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**FDI and Technology Spillovers under Vertical Product Differentiation**

**Abstract**

When Northern firms undertake FDI in the South, the superior technology they bring to their Southern operations spills over to Southern firms. Technology spillovers accompanied by FDI often enable Southern firms to enhance their product quality. This paper explores a model that incorporates *quality-enhancing spillovers* in an international duopoly model of vertical product differentiation. We find that the Northern firm, when it chooses to undertake FDI, strategically reduces its product quality to reduce the amount of technology that spills over to the Southern firm. This *strategic quality reduction*, which is often observed in reality, plays a critical role in welfare consequences and policy implications of quality-enhancing technology spillovers.

*JEL classification:* F12, F13, F21, L13

*Keywords:* FDI, international oligopoly, quality-enhancing spillovers, strategic quality reduction, vertical product differentiation, welfare.

# 1 Introduction

Foreign direct investment (FDI) induces technology spillovers, which often enhance local firms' quality standards. That is, if a foreign firm builds its manufacturing plant in a less developed country, local competitors can enhance their product quality by learning from the foreign firm's performance, or by employing workers from the foreign firm.[1]This phenomenon is referred to as *quality-enhancing technology spillovers* throughout the paper. For example, the Chinese automaker Chery Automobile hired a number of engineers from the Nissan-Dongfeng joint venture which was established upon Nissan's FDI in China. The resulting technology spillovers through these engineers significantly improved Chery's car quality (Luo, 2005). Similarly, the investment of U.S. software firms in Bangalore since 1984 has created technological and information externalities to Indian software firms. Consequently, this has enabled local firms to produce software meeting international standards (Patibandla, Kapur, and Petersen, 2000; Pack and Saggi, 2006). In section 2, we present real-world examples of quality-enhancing technology spillovers in more detail.

Anticipating the potential benefits of technology spillovers, Southern governments often induce FDI in industries where local firms need to learn advanced technologies and know-how

[1] The UNCTAD *World Investment Report* (1997) argues that transnational corporations (TNCs) are often more cost-efficient and produce higher quality products than domestic firms in developing countries. To survive, domestic firms need to learn or imitate the production performance of TNCs. This leads to production efficiency gains in which domestic manufacturers either have to offer less expensive products or improve quality to win consumers back from the TNCs.

from foreign firms. In the case of the Chinese automobile industry, the Chinese government imposed high tariffs on imports of foreign cars to induce foreign automakers to undertake FDI in China.[2] In a similar move, the Indian government promoted FDI in the software sector by enforcing the copyright act. This strengthened Intellectual Property Rights (IPR) protection for both local and foreign firms in India.[3] These types of policies have proved to be successful in attracting FDI to industries where local firms need to learn technologies from foreign firms.

Despite the important connection between technology spillovers and FDI, to the best of our knowledge, no theoretical models capture this connection in the context of quality-enhancing spillovers. We aim to fill this gap in the literature. We explore a model that incorporates quality-enhancing spillovers in an international duopoly model of vertical product differentiation, where we focus on market-seeking FDI, that is, FDI with the motive of serving particular markets by local production and distribution (UNCTAD, 1998; Nachum and Zaheer, 2005).

A Northern firm (firm $N$) and a Southern firm (firm $S$) compete in the Southern market, where firm $N$ chooses either home-production or FDI in the South. We demonstrate that when firm $N$ undertakes FDI, it may choose a relatively low quality level for its product to reduce the amount of technology that spills over to firm $S$. Consequently, the equilibrium level of firm $N$'s product quality can be lower under FDI than under home-production.

We call this phenomenon firm $N$'s *strategic quality reduction*, which happens under a broad range of parameterizations in our model. This is a new finding in the analyses of international oligopoly models, and consistent with real-world observations (see Section 2). Markus (2004) finds, in interviews of public officials, university scholars and enterprise managers conducted in China in 1998 and 2001, that foreign companies may undertake defensive actions in the presence of weak IPR protection. In the interviews, nearly all managers of foreign enterprises indicated that in the past they transferred technologies that are at least five years behind global standards in the expectation that those technologies would be lost to local competition.

