Chapter 5

Trade Patterns and International Technology Spillovers: Theory and Evidence from Japanese and European Patent Citations

5.1 Introduction

International diffusion of knowledge is important to both the speed of the world's technology frontier expansion and income convergence across countries. For example, Eaton and Kortum (1996) estimate innovation and technology diffusion among 19 Organization for Economic Co-operation and Development (OECD) countries to test predictions from a quality ladders model of endogenous growth with patenting. They find that each OECD country other than the United States obtains more than half of its productivity growth from technological knowledge originated abroad. They also find that more than half of the growth in every OECD country is derived from innovation in the United States, Japan, and Germany. Eaton and Kortum (1999) fit a similar model to research employment, productivity, and international patenting among the five leading research economies, i.e., the United States, Japan, Germany, the United Kingdom, and France. They find that research performed abroad is about two-thirds as influential as domestic research. In particular, technological knowledge from Japan and Germany diffuses most rapidly, while France and Germany are the quickest to exploit knowledge. They also show that the United States and Japan together contribute to over 65% of the growth in each of the five countries.

Previous studies have identified international trade as a major channel of international diffusion of knowledge.¹ Coe and Helpman (1995) examine international

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¹ Trade works as a channel of international diffusion of knowledge because, for example, firms can obtain information on advanced technology by reverse engineering of imported goods. International trade also provides channels of cross-border communication that facilitates learning of production and organizational methods and market conditions (Grossman and Helpman 1991). Another major channel is foreign direct investment (FDI). Productivity spillovers through FDI are empirically confirmed by a number of studies (Branstetter 2006; Haskel et al. 2007; Javorcik 2004; Keller and Yeaple 2009), while some studies do not find significant spillovers (Aitken and Harrison 1999; Haddad and Harrison 1993).

productivity spillovers among OECD countries and find large spillover effects from foreign research and development (R&D) capital stocks to domestic productivity that is measured by total factor productivity (TFP). They also show that countries exhibit higher productivity levels by importing goods from countries with high levels of technological knowledge, which supports the existence of trade-related international productivity spillovers. However, Keller (1998) provides a finding that casts doubt on Coe and Helpman's result by employing a Monte-Carlo-based robustness test. He finds that estimated international productivity spillovers among randomly matched trade partners turn out to be large (and even larger than those among actual trade partners). Xu and Wang (1999) estimate that about half of the returns on R&D investment in seven OECD countries spilled over to other OECD countries and that trade in capital goods is a significant channel of productivity spillovers. Acharya and Keller (2009) find that the diffusion of technological knowledge is strongly varying across country-pairs. They show that imports are crucial for technology diffusion from Germany, France, and the United Kingdom, while non-trade channels are relatively more important for the United States, Japan, and Canada.

Although a number of studies have investigated international diffusion of technological knowledge through trade, none of the existing studies have paid attention to the relationship between bilateral trade patterns and technology spillovers. The only exception is Jinji et al. (2015). They empirically examine the relationship between the bilateral trade structure and technology spillovers. In this chapter, we complement Jinji et al. (2015) by both analyzing theoretically the relationship between the bilateral trade structure and technology spillovers and providing further evidence on such a relationship based on Japanese and European patent data. We follow Jinji et al. (2015) to categorize bilateral trade flows into one way trade (OWT), or inter-industry trade, and two-way trade, or intra-industry trade (IIT). IIT is further decomposed into horizontal intra-industry trade (HIIT) and vertical intra-industry trade (VIIT) (e.g., Fontagné and Freudenberg 1997; Fukao et al. 2003; Greenaway et al. 1995). The difference between HIIT and VIIT reflects differences in the quality of products in the same category traded between two countries. In HIIT, horizontally differentiated products (i.e., products with similar quality but different varieties) are traded, whereas vertically differentiated products (i.e., products with different qualities) are traded in VIIT.² As for data, HIIT and VIIT can be distinguished by using unit values (i.e., total value of import or export in one product category divided by the quantity of import or export in that product category) under the assumption that unit values are increasing in product quality.

The theoretical literature on IIT has been separated into two branches for a long period. As is well known, trade models with monopolistic competition could explain HIIT (e.g., Eaton and Kierzkowski 1984; Helpman 1981; Krugman 1979, 1980). However, in these models, product varieties are symmetric and not differentiated in

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² Note that in the literature the terms of HIIT and VIIT are sometimes used in different meanings. In an alternative definition, HIIT means trade of final goods in the same industry across countries, while VIIT involves trade of intermediate goods with final goods in the same industry (Yomogida 2004). Since we do not consider the distinction between intermediate goods and final goods in this chapter, this alternative definition of HIIT and VIIT is not applicable.

quality. Trade models with vertical differentiation, on the other hand, could explain VIIT but could not explain HIIT (e.g., Falvey 1981; Falvey and Kierzkowski 1987; Flam and Helpman 1987; Herguera and Lutz 1998; Lambertini 1997; Motta et al. 1997; Shaked and Sutton 1984). Given the fact that HIIT and VIIT arise in continuous phenomena, this divergence in the theory would not be acceptable. More recently, a number of studies have attempted to introduce quality differentiation into the monopolistically competitive trade model. Some studies use a quality-augmented type of Dixit–Stiglitz demand specification (Dixit and Stiglitz 1977) in the framework of Melitz (2003)³ with the assumption that higher quality is associated with higher marginal cost (Baldwin and Harrigan 2011; Gervais 2015; Helble and Okubo 2008; Johnson 2012; Kugler and Verhoogen 2012; Mandel 2010). On the other hand, Antoniadou (2015) introduces quality differentiation into the quasi-linear utility with a quadratic subutility specification in the framework of Melitz and Ottaviano (2008) and considers endogenous quality upgrading by heterogeneous firms. He shows that firms with higher productivity choose higher qualities and charge higher prices. However, his model has some limitations when it is extended to the case of two-country trade. In this chapter, we also introduce quality differentiation into the framework of Melitz and Ottaviano (2008). We employ a different approach from Antoniadou (2015). We assume that firms randomly draw their product quality so that firms with identical productivity are heterogeneous in product quality. This reflects the stochastic nature of product R&D. This formulation of quality differentiation turns out to be tractable. Then, we show that our model can explain OWT, HIIT, and VIIT in one unified framework. Using this framework, we examine how international technology spillovers are associated with bilateral trade structure.

For empirical analysis of international technology spillovers, we use data on patent citations as a proxy for spillovers of technological knowledge. There are a number of empirical studies on knowledge flow based on patent citations (e.g., Haruna et al. 2010; Hu and Jaffe 2003; Jaffe and Trajtenberg 1999; Jaffe et al. 1993; MacGarvie 2006; Mancusi 2008).⁴ In the literature, patent citation data are used as a direct measure of technology spillovers (Hall et al. 2007). Hu and Jaffe (2003) use data on patents granted in the United States and examine patent citations by inventors residing in Korea, Japan, Taiwan, and the United States to infer the pattern of technological knowledge flows from the United States and Japan to Korea and Taiwan. They find that Korean patents are much more likely to cite Japanese patents than US patents, while Taiwanese patents cite both Japanese and US patents evenly. Mancusi (2008) estimates technological knowledge diffusion within and across sectors and countries by using European patents and citations for 14 OECD countries. She finds that international knowledge diffusion is effective in increasing innovative productivity in technologically laggard countries, while technological leaders (the United States,

³ Originally, Melitz (2003) mentions that differences in productivity may be interpreted as those in product quality at equal cost.

⁴ However, Jaffe et al. (1993) admit that patent citations are a coarse and noisy measure of knowledge flow, because not all inventions are patented and not all knowledge flows can be captured by patent citations. Based on a survey of inventors, Jaffe et al. (2000) suggest the validity of patent citations as indicators of technology spillovers, despite the presence of noise.

Japan, and Germany) are a source rather than a destination of knowledge flows. Using French firms' patent citations and firm-level trade data, MacGarvie (2006) finds that the patents of importing firms are significantly more likely to be influenced by technology in the exporting country than are the patents of firms that do not import. In contrast, she finds no significant evidence of exporting firms' citing more patents from their destination countries. Moreover, Haruna et al. (2010) investigate whether the trade structure plays an important role as a channel of technological knowledge diffusion between Asian economies (Korea, Taiwan, China, and India) and G7 countries including the United States and Japan. In that paper, they use a modified version of the Balassa's index of Revealed Comparative Advantage (RCA), which represents the share of country i in sector j relative to the country's export (or import) share for all sectors. Then, they find that trade specialization, especially import specialization, has a direct effect on knowledge diffusion.

