (1), 142-158.

Park, W.G. (2005), “Do intellectual property rights stimulate R&D and Productivity growth? Evidence from cross-national and manufacturing industries data”, In: Putnam, J. (Ed.), *Intellectual Property and Innovation in the Knowledge-Based Economy*, Industry Canada, Ottawa, Ontario, Canada, pp. 9-51.

Park, W.G. (2008), “International patent protection: 1960–2005”, Research Policy 37 (4), 761–766, with the updated data at: http://nw08.american.edu/~wgp/.

Png, I.P.L. (2012), "Trade Secrets, Non-Competes, and Mobility of Engineers and Scientists: Empirical Evidence", Paper presented at the 2013 Annual Meeting of American Economic Association (AEA), San Diego, CA, USA, at: https://www.aeaweb.org/conference/2013/retrieve.php?pdfid=56.

Png, I.P.L. (2017), “Law and Innovation: Evidence from State Trade Secrets Laws”, The Review of Economics and Statistics, 99 (1), 167-179.

Png, I.P.L. and Samila, S. (2015), "Trade Secrets Law and Mobility: Evidence from 'Inevitable Disclosure'", Working Paper at Social Science Research Network (SSRN): https://papers.ssrn.com/sol3/papers.cfm?abstract_id=1986775.

Qian, Y. (2007), "Do National Patent Laws Stimulate Domestic Innovation in a Global Patenting Environment? A Cross-Country Analysis of Pharmaceutical Patent Protection, 1978–2002". Review of Economics and Statistics 89 (3), 436-453.

Reddy, P. (1997), "New trends in globalization of corporate R&D and implications for innovation capability in host countries: A survey from India", World Development 25(11), 1821-1837.

Reed, R. and Defillippi, R.J. (1990), "Causal Ambiguity, Barriers to Imitation, and Sustainable Competitive Advantage", The Academy of Management Review 15 (1), 88-102.

Ronstadt, R. (1977), *Research and Development Abroad by U.S. Multinationals*, Praeger, New York, NY, USA.

Samila, S. and Sorensen, O. (2011), "Non-compete Covenants: Incentives to Innovate or Impediments to Growth", Management Science 57(3), 425-438.

Scotchmer, S. (2004), *Innovation and Incentives*, MIT Press: Cambridge, MA.

Shapiro, C. (2001), "Navigating the patent thicket: Cross licenses, patent pools, and standard setting", Innovation Policy and the Economy 1, 119–150.

Siebeck (1990) 'Strengthening protection of intellectual property: a survey of the literature', World Bank Discussion Paper No. 112, Washington, DC: World Bank.

Sun, Y. (2003), “Strategic or tactical? Foreign research and development in developing countries, a case study of China”, Asian Geographer 22 (1-2), 143-167.

Sun, Y., Du, D. and Huang, L. (2006), “Foreign R&D in developing countries: empirical evidence fromShanghai, China”, The China Review 6 (1), 67–91.

U.S. Census Bureau (USCB), *International Data Base (IDB)*, at: http://www.census.gov/population/international/data/idb/informationGateway.php.

Varsakelis, N.C. (2001), “The impact of patent protection, economy openness and national culture on R&D investment: A cross-country empirical investigation”, Research Policy 30 (7), 1059–1068.

Wooldridge, J. M. (2002), *Econometric analysis of cross section and panel data*, MIT Press: Cambridge, MA & London.

Wortmami, M. (1990), “Multinationals and the internalization of R&D: New developments in German companies”, Research Policy 19 (2), 175-183.

World Bank, *2005 International Comparison Program (ICP)*, at: http://databank.worldbank.org/data/reports.aspx?source=international-comparison-program-2005.

World Bank, *World Development Indicators (WDI) Database*, at: *http://data.worldbank.org/products/wdi*.

Yang, G. and Maskus, K.E. (2001), “Intellectual Property Rights and Licensing: An EconometricInvestigation”, Review of World Economics 53(1), 169-187.

Zander, U., and Kogut, B. (1995). “Knowledge and the Speed of the Transfer and Imitation of Organizational Capabilities: An Empirical Test”, Organization Science 6 (1):76 – 92.

Zhao, M. (2006), “Conducting R&D in countries with weak intellectual property rights protection”, Management Science 52 (8), 1185–1199.