In our model, the Southern market consists of two types of consumers: high-valuation and low-valuation types. Each firm $N$ and $S$ chooses its product quality, where the production cost is increasing in quality level. Firm $N$ has a superior technology in the sense that it does not have a binding constraint on its choice of product quality, whereas firm $S$ cannot

[2]The Chinese automobile industry developed quickly in late 1990s and early 2000s following investment by foreign automakers. High levels of trade barriers have induced foreign automakers to set up their manufacturing plants in China (Gallagher, 2003; Luo, 2005); these barriers to trade are evidenced by an average tariff rate of around 50 percent for complete vehicles in 1999 and 30 percent in 2005, even after China became a member of WTO in 2001.

[3]With the enforcement of the copyright act, domestic firms launched about 120 new software products and foreign firms launched about 160 in 1989-1990 (Patibandla, Kapur, and Peterson, 2000).

choose the profit maximizing quality level due to its technological limitation. Firm $S$ is located in the South, while firm $N$ can be located in the North (home-production) or in the South (FDI). By undertaking FDI, firm $N$ can avoid tariffs.[4] However, a fraction of firm $N$'s technology spills over to firm $S$ under FDI, and the technology spillovers increase the highest possible level of quality firm $S$ can choose for its product. We find that firm $N$ undertakes FDI when $\theta$ is relatively small and/or the tariff rate is relatively high.

Firm $N$'s strategic quality reduction drives the following two welfare consequences and policy implications, where our discussion on policy implications are based on the assumption that stronger IPR protection reduces the rate of technology spillovers.[5] First, FDI may hurt the South in the sense that Southern welfare can be lower under FDI than under home-production. This finding suggests that when Southern governments formulate IPR protection and trade policy, they should carefully assess the impact of quality-enhancing technology spillovers accompanied by FDI, especially when Northern firms are expected to strategically reduce product quality upon FDI. Second, the socially optimal spillover rate, which maximizes the sum of Northern and Southern welfare, is strictly higher than the North-optimal level but can be strictly less than the South-optimal level. This finding suggests that international organizations such as the WTO have an active role to play in reconciling North-South conflicts on IPR protection. See Section 6 for details.

A number of papers have studied models of technology spillovers in North-South trade contexts, where spillovers reduce production costs (see Section 3). As the spillover rate decreases, more technology spills over to Southern firms but innovating firms have lower incentives to invest in their R&D activities. Previous papers in the literature have analyzed this trade-off and explored its welfare consequences and policy implications.

We contribute to the literature by exploring quality-enhancing spillovers under the vertical product differentiation model. In our analysis, the trade-off arises not from lower R&D incentives but from the Northern firm's strategic quality reduction. As the spillover rate increases, more technology spills over to the Southern firm but the Northern firm's product quality falls further below the socially optimal level because of strategic quality reduction. Our analysis suggests that this new trade-off is also important when we consider the welfare consequences and the economic impact of technology spillovers in North-South trade contexts.

The rest of the paper is organized as follows. Section 2 presents real-world examples of quality-enhancing technology spillovers. Section 3 discusses our contributions to the litera-

[4]The qualitative nature of our results would remain unchanged under an alternative setup in which firm $N$ can also save on production and transport costs by undertaking FDI. See the last paragraph of subsection 4.1.

[5]See, for example, Cohen and Levinthal (1989), Žigić (1998), McCalman (2005), Naghavi (2007), and Belderbos, Lykogianni, and Veugelers (2008) for papers that make similar assumptions.

ture. Section 4 presents our model and its equilibrium characterization. Section 5 explores economic and welfare consequences of spillover and tariff rates. Section 6 explores the policy implications of our findings and compares quality-enhancing with cost-reducing technology spillovers. Section 7 concludes.

# 2 Quality-enhancing Technology Spillovers: Examples

In this section we present real-world examples of quality-enhancing technology spillovers from Northern to Southern firms. In China's automobile industry, many foreign manufacturers undertook FDI by forming joint ventures, given the Chinese government's policy of allowing foreign automakers to enter the Chinese market only through joint ventures with local partners (Tang, 2009). It has been widely recognized that FDI has induced the transfer of advanced technology from foreign to local automakers in China (see, for example, Gallagher, 2003; Luo, 2005). Technology transfer occurs not only within joint ventures but also from joint ventures to independent local automakers. For example, Chery Automobile, an independent local automaker, hired a group of more than twenty engineers from the Nissan-Dongfeng joint venture, mainly from the sedan department of their R&D center, in the early 2000s. These engineers played a critical role in rapidly enhancing Chery's product development capability (Luo, 2005). The quality of automobiles produced by Chinese manufacturers increased sharply as they benefited from the presence of foreign automakers in China. The 2007 survey of J.D. Power in China's automobile market found that the average number of quality problems per 100 vehicles produced by local firms in China was 368, compared to 800 in 2000 (Li, 2007).