In this chapter, we take our study one step further and investigate in more detail the relationship between bilateral trade patterns and international knowledge flow. In order to accomplish this task, we develop a two-country model of monopolistic competition with quality differentiation, in which inter- and (horizontal and vertical) intra-industry trade patterns endogenously arise, depending on the conditions of trading countries. Our model is an extension of the model developed by Melitz and Ottaviano (2008), and firms are heterogeneous in product quality rather than in productivity. Then, after deriving hypotheses from the model, we test them by using data on bilateral trade among 44 countries/economies and patent citations at the European and Japanese patent offices.

The main results are as follows. Our model predicts that the bilateral trade pattern is HIIT when the two countries have access to a similar level of technology, while it is VIIT when there is technological difference between them. Moreover, if the technological difference is sufficiently large, the bilateral trade pattern becomes OWT. Our model also predicts that technology spillovers are highest when the bilateral trade pattern is HIIT, followed by VIIT and OWT. Our estimation results basically confirm the predictions of the model. We find that an increase in the share of intra-industry trade in the bilateral trade has a positive effect on the number of patent citations between the two countries. HIIT has a larger effect than VIIT. On the other hand, the effects of OWT on the number of citations are much weaker than those of IIT. These findings for Japanese and European patents are generally consistent with that of Jinji et al. (2015) for the US patents.

The remainder of the chapter is organized in the following way. Section 5.2 sets up a closed-economy model of monopolistic competition with quality differentiation. Section 5.3 extends the model to the case of two-country trade and derives testable implications from the theoretical model. Section 5.4 conducts an empirical analysis. Section 5.5 concludes this chapter.

5.2 The Basic Model

In this section, we describe the basic structure of the model in a closed economy. Consider country d that has two sectors: a homogenous numeraire sector and a differentiated manufacturing sector.⁵ We introduce quality differentiation in a quasi-linear (instantaneous) utility with a quadratic subutility, developed by Ottaviano et al. (2002) and Melitz and Ottaviano (2008).⁶ There are L^d consumers, which is constant over time. Preferences are identical across consumers and defined over a continuum of differentiated varieties indexed by $i \in \Omega^d$, where Ω^d is a set of varieties available in the market, and a homogeneous numeraire good. The infinitely lived representative consumer maximizes an additively separable intertemporal utility:

$$U = \int_0^\infty u(t) e^{-\rho t} dt, \quad (5.1)$$

where ρ is the common subjective discount rate and $u(t)$ is the instantaneous utility given by

$$u(t) = q_{0t} + \int_{i \in \Omega_t^d} \alpha_{it} q_{it} di - \frac{1}{2} \gamma \int_{i \in \Omega_t^d} (q_{it})^2 di - \frac{1}{2} \eta \left(\int_{i \in \Omega_t^d} q_{it} di \right)^2, \quad (5.2)$$

where q_{0t} and q_{it} are the individual consumption levels of the numeraire and variety i , and $\alpha_{it} > 0$ measures the product quality of variety i at time t .⁷ The parameter $\gamma > 0$ measures the degree of horizontal differentiation, and the parameter $\eta > 0$ captures the degree of substitution between the differentiated varieties and the numeraire.

We assume that consumers have positive demands for the numeraire. The inverse demand for variety i is then given by

$$p_{it}^d = \alpha_{it} - \gamma q_{it} - \eta Q_t, \quad (5.3)$$

where p_{it}^d is the price of variety i , and $Q_t = \int_{i \in \Omega_t^d} q_{it} di$ is the total consumption level over all varieties. Let $\Omega_t^{d*} \subset \Omega_t^d$ be the subset of varieties that are actually consumed. From Eq. (5.3), the market demand for variety $i \in \Omega_t^{d*}$ is

⁵ In this section, we develop a simple two-sector model. The analysis can be easily extended to a model with many differentiated manufacturing sectors, similar to that in Eckel and Neary (2010). However, such an extension will not qualitatively change the main results.

⁶ The formulation proposed by Antoniadis (2015) is different from ours. In his model, more productive firms choose higher qualities and charge higher prices. Another approach is to use a quality-augmented Dixit–Stiglitz demand specification (Dixit and Stiglitz 1977) in the framework of Melitz (2003), which assumes that higher quality is associated with higher marginal cost (Baldwin and Harrigan 2011; Johnson 2012; Kugler and Verhoogen 2012).

⁷ Häckner (2000) provides this treatment of product quality in a discrete version of quadratic utility.

$$q_{it}^d \equiv L^d q_{it} = \frac{L^d}{\gamma} \alpha_{it} - \frac{\eta L^d N_t^d}{\gamma(\eta N_t^d + \gamma)} \bar{\alpha}_t^d - \frac{L^d}{\gamma} p_{it}^d + \frac{\eta L^d N_t^d}{\gamma(\eta N_t^d + \gamma)} \bar{p}_t^d, \quad (5.4)$$

where N_t^d is the measure of consumed varieties in Ω_t^{d*} , and $\bar{\alpha}_t^d = (1/N_t^d) \int_{i \in \Omega_t^{d*}} \alpha_{it} di$ and $\bar{p}_t^d = (1/N_t^d) \int_{i \in \Omega_t^{d*}} p_{it}^d di$ are their average quality and price.

In both sectors, labor, which is inelastically supplied in the competitive labor market, is the only production factor. One unit of labor is required to produce one unit of the numeraire, yielding that the wage rate w is equal to one.

In the differentiated manufacturing sector, each firm produces a different variety. Every product variety has generations (or versions) depending on the date of development. For simplicity, we assume that each product generation loses its consumption value after one period. Thus, each firm must engage in product R&D to develop a new generation of variety in every period. While the cost of product R&D, f (measured in units of labor), is identical for all manufacturing firms, the outcome of product R&D, α_{it} , is stochastic.⁸ Since R&D in practice has an uncertain outcome, it is quite natural to model R&D as a stochastic process. Let α_{Mt}^d be the maximum possible product quality with the current technology. For firm i the degree of successfulness of R&D, a_{it} , is randomly given from a time-invariant common (and known) probability density function $g(a)$ with support on $[\underline{a}, 1]$, where $\underline{a} \in (0, 1)$. Assume that $g'(a) < 0$. Then, firm i 's product quality is given by $\alpha_{it} = a_{it} \alpha_{Mt}^d$. This implies that the product R&D can be equivalently expressed as a random draw from a cumulative distribution function $G_t^d(\alpha)$ with support on $[\underline{\alpha}_t^d, \alpha_{Mt}^d]$, where $\underline{\alpha}_t^d = \underline{a} \alpha_{Mt}^d$. As is explained below, $G_t^d(\alpha)$ shifts as time passes. Let us normalize $\alpha_{M0}^d = 1$.

In the manufacturing sector, firms compete in a three-stage game. In stage one, all potential entrants decide whether to engage in product R&D. In stage two, the firms that chose to conduct R&D observe the outcome of the R&D and then decide whether to stay in the market. In stage three, the firms that chose to stay in the market select prices to maximize their own profits.

A variety of the manufactured goods is produced under the constant returns to scale technology at unit labor requirement c . Given $w = 1$, c is the (constant) marginal cost. Since the R&D costs are sunk costs, firms able to cover their marginal production costs survive and supply goods to the market. Surviving firms maximize their profits in each period by taking the average quality level $\bar{\alpha}^d$, the average price level $\bar{p}^d$ and the number of firms N^d in that period as given. Hereafter, we omit the time index unless it is necessary. Given the market demand for variety i (Eq. (5.4)), it is easily seen that the price elasticity of demand, $\varepsilon_i \equiv -(\partial q_i^d / \partial p_i^d)(p_i^d / q_i^d)$, does not tend to infinity as N^d goes to infinity. Thus, the manufacturing sector is characterized by monopolistic competition. Let $p_{\max}^d(\alpha)$ be the price at which demand for a variety with quality α is driven to 0. Equation (5.4) yields

⁸ The cost of product R&D serves as a fixed entry cost. Since firms pay a fixed entry cost and are randomly given their productivity parameter in Melitz (2003) and Melitz and Ottaviano (2008), they engage in stochastic *process* R&D. In our model, however, firms engage in stochastic *product* R&D.

$$p_{\max}^d(\alpha) \equiv \alpha - \frac{\eta N^d}{\eta N^d + \gamma}(\bar{\alpha}^d - \bar{p}^d). \quad (5.5)$$

Then, any $i \in \Omega^{d*}$ satisfies $p_i^d \leq p_{\max}^d(\alpha_i)$. Given Eq. (5.4), firm i 's gross profit from domestic sales is $\pi_i^d = p_i^d q_i^d - c q_i^d$. From the first-order condition for profit maximization, we obtain

$$q_D^d(\alpha) = \frac{L^d}{\gamma} [p_D^d(\alpha) - c], \quad (5.6)$$

where $q_D^d(\alpha)$ and $p_D^d(\alpha)$ are profit-maximizing output and price for domestic sales of the product with quality α and the subscript D indicates variables for domestic sales. Let α_D^d be the quality level for the firm that earns zero profit from domestic sales due to $p_D^d(\alpha_D^d) = p_{\max}^d(\alpha_D^d) = c$. Equation (5.5) yields

$$\alpha_D^d = \frac{\eta N^d}{\eta N^d + \gamma}(\bar{\alpha}^d - \bar{p}^d) + c. \quad (5.7)$$

Then, substitute Eq. (5.4) into Eq. (5.6) and use Eq. (5.7) to obtain

$$p^d(\alpha) = \frac{\alpha - \alpha_D^d}{2} + c.$$

This implies that firms with positive demands charge prices above the marginal cost and the prices increase with product quality. The average price $\bar{p}^d$ is given by

$$\bar{p}^d = \frac{\bar{\alpha}^d - \alpha_D^d}{2} + c. \quad (5.8)$$

Equations (5.7) and (5.8) yield the mass of surviving firms:

$$N^d = \frac{2\gamma(\alpha_D^d - c)}{\eta(\bar{\alpha}^d - \alpha_D^d)}. \quad (5.9)$$

Note that the average product quality of the surviving firms, $\bar{\alpha}^d$, is expressed as $\bar{\alpha}^d = [\int_{\alpha_D^d}^{\alpha_M^d} \alpha dG_t^d(\alpha)]/[1 - G_t^d(\alpha_D^d)]$ and the mass of entrants in country d is given by $N_E^d = N^d/[1 - G_t^d(\alpha_D^d)]$.

We assume the following condition:

Assumption 5.1 $0 < d\bar{\alpha}^d/d\alpha_D^d < 1$.

This condition means that an increase in the cut-off quality increases the average quality of products supplied in the market, but the extent of the increase in the average quality of the products is smaller than that of the increase in α_D^d . This condition restricts the shape of the distribution $G_t^d(\alpha)$.

Let $\mu_D^d(\alpha) = p_D^d(\alpha) - c$ and $\pi_D^d(\alpha) = p_D^d(\alpha)q_D^d(\alpha) - q_D^d(\alpha)c$ be the absolute mark-up and the profit of a firm that produces a product with quality α , respectively. It holds that

$$\mu_D^d(\alpha) = \frac{\alpha - \alpha_D^d}{2} \quad \text{and} \quad \pi_D^d(\alpha) = \frac{L^d}{4\gamma}(\alpha - \alpha_D^d)^2. \quad (5.10)$$

Since the expected profit prior to entry at time t is given by $\int_{\alpha_D^d}^{\alpha_M^d} \pi_D^d(\alpha) dG_t^d(\alpha) - f$ from Eq. (5.10), the free-entry equilibrium condition is given by

$$\int_{\alpha_D^d}^{\alpha_M^d} \pi_D^d(\alpha) dG_t^d(\alpha) = \frac{L^d}{4\gamma} \int_{\alpha_D^d}^{\alpha_M^d} (\alpha - \alpha_D^d)^2 dG_t^d(\alpha) = f. \quad (5.11)$$

From Eqs. (5.9) and (5.11), we obtain

Lemma 5.1 (i) Given $G_t^d(\alpha)$, α_D^d and $\bar{\alpha}^d$ are both decreasing in f (R&D cost) and γ (the degree of horizontal differentiation) and increasing in L^d (the market size).
(ii) Under Assumption 5.1, for a given $G_t^d(\alpha)$, a higher α_D^d results in a higher N^d (more varieties) and a higher N_E^d (more entrants).

Proof Part (i) is directly obtained from Eq. (5.11). For part (ii), differentiate Eq. (5.9) with respect to α_D^d to yield

$$\frac{dN^d}{d\alpha_D^d} = \frac{2\gamma}{\eta(\bar{\alpha}^d - \alpha_D^d)} - \frac{2\gamma(\alpha_D^d - c)}{\eta(\bar{\alpha}^d - \alpha_D^d)^2} \frac{d(\bar{\alpha}^d - \alpha_D^d)}{d\alpha_D^d} > 0.$$

Assumption 5.1 ensures that the right-hand side of the above equation is positive. Then, since $N_E^d = N^d / [1 - G_t^d(\alpha_D^d)]$, a higher α_D^d and a higher N^d result in a higher N_E^d . *Q.E.D.*

We consider a shift of the distribution $G^d(\alpha)$ to the right with keeping its shape.

Lemma 5.2 An upward shift of $G^d(\alpha)$ leaves $\mu_D^d(\alpha)$ and $\pi_D^d(\alpha)$ unchanged, but increases N^d and N_E^d .

Proof Let $G^{d0}(\alpha^0)$ and $G^{d1}(\alpha^1)$ be the distributions before and after the change, respectively. Let α_M^{d0} and α_M^{d1} be the upper bounds of $G^{d0}(\alpha^0)$ and $G^{d1}(\alpha^1)$, and set $\alpha_M^{d1} = \alpha_M^{d0} + k$ with $k > 0$. Then, since $\alpha^1 = \alpha^0 + k$ holds for any α^0 and α^1 that take the same relative position in each distribution, Eq. (5.11) for $G^{d0}(\alpha^0)$ can be transformed to that of $G^{d1}(\alpha^1)$. Thus, Eq. (5.10) is unchanged. However, since $\bar{\alpha}^d - \alpha_D^d$ is unchanged and $\alpha_D^{d1} = \alpha_D^{d0} + k$, Eq. (5.9) yields a higher N^d and hence a higher N_E^d . *Q.E.D.*

This lemma implies that as long as all firms have equal access to general knowledge, technology improvement, in the sense of an upward shift of $G^d(\alpha)$, increases the absolute levels of product quality for all varieties, but the relative positions of the

firms in the industry remain unchanged. Besides, Lemma 5.2 implies that there are more varieties in an economy with advanced technology than in an economy with less advanced technology.

5.3 Trade Between Two Countries

5.3.1 A Two-Country Setting

Now, we consider two countries, Home (H) and Foreign (F), with L^d consumers in country d ($= H, F$). Consumers in both countries share the same preferences given by Eqs. (5.1) and (5.2). We assume that the markets in the two countries are segmented, while firms can produce in one location and supply their products to the market in the other country by incurring a per-unit trade cost.

Manufacturing firms in the two countries have the same marginal cost c and draw product quality α^d from their domestic distributions $G_t^d(\alpha)$ with support on $[\underline{\alpha}_t^d, \alpha_{Mt}^d]$.

Following Melitz and Ottaviano (2008), we assume that firms in country s ($\neq d$, $s = H, F$) must incur the unit cost of $\tau^d c$ with $\tau^d > 1$ to deliver one unit of their products to the market in country d . We also assume that the homogeneous numeraire good is always produced in each country after opening up to trade, such that the wage rate is equal to one in both countries.

The price threshold for positive demand in market d is given by Eq. (5.5), but N^d denotes the mass of firms selling in country d , which includes both domestic firms in country d and exporters from country s , and $\bar{\alpha}^d$ and $\bar{p}^d$ are average quality and average price of both local and exporting firms in country d . Let N_D^d and N_X^d denote the masses of firms producing in country d that supply products to the domestic market and the other country's market, respectively. Then, $N^d = N_D^d + N_X^d$ holds.

Firms maximize their profits earned from local and export sales independently (due to the assumptions of segmented markets and constant returns to scale technology). The quality level for a firm producing in country d that earns zero profits from local sales, α_D^d , is still given by Eq. (5.7). Similarly, let α_X^d be the quality level for the firm producing in country d that earns zero profits from export sales. From $p(\alpha_X^d) = p_{\max}^s(\alpha_D^d) = \tau^s c$, we obtain

$$\alpha_X^d = \frac{\eta N^s}{\eta N^s + \gamma} (\bar{\alpha}^s - \bar{p}^s) + \tau^s c. \quad (5.12)$$

From Eqs. (5.7) and (5.12), it holds that

$$\alpha_X^s = \alpha_D^d + (\tau^d - 1)c. \quad (5.13)$$

Let $\pi_X^d(\alpha) = [p_X^d(\alpha) - \tau^s c]q_X^d(\alpha)$ be the maximized value of profits for a firm with quality α producing in country d from export sales, where $p_X^d(\alpha)$ is the profit-maximizing price for export sales and $q_X^d(\alpha)$ is the corresponding quantity. From the first-order condition, it holds that $q_X^d(\alpha) = (L^s/\gamma)[p_X^d(\alpha) - \tau^s c]$. Then, the optimal price and output for export sales are respectively given by

$$p_X^d(\alpha) = \frac{\alpha - \alpha_X^d}{2} + \tau^s c, \quad q_X^d(\alpha) = \frac{L^s(\alpha - \alpha_X^d)}{2\gamma}.$$

The maximized profits from export sales are given by

$$\pi_X^d(\alpha) = \frac{L^s}{4\gamma}(\alpha - \alpha_X^d)^2. \quad (5.14)$$

Note that the maximized profits from domestic sales, $\pi_D^d(\alpha)$, are still given by Eq. (5.10).