Phenomena consistent with strategic quality reduction, which occurs under a broad range of parameterizations in our model, are often observed in China. Markus (2004) finds, in interviews of public officials, university scholars and enterprise managers conducted in China in 1998 and 2001, that foreign companies may undertake defensive actions in the presence of weak IPR protection. In the interviews, nearly all managers of foreign enterprises indicated that in the past they transferred technologies that are at least five years behind global standards in the expectation that those technologies would be lost to local competition, or they brought in technologies that would be obsolete quickly. Consistent with Markus' findings, Gallagher (2003) documents that since 2001, Ford has brought only second and third generations of the Ford Fiesta model to its joint venture with the Chang An Automobile Group in China. The technologies of these generations are far below the cutting-edge. Gallagher argues that this was because of a weak IPR environment in China. Gallagher also reports that since introducing the BJ2020 model in the Beijing Jeep Corporation (a joint venture between Chrysler and Beijing Automobile Industry Corporation) in the 1980s, Chrysler has done very little to improve the model. Engineers in this joint venture said that the technologies transferred from Chrysler to the joint venture were very limited. As a result, the quality of cars manufactured and sold in China by Ford for Fiesta model and Chrysler for Jeep model was below that of cars sold in Europe and the US.[6]

Quality-enhancing technology spillovers are not limited to the automobile industry. In 1979, the Daewoo Corporation of Korea signed a five-year collaboration agreement with the Desh Garment Company of Bangladesh (the information presented below is based on Rhee's (1990) detailed case study of the Daewoo/Desh collaboration). Under the collaboration, Daewoo trained 130 Desh workers to acquire and enhance their skills and knowledge in production, quality inspection, administration, and marketing. As a consequence, Desh experienced a significant increase in product quality, evidenced by an increase in the export value per piece from $1.30 in 1979-80 to $2.30 in 1986-87. Meanwhile, 115 of the 130 Daewoo trained workers left Desh to set up their own company, or to join other newly established garment companies. Rhee (1990) argues that the 115 workers proved a very powerful medium for transferring know-how throughout the garment sector (see also UNCTAD, 1992). The transfer of know-how from the Daewoo/Desh collaboration to other garment companies in Bangladesh is an example of quality-enhancing technology spillovers. In Mohammadi Apparels Ltd., which was established in 1985, twelve former Desh workers' skills in production, administration, and marketing played critical roles in rapidly enhancing the company's product quality.

Thompson (2003) examines the role of Hong Kong FDI in the transfer of technology to China by analyzing data from 84 Hong Kong based garment manufacturers that have invested directly in mainland China. He finds that Hong Kong firms' technology for the efficient production of superior quality products was transferred to local firms through trade and industry associations and mobility of workers. In a case study of India's software industry, Patibandla et al. (2000) document that investment by Texas Instruments and other U.S. software firms in the late 1980s created significant technological and information externalities for Indian software firms: it gave Indian firms access to trends in the global software market and enabled them to move to the higher-end market (see also Pack and Saggi, 2006).

# 3 Relationship to the Literature

This section surveys existing theoretical models of technology spillovers in North-South trade contexts, and discusses our contributions to the literature.[7] In a seminal contribution to this

[6]Similarly, Praussello (2005) points out that Japanese firms often brought technologies at their mature period to the Malaysian electronics industry.