In the case of the open economy, the free-entry equilibrium condition in country d at t is given by

$$\int_{\alpha_{Dt}^d}^{\alpha_{Mt}^d} \pi_D^d(\alpha) dG_t^d(\alpha) + \int_{\alpha_{Xt}^d}^{\alpha_{Mt}^d} \pi_X^d(\alpha) dG_t^d(\alpha) = f.$$

Substitute Eqs. (5.10), (5.13), and (5.14) into this to yield the two free-entry equilibrium conditions for countries H and F:

$$\begin{aligned} & L^H \int_{\alpha_{Dt}^H}^{\alpha_{Mt}^H} (\alpha - \alpha_{Dt}^H)^2 dG_t^H(\alpha) \\ & + L^F \int_{\alpha_{Dt}^F + (\tau^F - 1)c}^{\alpha_{Mt}^H} [\alpha - \alpha_{Dt}^F - (\tau^F - 1)c]^2 dG_t^H(\alpha) = 4\gamma f, \end{aligned} \quad (5.15)$$

$$\begin{aligned} & L^F \int_{\alpha_{Dt}^F}^{\alpha_{Mt}^F} (\alpha - \alpha_{Dt}^F)^2 dG_t^F(\alpha) \\ & + L^H \int_{\alpha_{Dt}^H + (\tau^H - 1)c}^{\alpha_{Mt}^F} [\alpha - \alpha_{Dt}^H - (\tau^H - 1)c]^2 dG_t^F(\alpha) = 4\gamma f, \end{aligned} \quad (5.16)$$

which jointly determine the cut-off qualities for domestic sales in countries H and F at time t , α_{Dt}^H and α_{Dt}^F . We then assume the following:

Assumption 5.2 $\int_{\alpha_{Dt}^d}^{\alpha_{Mt}^d} \pi_D^d(\alpha) dG_t^d(\alpha) + \int_{\alpha_{Xt}^d}^{\alpha_{Mt}^d} \pi_X^d(\alpha) dG_t^d(\alpha) > f$.

Assumption 5.2 ensures that the range of possible product qualities is wide enough to yield the interior cut-off for country d , that is, $\alpha_{Dt}^d > \underline{\alpha}_t^d$, even in the latter case. This assumption implies that there are always some firms that exit the market in country d even if no firm enters the market in country s .

The mass of firms selling in country d at time t is still determined by Eq. (5.9), but $\bar{\alpha}_t^d$ is now given by

$$\bar{\alpha}_t^d = \frac{\int_{\alpha_{Dt}^d}^{\alpha_{Mt}^d} \alpha \, dG_t^d(\alpha) + \int_{\alpha_{Dt}^d + (\tau^d - 1)c}^{\alpha_{Mt}^d} \alpha \, dG_t^s(\alpha)}{2 - G_t^d(\alpha_{Dt}^d) - G_t^s(\alpha_{Dt}^d + (\tau^d - 1)c)}, \quad d \neq s.$$

The mass of entrants producing in country d at time t , N_{Et}^d , is now determined by

$$\begin{aligned} [1 - G_t^H(\alpha_{Dt}^H)]N_{Et}^H + [1 - G_t^F(\alpha_{Xt}^F)]N_{Et}^F &= N_t^H, \\ [1 - G_t^F(\alpha_{Dt}^F)]N_{Et}^F + [1 - G_t^H(\alpha_{Xt}^H)]N_{Et}^H &= N_t^F, \end{aligned}$$

where $[1 - G_t^d(\alpha_{Dt}^d)]N_{Et}^d = N_{Dt}^d$ and $[1 - G_t^d(\alpha_{Xt}^d)]N_{Et}^d = N_{Xt}^d$, for $d = H, F$. The free-entry equilibrium conditions (5.15) and (5.16) hold so long as there is a positive mass of entrants $N_{Et}^s > 0$ in country s at time t . Otherwise, $N_{Et}^s = 0$ and country s specializes in the production of the numeraire good.

5.3.2 Technology Spillovers

In the manufacturing sector, an individual firm's technological knowledge spills over to other firms irrespective of whether or not its spillovers are deliberate. In the spirit of Romer (1990) and Grossman and Helpman (1990, 1991), we assume that technological knowledge has a public-good nature. That is, each individual firm's R&D output contributes to "knowledge" in the country, and all firms in the same country have equal access to the general knowledge of the country without any added cost. We capture technology spillovers by the expansion of the technology frontier, α_{Mt} . More specifically, we assume that α_{Mt}^d changes in the following way:

$$\dot{\alpha}_{Mt}^d = \lambda K_t^d \alpha_{Mt}^d, \quad d = H, F, \quad (5.17)$$

where $\lambda > 0$ and K_t^d is the knowledge flow at time t . Assuming that the knowledge flow is proportional to the number of varieties supplied in the country and knowledge spillover is perfect within a country but imperfect across countries, we have

$$K_t^d = N_{Dt}^d + \phi^d(\alpha_{Mt}^d, \alpha_{Mt}^s)N_{Xt}^s, \quad d, s = H, F, \quad s \neq d, \quad (5.18)$$

where

$$\phi^d(\alpha_{Mt}^d, \alpha_{Mt}^s) \begin{cases} = 1, & \text{if } \alpha_{Mt}^d = \alpha_{Mt}^s, \\ \in (0, 1), & \text{otherwise,} \end{cases} \quad (5.19)$$

which controls the degree of international knowledge spillovers, depending on the technology gap between the two countries. We assume $\partial\phi^d/\partial\alpha_{Mt}^d > 0$ for $\alpha_{Mt}^d < \alpha_{Mt}^s$.

In Eq. (5.18), our primary interest is in technology spillovers from countries s to d at time t , S_{dst} :

$$S_{dst} = \phi^d(\alpha_{Mt}^d, \alpha_{Mt}^s)N_{Xt}^s. \quad (5.20)$$

We assume that technology spillovers are proportional to the number of varieties actually imported. However, the degree of technology spillovers is reduced unless the two countries share the same technology level: when country d is more technologically advanced than country s , knowledge spillovers from s to d are reduced because a technologically advanced country benefits less from an inferior technology, and when country d is technologically less advanced than country s , knowledge spillovers from s to d may also be reduced as a technologically less advanced country has a lower capacity to absorb knowledge.

5.3.3 Trade Patterns and Technology Spillovers

We now investigate the relationship between trade patterns and international technology spillovers. First consider a case in which two countries share the same technology at a given time t , that is, $\alpha_{Mt}^H = \alpha_{Mt}^F$. If the size of the market and the trade barriers are symmetric (i.e., $L^H = L^F$ and $\tau^H = \tau^F$), then the countries have the same average quality and the same average price of export goods. Then the two countries have an HIIT trade pattern. As a result, technology spillovers occur in both directions in the same degree (i.e., $S_{Hft} = S_{Fht}$) because $\phi^H = \phi^L = 1$ and $N_{Xt}^H = N_{Xt}^F$.

We next consider cases in which there is a technology gap between the two countries. Without loss of generality, we assume that the home country is technologically superior to the foreign country at a given time. We continue to assume that $L^H = L^F$.

It is useful to consider both a symmetric case, $\alpha_{Mt}^H = \alpha_{Mt}^F$, and an asymmetric case, $\alpha_{Mt}^H > \alpha_{Mt}^F$. Let us label the symmetric case as “case 0” and the asymmetric case as “case 1”. Assume that $\alpha_{Mt}^{H0} = \alpha_{Mt}^{H1} = \alpha_{Mt}^{F0} > \alpha_{Mt}^{F1}$ holds, where the numerical superscript (0 or 1) indicates the symmetric or asymmetric case. It follows from this assumption that $G_t^{H0}(\alpha) = G_t^{H1}(\alpha) = G_t^{F0}(\alpha)$ holds for all α , and $G_t^{F0}(\alpha)$ first-order stochastically dominates $G_t^{F1}(\alpha)$, i.e., $G_t^{F1}(\alpha) \geq G_t^{F0}(\alpha)$ for any α . Then, from Lemmas 5.1 (ii) and 5.2, both $\alpha_{Dt}^{d0} > \alpha_{Dt}^{d1}$ and $N_t^{d0} > N_t^{d1}$ hold, and then $N_{Et}^{d0} > N_{Et}^{d1}$ holds ($d = H, F$). Moreover, from Eq. (5.13), $\alpha_{Dt}^{d0} > \alpha_{Dt}^{d1}$ implies $\alpha_{Xt}^{d0} > \alpha_{Xt}^{d1}$, and hence $N_{Xt}^{d0} > N_{Xt}^{d1}$ holds for the free-entry equilibrium conditions.

In case 0, due to transport costs, competition must be more intensive in the home market than in the foreign market unless τ^F is sufficiently higher than τ^H , so that both $\alpha_{Dt}^{H1} > \alpha_{Dt}^{F1}$ and $\alpha_{Xt}^{H1} < \alpha_{Xt}^{F1}$ hold.⁹ The average quality and price of goods exported from country d are given by

⁹ Note that if $\tau^H = \tau^F = 1$, then the cut-off quality has to be identical in the two markets.

$$\bar{\alpha}_{X_t}^d = \frac{\int_{\alpha_{X_t}^d}^{\alpha_{M_t}^d} \alpha \, dG_t^d(\alpha)}{1 - G_t^d(\alpha_{X_t}^d)}, \quad \text{and} \quad \bar{p}_{X_t}^d = \frac{\bar{\alpha}_{X_t}^d - \alpha_{X_t}^d}{2} + \tau^s c.$$

In case 1, $\alpha_{M_t}^{H1} > \alpha_{M_t}^{F1}$ holds, and this difference is larger than that between $\alpha_{X_t}^{F1}$ and $\alpha_{X_t}^{H1}$ unless the transport costs are highly asymmetric. Consequently, $\bar{\alpha}_{X_t}^{H1} > \bar{\alpha}_{X_t}^{F1}$ and $\bar{p}_{X_t}^{H1} > \bar{p}_{X_t}^{F1}$ hold. On average, the home country exports varieties with a higher quality at a higher price.

Recall that the size of technology spillovers from countries s to d is measured by Eq. (5.20), which consists of the degree of technology spillovers, ϕ^d , and the mass of varieties actually imported, $N_{X_t}^s$. As for technology spillovers under VIIT, ϕ^H and ϕ^F are both smaller in case 1 than in case 0, and $N_{X_t}^H$ and $N_{X_t}^F$ are both smaller in case 1 than in case 0. In other words, when countries engage in VIIT, both the degree of technology spillovers and the mass of varieties actually imported are smaller in either direction, compared to the case of HIIT. Therefore, we obtain

Result 5.1 The size of technology spillovers is lower in either direction when the trade pattern is VIIT than when it is HIIT.

This result implies that two countries with similar levels of technologies benefit more from technology spillovers than those with different levels of technologies.

In which direction is the size of technology spillovers larger when countries engage in VIIT? Since $\alpha_{D_t}^{H1} > \alpha_{D_t}^{F1}$ and $\bar{\alpha}_{X_t}^{H1} > \bar{\alpha}_{X_t}^{F1}$, it yields $N_{X_t}^{H1} > N_{X_t}^{F1}$. However, this does not necessarily imply that the size of technology spillovers from countries H to F is larger than in the opposite direction. The reason is that $\phi^H > \phi^F$ may hold and may cause $S_{HF} > S_{FH}$ to hold. Thus, we obtain

Result 5.2 When the trade pattern is VIIT, the relative size of technology spillovers from the home country to the foreign country and those in the opposite direction is ambiguous.

The intuition is the following: the country exporting varieties with higher average quality exports more varieties than the other exporting country. However, the country importing varieties with higher average quality may not necessarily benefit more from technology spillovers because its absorptive capacity of technology is lower and a difference in the absorptive capacity may dominate the effect of a larger mass of varieties in imports.

We next consider a case where the technology gap between the two countries is widened further, such that either (i) $\alpha_{M_t}^F < \alpha_{X_t}^F$ holds or (ii) the free-entry equilibrium condition in country F (Eq. (5.16)) becomes

$$\begin{aligned} & L^F \int_{\alpha_{D_t}^F}^{\alpha_{M_t}^F} (\alpha - \alpha_{D_t}^F)^2 \, dG_t^F(\alpha) \\ & + L^H \int_{\alpha_{D_t}^H + (\tau^H - 1)c}^{\alpha_{M_t}^H} [\alpha - \alpha_{D_t}^H - (\tau^H - 1)c]^2 \, dG_t^F(\alpha) < 4\gamma f. \end{aligned}$$

In the former case, some foreign firms may still enter the manufacturing sector but no foreign firms can export goods to country H. In the latter case, $N_{Et}^F = 0$ holds and country F is specialized in the numeraire. In either case, the trade pattern is characterized by pure OWT. Technology spillovers still occur from countries H to F but no spillovers occur in the opposite direction. As is evident from the above discussion of the VIIT trade pattern, a widened technology gap causes α_{Dt}^H and α_{Dt}^F to be smaller under OWT than under VIIT. Then, α_{Xt}^H is also smaller when there is OWT than when there is VIIT, which implies that the mass of varieties exported from country H (i.e., N_{Xt}^H) is smaller when there is OWT. Moreover, since the gap between α_{Mt}^H and α_{Mt}^F is greater, ϕ^F becomes smaller.

Result 5.3 The size of technology spillovers is lower in the OWT case than in the VIIT case.

As will be argued in the next section, OWT does not necessarily mean that the trade pattern is *completely* inter-industry. In the empirical analysis, a small amount of intra-industry trade that is below some critical value is categorized into OWT. Thus, the direction of technology spillovers in the case of OWT is not necessarily one way.

One may presume that the technology gap between two countries rather than trade patterns is the primary factor determining international technology spillovers. This may not hold true because the technology gap itself does not induce technology spillovers if there is no trade between two countries.

From the theoretical investigation, we obtained three testable hypotheses (i.e., Results 5.1, 5.2, and 5.3) on the relationship between trade patterns and international technology spillovers. In the next section, we empirically test these three hypotheses.

5.4 Empirical Analysis

In the previous section, we have shown that technology spillovers across countries may be related to the patterns of bilateral trade. In this section, we empirically test the predictions of the theoretical model by using bilateral trade data and patent citation data.

5.4.1 Estimation Framework

We first explain the method of categorizing bilateral trade flows. In the previous studies, trade patterns are usually categorized into three types, namely, OWT, HIIT, and VIIT (e.g., Fontagné and Freudenberg 1997; Fukao et al. 2003; Greenaway et al. 1995). The standard method of categorization is given by Fontagné and Freudenberg (1997), which is based on the assumption that the gap between the unit values of imports and exports for each commodity reflects the qualitative differences of the

products exported and imported between two countries.¹⁰ We extend the standard method to take the direction of trade into account and categorize bilateral trade flows into five types.

Let X_{ijk} and M_{ijk} be the values of country i 's exports to and imports from country j of product k , respectively. Then, the trade pattern in industry k is *one-way trade with importing* (OWT_M) if

$$\frac{\min(X_{ijk}, M_{ijk})}{\max(X_{ijk}, M_{ijk})} \leq \theta \quad \text{and} \quad X_{ijk} < M_{ijk}$$

hold, where θ is set at some value, and *one-way trade with exporting* (OWT_X) if

$$\frac{\min(X_{ijk}, M_{ijk})}{\max(X_{ijk}, M_{ijk})} \leq \theta \quad \text{and} \quad X_{ijk} > M_{ijk}$$

hold. The trade pattern in industry k is *two-way trade* or *intra-industry trade* (IIT) if

$$\frac{\min(X_{ijk}, M_{ijk})}{\max(X_{ijk}, M_{ijk})} > \theta$$

holds. IIT is further divided into three types. Let UV_{ijk}^X and UV_{ijk}^M be unit values of country i 's exports to and imports from country j of product k , respectively. Then, the trade pattern in industry k is *horizontal intra-industry trade* (HIIT) if

$$1 - \xi \leq \frac{UV_{ijk}^X}{UV_{ijk}^M} \leq 1 + \xi$$

holds (This condition is the same as that in the standard method), where ξ is set at some value. The trade pattern in industry k is *vertical intra-industry trade with importing higher-quality products* (VIIT_M) if

$$\frac{UV_{ijk}^X}{UV_{ijk}^M} < 1 - \xi$$

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¹⁰ There is another method of categorizing trade patterns proposed by Greenaway et al. (1994, 1995), which is based on a decomposition of Grubel–Lloyd index. In their method, intra-industry trade in industry k is measured by

$$IIT_k = 1 - \frac{\sum_n |X_{kn}^z - M_{kn}^z|}{\sum_n (X_{kn}^z + M_{kn}^z)},$$

where n refers to products and z denotes HIIT or VIIT. In order to disentangle total IIT into HIIT and VIIT, they also use the ratio of unit values. Fontagné et al. (2006) investigate the difference between these two methods. They argue that, while the two methods diverge on the definition of IIT, they rely on the same assumption regarding the relationship between unit values and the quality of traded products.

holds, and *vertical intra-industry trade with exporting higher-quality products* ($VIIT_X$) if

$$\frac{UV_{ijk}^X}{UV_{ijk}^M} > 1 + \xi$$

holds. Now the share of each trade pattern is defined by

$$\frac{\sum_k (X_{ijk}^z + M_{ijk}^z)}{\sum_k (X_{ijk} + M_{ijk})},$$

where z denotes one of the five trade types, i.e., OWT_M , OWT_X , $HIIT$, $VIIT_M$, and $VIIT_X$. In the above conditions, the choice of θ and ξ is to a large extent arbitrary. Although Fontagné and Freudenberg (1997) and some other studies use $\xi = 0.15$, Fontagné et al. (2006) report the sensitivity of the relative importance of $HIIT$ to total intra-industry trade and argue that defining θ as 0.1 and ξ as 0.25 is quite reasonable. Fukao et al. (2003) also employ $\theta = 0.1$ and $\xi = 0.25$ and argue that a 25% threshold would be reasonable because of the possible effects of exchange rate fluctuations on the value recorded in trade statistics and noise in the measurements of unit values at a six-digit level of trade statistics. Then we use $\theta = 0.1$ and $\xi = 0.25$ in our analysis.