[7]Many studies have empirically investigated technology spillovers from foreign to local firms upon FDI, where technology spillovers are often measured by changes in local firms' productivity. Their findings are mixed. Caves (1974) finds a positive relationship between FDI and value-added per worker in the Australian

literature, Chin and Grossman (1990) study a Cournot duopoly model in which a Northern firm competes with a Southern firm in an integrated world market. They assume that both firms have access to standard technology, but only the Northern firm can invest in R&D in order to lower its production costs. Chin and Grossman consider two polar cases of complete IPR protection or no protection, where the Southern firm can imitate the Northern firm's technology under no IPR protection. They find that the interests of the North and the South are generally conflicting on IPR protection: the South benefits from no protection and the North benefits from complete protection. Complete protection may or may not enhance global welfare in their analysis. Žigić (1998) extends Chin and Grossman's model by considering a continuum of IPR protection between the two polar cases. Žigić finds that the North-South conflict on IPR protection does not necessarily arise in this extension, showing a congruence of interests between North and South when the level of R&D efficiency is relatively high.[8]

Diwan and Rodrik (1991) consider the incentives of the North and the South to provide patent protection in a model that allows for a continuum of potential technologies with a different distribution of preferences in the North and the South. In their model, the Northern and Southern markets are segmented, and entry into the R&D section in the North is free. They find that a benevolent global planner who places greater weight on the South's welfare would require a higher level of patent protection in the North.[9] Deardorff (1992) studies the impact of extending patent protection from the innovating country to another country. He shows that if the innovating country is large, this spread of patent protection benefits the innovating country and harms the other country; the total impact on global welfare is negative. Helpman (1993) examines the debate on the enforcement of IPR within a dynamic general equilibrium framework in which the North invents new products and the South imitates them. He finds that tightening IPR protection in the South hurts the South and may or may not benefit the North. Lai and Qiu (2003) explore a model in which both Northern and Southern firms can innovate, and IPR protection in each region is represented by the length of patent protection. Comparing the Nash equilibrium IPR protection standards of the South and the North, they find that the former is weaker than the latter. They also show that both regions can gain from an agreement that requires the South to harmonize its IPR standards with those of the North, and the North to liberalize

manufacturing sectors. Kee (2010) also finds positive horizontal spillovers from foreign to domestic firms using data from 297 Bangladeshi garment firms in the 1999-2003 period. However, Aitken and Harrison (1999) find a negative impact of FDI on local firms' productivity using data from 4,000 Venezuelan firms, and Djankov and Hoekman (2000) find negative spillovers in the Czech Republic. See Blomström and Kokko (1998) and Carluccio and Fally (2010) for related surveys.

[8]See also Žigić (2000) and Kim and Lapan (2008) for related analyses.

[9]In their model, the levels of patent protection in the two regions must be identical to maximize global welfare; global welfare is the equally weighted sum of the welfares of the North and the South.

its traditional goods market.[10]

The papers mentioned above do not address the link between FDI and technology spillovers, which is a focus of our analysis. Glass and Saggi (1999, 2002) and Naghavi (2007) have previously explored this link. Glass and Saggi (2002) construct a Cournot oligopoly model in which a source firm has superior technology compared to a host firm, and the two compete by producing a homogeneous good for a market outside the host country. Workers employed by the source firm acquire knowledge of its superior technology. FDI helps the source firm to save on production costs, but may induce its workers to work for the host firm. With the knowledge acquired from the source firm, these workers can produce the product at lower costs. The source firm may pay a wage premium to prevent the local firm from hiring its workers and thus gain access to their knowledge (technology spillovers). Glass and Saggi find that the host government has an incentive to attract FDI because of technology spillovers to local firms or the wage premium earned by employees of the source firm. However, when FDI is particularly attractive to the source firm, the host government has an incentive to discourage FDI.[11]

Naghavi (2007) considers a cost-reducing technology spillovers model in which a Northern firm can choose to either export or undertake FDI in a Southern country, which has a potential competitor. The game consists of five stages starting with the Southern government choosing its IPR policy, which is represented by the spillover rate. In the second stage, the Northern firm chooses its mode of entry. If it chooses export, it will be the monopolist in the Southern market and the game proceeds to the third stage where the Southern government chooses its optimal tariff rate. If the Northern firm chooses FDI instead, a Southern firm could emerge and benefit from the technology spillovers from the Northern firm. In the fourth stage, the Northern firm chooses the level of R&D investment. The final stage is the production stage, in which the firms compete in quantity. Naghavi finds that a stringent IPR regime in the South induces the Northern firm to undertake FDI. The resulting FDI improves Southern welfare whenever the Northern firm's FDI induces an entry of the Southern firm.