We use patent citations to measure technology spillovers. The use of patent citations in measuring technology spillovers has been pioneered by Jaffe et al. (1993), in which patent citations are used to measure the extent of technology spillovers within the United States. Every US patent applicant is required to disclose any knowledge of the “prior art” in his or her application. Hall et al. (2001) point out that the presumption for using patent citations as a proxy for learning technology is that the citations to the “prior art” are informative of the causal links between those patented innovations, because citations made may constitute a “paper trail” for diffusion, i.e., the fact that patent B cites patent A may be indicative of knowledge flowing from A to B. This logic is also practicable to the case of the patent citations between countries.

On the other hand, patent citations between two countries may be associated with the past records of patenting in both the cited and the citing countries. The number of patents filed by the citing country is related to the scale of human resource in this country, and reflects the indigenous capacity to absorb foreign technology. The number of patents in the cited country simultaneously implies a potential opportunity of citations for the citing country. Based on the reasoning above, our regression model is defined as follows:

$$\begin{aligned} \ln c_{ijt}^* &= \beta' x_{ijt} + \epsilon_{ijt} \\ &= \beta_1 \text{Share}_{ijt}(OWT_M, OWT_X, HIIT, VIIT_M, \text{ or } VIIT_X) \\ &\quad + \beta_2 \ln(P_{it} \times P_{jt}) + u_{ij} + e_{ijt}, \end{aligned}$$

where c_{ijt}^* is the number of patent citations made by patents filed by country i (the citing country) to country j (the cited country) in year t , x_{ijt} is a vector of independent variables, Share_{ijt} is bilateral OWT_M , OWT_X , $HIIT$, $VIIT_M$, or $VIIT_X$ share between

countries i and j in year t , P_{it} and P_{jt} are the number of patent applications filed by countries i and j , respectively, in year t .¹¹ Thus, we use c_{ijt}^* as a proxy for technology spillovers from countries j to i . The term $P_{it} \times P_{jt}$ is included to control the effects of the citing country's absorptive capacity of technology and the cited country's potential opportunity of citations.

Since some countries rarely cite patents applied by inventors of other countries, there are substantial zero values in c_{ijt}^* . We then use a random-effects panel Tobit model to deal with this issue. In that case, the dependent variable is now a latent variable, where

$$\ln c_{ijt} = \begin{cases} \ln c_{ijt}^*, & \text{if } c_{ijt}^* > 0, \\ 0, & \text{otherwise,} \end{cases}$$

and

$$\epsilon_{ijt} = u_{ij} + e_{ijt}, \quad u \sim NID(0, \sigma_u^2), \quad e \sim NID(0, \sigma_e^2), \quad \rho \equiv \frac{\sigma_u^2}{\sigma_u^2 + \sigma_e^2}.$$

In general, independence between the u and e is assumed. On the other hand, there is neither a convenient test nor an estimation method for the test of random versus fixed-effects of the Tobit model as well as for estimation of a conditional fixed-effects model.¹² In order to assess the robustness of the estimated results by the random-effects panel Tobit model, we try to use a fixed-effects negative binomial model proposed by Hausman et al. (1984) for our same sample.

5.4.2 Data

5.4.2.1 Trade Data

There are several kinds of datasets on empirical analysis of international trade such as International Trade Commodity Statistics (ITCS–SITC) released by the OECD, and Personal Computer Trade Analysis System (PC–TAS) published by the United Nations Statistical Division. As indicated by Gaulier and Zignago (2008), the empirical analysis suffers due to the two different figures for the same trade flow, because the import values are generally reported in CIF (cost, insurance, and freight) and export values in FOB (free on board). To reconcile the two figures, Gaulier and Zignago (2008) develop a procedure to estimate an average CIF rate and remove it from

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¹¹ The stochastic nature of product R&D assumed in our theoretical model is not directly reflected in our estimation framework. As we have shown in the previous sections, however, the average quality and the distribution of quality among actually supplied products in an industry are invariant for a given distribution $G_I(\alpha)$. Since we use the industry average to determine the bilateral trade patterns, our empirical framework is considered to be consistent with the theoretical model in the previous sections.

¹² Honoré (1992) has developed a semiparametric estimator for fixed-effects Tobit models.

the declarations of imports to provide FOB import values for bilateral trade flows drawn on United Nations COMTRADE data. Now we utilize this reconstructed trade dataset, called BACI. The BACI dataset covers more than 200 countries and 5,000 products from 1995.¹³ In this chapter we use the BACI data from 1995 to 2004.

5.4.2.2 Patent Citation Data

The data on patents and patent citations used in this chapter consist of two sources, i.e., European Patent Office (EPO) Worldwide Patent Statistical Database (PATSTAT) and the Institute of Intellectual Property (IIP) Dataset. We collect the patent statistics of EPO from the former, and those of the Japanese Patent Office (JPO) from the latter. The two datasets include the dates of patent applications, the International Patent Classification (IPC), the citation information, and the country names of both citing and cited patent applicants.

Unlike the patent applications in the United States Patent and Trademark Office (USPTO), the patent applicants in the JPO have no legal duty to list the patents that he/she cites on the front page of document, although some referenced information provided by the applicants lies scattered across the patent body text. The citations information on the front page is usually added by the examiners in the JPO as well as in the EPO (Hall et al. 2007). According to Goto and Motohashi (2007), since the 1990s about two thirds of JPO citations have been decided by the examiners.

Although the decision on which patents to cite ultimately depends on the patent examiner, implying that the inventors may have been unaware of the cited patents, the presumption that the citations are relevant as the indicator of technology links between the citing and the cited is widely recognized in many empirical studies, such as Jaffe et al. (1993), Jaffe and Trajtenberg (1996, 1999), and Hall et al. (2001) for US patents, and Maurseth and Verspagen (2002), and MacGarvie (2006) for European patents.

5.4.2.3 Sample Selection

We start to select our sample from the top 60 trading countries/economies in 2008, according to the quantity of their import and exports in the world. Because crude oil makes up most of the trade in some top trade countries/economies such as Saudi Arabia, Nigeria, Russia, and Venezuela, we exclude these countries from our sample. At the same time, we exclude countries such as Kazakhstan, Peru, and Vietnam, since they rarely made or received patent citations in the JPO or EPO. As a result, we obtain a sample that covers 44 countries/economies across advanced, emerging, and developing economies in the world. The list of sample countries/economies is presented in Table 5.1.

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¹³ See the CEPII website (www.cepii.fr) for the details of BACI dataset. The existing studies that use BACI dataset include Fontagné et al. (2005, 2006) and Olper and Raimondi (2009).

Table 5.1 Sample countries/economies

No.	Country/Economy	No.	Country/Economy
1	Germany	23	Australia
2	China	24	Norway
3	United States	25	Poland
4	Japan	26	Czech Republic
5	France	27	Ireland
6	Italy	28	Indonesia
7	Netherlands	29	Turkey
8	United Kingdom	30	Denmark
9	Belgium–Luxembourg	31	Hungary
10	Canada	32	Finland
11	Korea	33	South Africa
12	Singapore	34	Chile
13	Mexico	35	Slovak Republic
14	Spain	36	Argentina
15	Taiwan	37	Israel
16	Malaysia	38	Philippines
17	Sweden	39	Portugal
18	Switzerland	40	Ukraine
19	Brazil	41	Romania
20	Austria	42	Colombia
21	Thailand	43	New Zealand
22	India	44	Slovenia

The patent statistics used in this chapter are classified according to the IPC, which is based either on the intrinsic nature of the invention or on the function of the invention. Schmoch et al. (2003) provide a concordance between technical fields and industrial sectors. This concordance table refers to IPC for patents, and international classifications, namely the European Union's Classification of Economic Activities within the European Communities (NACE), the United Nations' International Standard Industrial Classification (ISIC), and the US Standard Industrial Classification (SIC) with 44 industrial sectors. The empirical analyses in Schmoch et al. (2003) show that this concordance with 44 industrial sectors (or technical fields) has a reasonable level of disaggregation, because the economic data on international comparisons are not available in the finer differentiation. Thus, we use their concordance table to allocate the patent statistics into 44 industrial sectors, as shown in Table 5.2. Since the number of citations is very limited in some sectors, especially for products in some light manufacturing sectors such as textiles, wearing, and paint, we focus our analysis on five fields, i.e., non-metal products, metal products, machinery, ICT related equipment, and motor vehicles. The five fields correspond with Sectors 17 and 18, Sector 20, Sectors 21–25, Sectors 28 and 34–38, and Sector 42 in Schmoch et al. (2003).