[10]See Grossman and Lai (2004) for a related analysis.

[11]Glass and Saggi (1999) develop a dynamic general equilibrium model to examine the impact of FDI on welfare and technology transfer from the North to the South. Three types of firms are considered: Northern firms producing in the North; Northern multinationals producing in the South; and Southern firms producing in the South. In this set up, Northern firms and multinationals innovate, while Southern firms imitate, and all of them serve consumers in both the North and the South. In steady state, imitated products of both Northern firms and multinationals are fully replaced by newly innovated products with quality improvement. Glass and Saggi find that if FDI is the only channel for technology transfer, that is, if the Southern firms only imitate technologies of the multinationals, then the increase in FDI inflows raises the rate of imitation and innovation, and improves welfare for both the North and the South. However, if FDI co-exists with imitation as channels for technology transfer, that is, Southern firms imitate technologies of both multinationals and Northern firms in the North, then the increase in FDI does not affect the rate of imitation and innovation, raises Southern welfare, and has an ambiguous impact on Northern welfare.

Hence, the Southern government can maximize Southern welfare by choosing the highest possible spillover rate that still induces the Northern firm to undertake FDI.

The present paper contributes to the literature by studying the link between FDI and technology spillovers in the context of quality-enhancing spillovers. To this end, we explore a model that incorporates quality-enhancing technology spillovers in an international duopoly model of vertical product differentiation. To the best of our knowledge, our paper is the first to study such a model. Several authors have previously used models of vertical product differentiation in international trade contexts to study a variety of issues including the role of trade policy in influencing a foreign monopolist's strategic decisions (Das and Donnenfeld, 1987), trade restrictions such as quantity and quality limitations on imports (Das and Donnenfeld, 1989), strategic trade policy with endogenous choice of quality and asymmetric costs (Zhou, Spencer, and Vertinsky, 2002), tariffs, quality reversals and exit (Herguera, Kujal, and Petrakis, 2002), trade policy and quality leadership (Moraga-González and Viaene, 2005), domestic quality dominance through quotas (Boccard and Wauthy, 2005), trade restrictions and quality upgrading of imports (Toshimitsu, 2005), and innovation and imitation under strategic trade policy versus free trade (Kováč and Žigić, 2008). However, to the best of our knowledge, neither quality-enhancing technology spillovers nor foreign firms' choice of modes of entry (home-production or FDI) have been previously analyzed in this literature.

The Northern firm has a technological advantage over the Southern firm in our model as in Glass and Saggi (2002).[12] We demonstrate that when the Northern firm undertakes FDI, it may strategically reduce the level of its product quality to limit technology spillovers to the Southern firm. The strategic quality reduction leads to a new trade-off in technology spillovers: as the spillover rate increases, larger amount of technology spillovers increase welfare, but the Northern firm's strategic quality reduction reduces welfare. We explore welfare consequences and policy implications of this trade-off in later sections.

# 4 Technology Spillovers under Vertical Product Differentiation

In this section, we present an international duopoly model of vertical product differentiation with quality-enhancing technology spillovers. We then characterize Subgame Perfect Nash Equilibria (SPNE) of the model, and show that the Northern firm strategically reduces its product quality when the spillover rate is relatively small.

[12] This is often referred to as ownership advantages. See the second last paragraph of subsection 4.1 for details.

## 4.1 The Model

We consider a Northern firm (firm $N$) and a Southern firm (firm $S$) that compete in the Southern market. Firm $S$ is located in the South, while firm $N$ can locate itself in the North (home-production, denoted HP) or in the South (FDI). If firm $N$ chooses HP, a specific tariff t ($> 0$) is imposed on firm $N$'s product imported to the Southern market.