Table 5.2 Correspondence between technical fields and ISIC industrial classifications

Field No.	Sector	ISIC ver. 3
1	Food	15
2	Tobacco	16
3	Textiles	17
4	Wearing	18
5	Leather	19
6	Wood products	20
7	Paper	21
8	Publishing	22
9	Petroleum	23
10	Basic chemicals	241
11	Pesticides	2421
12	Paint	2422
13	Pharmaceuticals	2423
14	Soaps	2424
15	Other chemicals	2429
16	Man-made fibers	243
17	Plastic products	25
18	Mineral products	26
19	Basic metals	27
20	Metal products	28
21	Energy machinery	2911, 2912, 2913
22	Non-specific machinery	2914, 2915, 2919
23	Agricultural machinery	2921
24	Machine-tools	2922
25	Special machinery	2923, 2924, 2925, 2926, 2929
26	Weapons	2927
27	Domestic appliances	293
28	Computers	30
29	Electrical motors	311
30	Electrical distribution	312, 313
31	Accumulators	314
32	Lightening	314
33	Other electrical	315
34	Electronic components	321
35	Telecommunications	322
36	Television	323
37	Medical equipment	3311
38	Measuring instruments	3312
39	Industrial control	3313
40	Optics	332
41	Watches	333
42	Motor vehicles	34
43	Other transport	35
44	Consumer goods	36

Source: Tables 3–1 and 3–5 in Schmoch et al. (2003)

Table 5.3 Descriptive statistics

Variable	No. of Obs.	Mean	Std. Dev.	Min	Max
<i>HIIT</i>	46764	0.05	0.10	0.00	1.00
<i>VIIT</i>	46764	0.17	0.19	0.00	1.00
<i>OWT</i>	46764	0.28	0.24	0.00	1.00
JPO citations	47300	14.5	419.0	0	39332
P_i in JPO	47300	2382.7	19395.3	0	279823
P_j in JPO	47300	1527.8	11114.7	0	233511
EPO citations	47300	0.9	18.3	0	1614
P_i in EPO	47300	275.1	1273.5	0	16533
P_j in EPO	47300	275.1	1273.5	0	16533

In order to match the data on trade with patents, we map the six-digit Harmonized System (HS6) and the ISIC rev. 3 according to the industrial concordance table provided by Jon Haveman.¹⁴ Then, we use the method explained above to measure the shares of OWT, HIIT, and VIIT for our sample countries in the five fields discussed above for the periods of 1995–1996, 1997–1998, 1999–2000, 2001–2002, and 2003–2004 (i.e., five periods). The descriptive statistics for the shares of OWT, HIIT, and VIIT, and the number of citations are presented in Table 5.3. On one hand, there are substantial citations between some developed countries, especially between the United States and Japan. For instance, the US patents that belonged to Sector 28 made more than 56,300 citations to Japanese patents during the period of 2003 and 2004. On the other hand, of about four fifths of observations citations are not identified in our sample period.

Table 5.4 describes the shares of OWT, HIIT, and VIIT for some selected sample countries averagely across five fields and five periods. From the table, we find that remarkable bilateral IIT (HIIT+VIIT) intensities are observed among European countries. More than 91% of trade is IIT for the trade between Germany and France, 79% for France and Belgium–Luxembourg, and 92% for Netherlands and Belgium–Luxembourg. These figures largely coincide with those reported by Fontagné et al. (2006) for the same country-pairs (86.2%, 80.4%, and 85.0%, respectively), based on trade statistics for the year 2000.

Table 5.5 presents how patent citations have been made by the patents of some selected countries filed to the USPTO, JPO, and EPO, respectively. Although the scale of citations is different across the patent offices, the patterns of citations between the selected countries are similar across the patent offices. For example, the United States, Japan, and Germany are the largest targets of citations not only for other countries, but also for each other, while citations are to date relatively less received as well as made by Chinese patents.

¹⁴ See www.maclester.edu/research/economics/page/haveman/trade/resources/tradedata.html.

Table 5.4 Shares of OWT, HIIT, and VIIT for selected countries

	China	US	Japan	France	Italy	Netherlands	UK	Belgium	Canada	Korea
Germany	0.63	0.25	0.36	0.08	0.19	0.11	0.12	0.16	0.52	0.58
	0.03	0.20	0.21	0.51	0.31	0.48	0.37	0.40	0.09	0.05
	0.25	0.54	0.42	0.41	0.50	0.40	0.51	0.43	0.29	0.29
China		0.63	0.50	0.59	0.53	0.64	0.63	0.50	0.63	0.42
		0.04	0.07	0.04	0.04	0.02	0.03	0.02	0.01	0.12
		0.30	0.39	0.23	0.34	0.19	0.25	0.18	0.16	0.37
US			0.48	0.28	0.41	0.36	0.21	0.44	0.08	0.58
			0.12	0.19	0.08	0.09	0.24	0.12	0.28	0.06
			0.40	0.52	0.51	0.52	0.53	0.41	0.28	0.35
Japan				0.51	0.48	0.57	0.44	0.59	0.67	0.42
				0.15	0.10	0.04	0.13	0.02	0.04	0.06
				0.28	0.33	0.30	0.40	0.22	0.12	0.50
France					0.19	0.20	0.08	0.11	0.34	0.51
					0.37	0.28	0.45	0.42	0.10	0.06
					0.43	0.51	0.47	0.47	0.42	0.26
Italy						0.29	0.26	0.32	0.50	0.53
						0.13	0.26	0.28	0.05	0.07
						0.55	0.47	0.39	0.28	0.21
Netherlands							0.14	0.07	0.37	0.46
							0.25	0.42	0.07	0.03
							0.60	0.50	0.38	0.18
UK								0.20	0.32	0.58
								0.26	0.11	0.03
								0.53	0.51	0.28
Belgium									0.45	0.35
									0.03	0.06
									0.22	0.23
Canada										0.57
										0.02
										0.15

Notes: (a) The upper, middle and lower figures are for OWT, HIIT and VIIT, respectively. (b) The sum of OWT, HIIT and VIIT could be less than 1.0 due to unavailability for the unit value in some cases. (c) Luxembourg is included in Belgium. Source: Authors’ calculation from the BACI data

5.4.3 Estimation Results

Table 5.6 summarizes the results for full fields, estimated based on the patent citations in the JPO and EPO, respectively. We added dummy variables to control for the fields and time periods, and, as we expected, the coefficient estimates of the number of patents held by citing and cited countries are positively significant. To assess the robustness of the estimated results in Table 5.6 at the same time, we also apply an alternative regression technique, namely, a fixed-effects negative binomial model proposed by Hausman et al. (1984), to the same sample. Table 5.7 summarizes the

Table 5.5 Patent citations for selected countries

Citing Country	Cited Country											
	Germany	China	US	Japan	France	Italy	Netherlands	UK	Belgium	Canada	Korea	
Citations in JPO												
Germany		8	5834	63171	835	350	499	578	85	117	317	
China	18		127	1550	21	3	3	3	0	6	15	
US	3855	21		177390	1729	463	1277	1457	182	400	1369	
Japan	32394	173	108506		10506	2939	7545	7001	1296	1870	15195	
France	737	0	2371	19458		102	207	213	25	48	162	
Italy	322	0	490	4327	152		33	35	2	21	19	
Netherlands	451	0	2374	23097	166	58		172	22	23	231	
UK	435	1	1560	10452	169	35	108		14	41	56	
Belgium	55	0	188	1844	33	5	8	24		8	16	
Canada	143	0	483	3608	43	9	27	50	4		21	
Korea	457	6	3790	67141	284	84	229	150	18	77		
Citations in EPO												
Germany		1	2041	2221	323	220	160	295	34	41	39	
China	6		48	62	9	0	0	4	0	9	3	
US	940	9		4581	513	247	300	538	99	129	178	
Japan	1121	10	6809		517	245	474	478	126	109	395	
France	247	1	1046	862		68	81	117	11	37	49	
Italy	136	0	303	318	58		16	34	5	2	14	
Netherlands	76	1	301	314	58	15		23	2	5	17	
UK	70	1	381	281	41	12	22		9	7	8	
Belgium	40	0	135	138	25	6	16	11		3	3	
Canada	20	1	226	117	14	4	9	6	2		9	
Korea	77	3	678	1357	59	12	54	35	5	24		

Note: US and UK denote the United States and the United Kingdom, respectively.