Let $q_k$ ($\geq 0$, $k = N$, $S$) denote the quality of firm $k$'s product. On the demand side, there are two groups of consumers, denoted $H$ (type $H$ consumers) and $L$ (type $L$ consumers); group $j$ consists of a continuum of nonatomic consumers of mass $m_j$, $j = H$, $L$. A representative individual in group $j$ consumes either zero units or one unit of the products, and derives a gross benefit of $v_j q_k$ from the consumption of one unit of quality $q_k$ product, where $v_H > v_L > 0$. Similar models of vertical product differentiation with two types of consumers have been adopted to analyze durable-goods pricing (Waldman, 1996, 1997), international technology transfer and the technology gap (Glass and Saggi, 1998), and entry, pricing, and product design (Davis, Murphy, and Topel, 2004). See Mussa and Rosen (1978) for a classic contribution to theoretical analyses of vertical product differentiation.

We assume that firm $N$ can choose any quality level for its product, $q_N$.[13] Meanwhile, firm $S$ uses less advanced technology, and can only choose a quality level for its product up to a certain upper bound value. This value differs under FDI and HP. Specifically, when firm $N$ locates itself in the North, the maximum possible quality level firm $S$ can choose is given by $\bar{q}_S$. When firm $N$ undertakes FDI, technology spillovers extend this upper bound quality level and the maximum quality level firm $S$ can choose for its product is given by $\hat{q}_S(q_N) = max(\bar{q}_S + \theta(q_N - \bar{q}_S), \bar{q}_S)$, $\theta \in [0, 1)$. In our model, $\theta$ captures the degree of technology spillovers from firm $N$ to firm $S$, which can only happen under FDI. Hence, when firm $N$ undertakes FDI and chooses $q_N > \bar{q}_S$, the higher $\theta$ enables firm $S$ to choose a higher product quality. Notice that each firm produces a single quality in our model. This is a standard modeling choice in oligopoly models with vertical product differentiation (see, for example, Shaked and Sutton, 1982; Das and Donnenfeld, 1987, 1989; Ronnen, 1991; Motta, 1993; Aoki and Prusa, 1996; Lehmann-Grube, 1997; Aoki, 2003; Jinji, 2003).

Each firm $k$ can produce a product of quality $q_k$ at a constant marginal cost of $c(q_k)$ with zero fixed costs, where $c(\cdot)$ is a twice-continuously differentiable function with $c'(\cdot) > 0$ and $c''(\cdot) > 0$ as in Mussa and Rosen (1978), Das and Donnenfeld (1987, 1989), and Toshimitsu (2005).[14] To derive closed form solutions, we assume that $c(q_k) = \frac{1}{2}q_k^2$.

[13] All our results would remain unchanged under an alternative assumption that firm $N$ can choose any $q_N$ satisfying $q_N \leq \bar{q}_N$, where $\bar{q}_N$ is a constant satisfying $\bar{q}_N \geq v_H$. This is because firm $N$ never sets $q_N$ strictly greater than $v_H$ in equilibrium, as Proposition 3 in the next subsection tells us.

[14] Johnson and Myatt (2003) also assume that the constant marginal cost in an increasing function of product quality. They consider the possibilities that the function has increasing returns, decreasing returns, or is U-shaped.

We consider a three-stage game, described below.

[**Stage 1**] Firm $N$ determines whether to locate itself in the North (HP) or in the South (FDI).

[**Stage 2**] Firm $N$ chooses quality level $q_N$ for its product. Having observed $q_N$, firm $S$ chooses quality level $q_S$, subject to $q_S \leq \hat{q}_S(q_N)$.

[**Stage 3**] Firms $N$ and $S$ simultaneously set prices for their products, and consumers make purchase decisions.

Notice that the game has two stage 2 subgames: one is the HP subgame in which firm $N$ locates itself in the North, while the other is the FDI subgame in which firm $N$ locates itself in the South.

**Remarks**

• A basic assumption of our model is that firm $N$ has a superior technology compared to firm $S$ in the sense that firm $N$ can choose any quality level for its product $q_N$, whereas firm $S$'s quality choice is constrained by an upper bound. This assumption is consistent with Markusen's (1995) discussion on the theory of the multinational enterprise, which is based on Hymer (1976) and Dunning (1981). Markusen points out that if foreign multinational enterprises are identical to domestic firms, they will not find it profitable to enter the domestic market because of the added costs of doing business in another country; these costs include communication and transport costs, higher costs of stationing personnel abroad, and barriers due to language and customs. He argues that the multinational enterprise must therefore arise because it possesses some special advantage such as superior technology or lower costs due to scale economies. Dunning (1981) labels this the ownership advantage. In their theoretical analysis of multinational firms and technology transfer, Glass and Saggi (2002) assume that a multinational firm has superior technology compared to local firms because of ownership advantages.