Source: Authors' calculation from the JPO and EPO patent citation data

Table 5.6 Random-effects panel Tobit estimates for patent citations

	JPO citations				EPO citations			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
<i>HIIT</i>	2.615*** (0.17)	2.699*** (0.17)		2.290*** (0.17)	2.434*** (0.13)	2.433*** (0.13)		1.974*** (0.13)
<i>VIIT_M</i>	2.338*** (0.15)	2.420*** (0.15)	2.548*** (0.16)		2.137*** (0.12)	2.100*** (0.12)	2.107*** (0.13)	
<i>VIIT_X</i>	2.399*** (0.16)	2.466*** (0.16)	2.580*** (0.16)		2.183*** (0.12)	2.195*** (0.12)	2.169*** (0.13)	
<i>OWT_M</i>	1.268*** (0.13)		1.600*** (0.14)	1.037*** (0.13)	1.116*** (0.10)		1.205*** (0.11)	0.754*** (0.10)
<i>OWT_X</i>		1.498*** (0.13)	1.737*** (0.13)	1.180*** (0.13)		1.128*** (0.10)	1.214*** (0.11)	0.781*** (0.10)
$\ln(P_i \times P_j)$	0.152*** (0.0045)	0.151*** (0.0045)	0.153*** (0.0045)	0.158*** (0.0047)	0.076*** (0.0031)	0.076*** (0.0031)	0.081*** (0.0032)	0.081*** (0.0032)
$1/\sigma_u$	1.991*** (0.037)	1.992*** (0.038)	2.000*** (0.038)	2.044*** (0.039)	1.379*** (0.030)	1.387*** (0.030)	1.414*** (0.030)	1.443*** (0.031)
$1/\sigma_e$	1.064*** (0.014)	1.063*** (0.014)	1.066*** (0.014)	1.066*** (0.015)	0.718*** (0.012)	0.715*** (0.012)	0.720*** (0.012)	0.712*** (0.012)
ρ	0.778 (0.97)	0.778 (0.97)	0.779 (0.97)	0.786 (0.98)	0.787 (0.98)	0.790 (0.99)	0.794 (0.99)	0.804 (1.01)
No. of obs.	46764	46764	46764	46764	46764	46764	46764	46764
Log likelihood	−13169	−13148	−13201	−13324	−8099	−8099	−8218	−8338
Ward test (Prob4>chi ²)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
LR test (Prob>chi ²)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Notes: (a) The regression is based on full sample and includes a constant term. (b) Period dummies and field dummies are included. (c) ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively. (d) The values in the parentheses are standard errors. (e) The likelihood ratio test for RE model versus pooled model

fixed-effects negative binomial estimates, where the number of citations is used as a dependent variable.

In Tables 5.6 and 5.7, we see that most of the coefficient estimates for HIIT and VIIT are significant and positive, implying that intra-industry trade plays a significant role in technology spillovers. The coefficients for HIIT are evidently larger than those for VIIT, when the two variables are used in the same regression for the two different patent statistics. This pattern remains true also in Table 5.7. Compared with the vertical intra-industry trade, the horizontal intra-industry trade shows a dominant effect on technology spillovers.

Unlike the intra-industry trade, the estimations for the relationship between OWT and the number of citations reveal somewhat mixed results. In Table 5.6, the estimated coefficients of OWT are significantly positive, whereas the magnitudes of the coefficients are smaller than those for HIIT and VIIT. In Table 5.7, the estimated coefficients of OWT_M are insignificant in the case of the EPO and even significantly

Table 5.7 Fixed-effects negative binomial estimates for patent citations

	JPO citations				EPO citations			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
<i>HIIT</i>	0.400*** (0.15)	0.871*** (0.15)	0.343** (0.14)		0.469** (0.20)	0.636*** (0.20)		0.234 (0.17)
<i>VIIT_M</i>	0.130 (0.14)	0.609*** (0.14)	0.235* (0.14)		0.295 (0.20)	0.459** (0.20)	0.219 (0.19)	
<i>VIIT_X</i>	0.493*** (0.15)	0.974*** (0.15)	0.598*** (0.15)		0.598*** (0.20)	0.773*** (0.20)	0.518*** (0.19)	
<i>OWT_M</i>	-0.259* (0.14)		-0.110 (0.15)	-0.248* (0.13)	0.235 (0.20)		0.192 (0.20)	0.052 (0.18)
<i>OWT_X</i>		0.968*** (0.13)	0.657*** (0.14)	0.514 *** (0.12)		0.608*** (0.20)	0.407** (0.19)	0.264 (0.17)
$\ln(P_i \times P_j)$	0.058*** (0.0048)	0.056*** (0.0048)	0.058*** (0.0048)	0.058*** (0.0048)	0.024*** (0.0036)	0.024*** (0.0036)	0.024*** (0.0036)	0.023*** (0.0036)
No. of obs.	8900	8900	8900	8900	6110	6110	6110	6110
Log likelihood	-11335	-11311	-11327	-11332	-6216	-6212	-6217	-6220
Ward test (Prob>chi ²)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Notes: (a) The regression is based on full sample. (b) Period dummies are included. (c) ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively. (d) The values in the parentheses are standard errors

negative in the case of the JPO. In contrast, some of the estimated coefficients of OWT_X are comparable to those for $HIIT$ and $VIIT$. These results imply that the effect of OWT on technology spillovers is much weaker than that of IIT if the country is an importer, whereas that effect may be comparable to that of IIT if the country is an exporter.

5.5 Conclusion

In this chapter, we have examined how technology spillovers across countries would differ according to bilateral trade patterns. We first developed a two-country model of monopolistic competition with quality differentiation by extending the model of Melitz and Ottaviano (2008). In our model, the quality of each product in the manufacturing sector is differentiated and stochastically determined by firms' engaging in product R&D. The structure of our model is similar to that of Melitz and Ottaviano (2008), except for the fact that firms are heterogeneous in product quality rather than in productivity. We then introduced technology spillovers in our model as the process of expanding the technology frontier of the industry. We assumed that, in a given sector, all firms in the same country equally have access to the "general knowledge" without paying any cost. However, technology spillovers are imperfect across countries. In particular, the degree of international technology spillovers falls as the

technology gap between the two countries increases. We then showed that in our model the trade pattern is intra-industry when the technology gap between the two countries is small, while it is inter-industry when the technology gap is sufficiently large. Since products are differentiated in quality in our model, both horizontal and vertical intra-industry trade patterns also emerge endogenously.

From the model we derived three testable hypotheses for empirical analysis. The first hypothesis (Result 5.1) was that technology spillovers are larger when the trade pattern between the two countries is HIIT than when it is VIIT. The second hypothesis (Result 5.2) was that when the trade pattern is VIIT, the relative size of technology spillovers from the country exporting high quality products on average to the country exporting low quality products on average and in the opposite direction is ambiguous. The third hypothesis (Result 5.3) was that technology spillovers are lower when the trade pattern is IIT or OWT than when it is VIIT.

We then empirically tested these hypotheses by using bilateral trade data among 44 countries at six-digit level and patent citations data at the EPO and JPO. Following Jaffe et al. (1993) and other recent studies on technology spillovers, we measure international technology spillovers by patent citations among countries.

Our estimation results basically confirmed the predictions of our model. That is, we found that an increase in the shares of HIIT and VIIT has a significantly positive effect on international technology spillovers. Our estimation results showed that HIIT has a larger effect on spillovers than VIIT does. On the other hand, the relative magnitudes of technology spillovers between the country exporting high quality products and the country exporting low quality products on average under VIIT are generally ambiguous. We also found that the effect of OWT on technology spillovers tends to be much weaker than that of other trade patterns. These results from Japanese and European patents are generally consistent with the finding by Jinji et al. (2015) from US patents. Therefore, we conclude that intra-industry trade plays a significant role in technology spillovers.

In this chapter, we primarily focused on technology spillovers through international trade but did not take the effects of FDI into account. As argued in the introduction, however, a number of existing studies have empirically confirmed that FDI is also a major channel of international technology spillovers. In our estimations, we found that an increase in the share of OWT has a significantly positive effect on technology spillovers in some cases, in particular in the cases of the JPO and EPO. The positive effect of OWT with exporting the good in question even exceeds those of HIIT and/or VIIT in some cases in Table 5.7, which contradicts the predictions by our theoretical model. This may be due to FDI. Thus, in the next chapter, we analyze the effects of FDI on technology spillovers.

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