• To capture technology spillovers from firm $N$ to firm $S$, the choice of qualities is sequential in our model. Sequential choice of qualities in vertical product differentiation models has been studied in the industrial organization literature (see, for example, Aoki and Prusa, 1996; Lehmann-Grube, 1997; Hoppe and Lehmann-Grube, 2001). In international trade contexts, Kováč and Žigić (2008) explore a duopoly model of vertical product differentiation with sequential choice of qualities, where their focus is leadership and imitation. In their model, a foreign firm chooses its quality and a domestic firm follows. When the domestic firm's quality is below the foreign firm's quality, the domestic firm's cost for quality is reduced because of imitation. Although related, our formulation is distinctively different from theirs. In our model, firm $S$ can choose its product quality up to a certain level. Firm $N$'s choice of quality determines the amount of technology spillovers, which, in turn, determines the maximum quality level that firm $S$ can choose. Firm $S$'s cost of quality is unaffected by firm

$N$'s quality choice in our model.

• In our model tariff is the only trade cost that firm $N$ incurs when it chooses HP and exports to the South. In reality, however, Northern firms incur other trade costs such as transport costs. By undertaking FDI, they can avoid these trade costs and also enjoy some cost advantages such as lower labor costs in the South. We can therefore assume that firm $N$ incurs trade costs $t + w$ if it chooses HP, where $w$ ($\geq 0$) represents non-tariff trade costs and cost disadvantages that firm $N$ incurs when it exports its product. We have found that the qualitative nature of our results remains unchanged under this assumption.

## 4.2 Equilibrium Characterization

Throughout our analysis we assume that $\bar{q}_S < v_L$ holds. If $\bar{q}_S \geq v_L$ holds, $\bar{q}_S$ does not impose a binding constraint on firm $S$'s choice of quality level, since firm $S$ can choose its profit-maximizing quality level, $v_L$, without technology spillovers as shown later in this section (see footnote 15). By assuming $\bar{q}_S < v_L$, we focus on cases in which quality-enhancing technology spillovers can play a role.

We derive Subgame Perfect Nash Equilibria of the model described above. We focus on a range of parameterizations in which firm $N$ sells its product to all type $H$ consumers, and firm $S$ sells its product to all type $L$ consumers in the equilibrium. We call this type of equilibrium a *segmentation equilibrium*. Note that all proofs are presented in the Appendix.

**Proposition 1.** There exists an unique value $\tilde{m}_H > 0$ such that the game has a segmentation equilibrium if and only if $m_H > \tilde{m}_H$. Furthermore, if $m_H > \tilde{m}_H$, the segmentation equilibrium is the unique equilibrium of the game.

To understand the logic behind Proposition 1, let us first consider the case in which the spillover rate, $\theta$, is equal to zero. This implies that technology does not spill over from firm $N$ to firm $S$ even when firm $N$ chooses to locate itself in the South. In this case, firm $N$'s optimal choice in Stage 1 is to locate itself in the South to avoid the tariff.

Suppose that the game has a segmentation equilibrium when $\theta = 0$. In equilibrium, firm $N$ sells its product with quality $q_N$ at price $p_N$ to $m_H$ type $H$ consumers, while firm $S$ sells its product with quality $q_S$ at price $p_S$ to $m_L$ type $L$ consumers. We find that

$$p_N = v_H q_N - (v_H - v_L) q_S, \tag{4.1}$$

$$p_S = v_L q_S, \tag{4.2}$$

where $q_N > q_S$. Firm $S$ extracts all the surplus from type $L$ consumers by charging $p_S = v_L q_S$. If a type $H$ consumer purchases firm $S$'s product at $p_S$, the consumer's net benefit is $v_H q_S - p_S = (v_H - v_L)q_S$. For firm $N$ to sell its product to type $H$ consumers, it must leave the same amount of surplus, $(v_H - v_L)q_S$, to be captured by consumers; hence, $p_N = v_H q_N - (v_H - v_L)q_S$. The equilibrium profits of firms $N$ and $S$ are $\pi_N(q_N)$ and $\pi_S(q_S)$, respectively, where

$$\pi_N(q_N) = m_H[p_N - c(q_N)] = m_H[v_H q_N - (v_H - v_L)q_S - \frac{1}{2}q_N^2], \tag{4.3}$$

$$\pi_S(q_S) = m_L[p_S - c(q_S)] = m_L[v_L q_S - \frac{1}{2}q_S^2]. \tag{4.4}$$

When $\theta = 0$, firm $S$'s maximum possible quality level is not affected by firm $N$'s quality level $q_N$; hence, $\hat{q}_S(q_N) = \bar{q}_S$ for all $q_N$. Given $\bar{q}_S < v_L$, firm $S$ chooses $q_S = \bar{q}_S$ to maximize $\pi_S(q_S)$, whereas firm $N$ chooses $q_N = v_H$ to maximize $\pi_N(q_N)$, in stage 2 in equilibrium.[15]

Proposition 1 tells us that the number of type $H$ consumers, $m_H$, must be greater than a threshold value $\tilde{m}_H$ for the game to have a segmentation equilibrium. If $m_H$ is lower than the threshold, ignoring type $L$ consumers is no longer firm $N$'s optimal choice, and firm $N$ is strictly better off by selling its product to both types of consumers.

In the case where $\theta > 0$, the positive spillover rate can negatively affect firm $N$'s profitability. Technology spillovers can increase firm $S$'s product quality by increasing its maximum possible quality level; this, in turn, increases the amount of surplus, $(v_H - v_L)q_S$, that firm $N$ must offer to type $H$ consumers to ensure their purchase of firm $N$'s product, resulting in the reduction of firm $N$'s profitability. Firm $N$ continues to undertake FDI when the value of $\theta$ is relatively small, but may switch to home-production when $\theta$ becomes higher. In any case, Proposition 1 again tells us that $m_H$ must be greater than a threshold for the game to have a segmentation equilibrium; otherwise, firm $N$ will be strictly better off by selling its product to both types of consumers.

Next we turn to Proposition 2, which tells us that if $m_H > \tilde{m}_H$, the unique equilibrium of the game is an FDI equilibrium if $\theta$ is relatively small, and an HP equilibrium otherwise.

**Proposition 2.** Suppose $m_H > \tilde{m}_H$. There exists a value $\theta^* \in (0, 1]$ such that the equilibrium of the game is an FDI equilibrium if $\theta \leq \theta^*$, and an HP equilibrium if $\theta > \theta^*$. Furthermore, there exists a value $\bar{t} \geq 0$ such that $\theta^*(< 1)$ is strictly increasing in $t$ if $t < \bar{t}$, and $\theta^* = 1$ otherwise.

As discussed above, firm $N$ chooses to undertake FDI if $\theta = 0$, and an increase in $\theta$ reduces firm $N$'s profitability. Proposition 2 tells us that if the tariff rate $t$ is relatively low, there exists a threshold $\theta^* < 1$ such that firm $N$ chooses home-production over FDI if $\theta > \theta^*$. The threshold $\theta^*$ is increasing in $t$ because firm $N$'s disadvantage in home-production

[15] Notice that if $\bar{q}_S \geq v_L$, firm $S$'s maximum possible quality level would not impose a binding constraint on firm $S$'s choice of quality; firm $S$ would choose $q_S = v_L$ to maximize $\pi_S(q_S)$ in stage 2.

increases as the tariff rate increases. When $t$ exceeds the threshold $\bar{t}$, firm $N$ undertakes FDI for all $\theta \in [0, 1)$ (that is, $\theta^* = 1$).

We now characterize equilibrium prices in Proposition 3, which tells us that firm $N$ strategically reduces its product quality when $\theta$ is relatively small.

**Proposition 3 [Strategic Quality Reduction].** Suppose $m_H > \tilde{m}_H$, and let $q_k^*$ denote the equilibrium level of firm $k$'s product quality. There exists a threshold $\hat{\theta}$, $\hat{\theta} \in (0, \theta^*]$, such that (i) and (ii) below hold in the equilibrium of the game.
(i) Firm $N$ chooses $q_N^* = (1-\theta)v_H + \theta v_L$ $(< v_H)$ if $\theta \leq \hat{\theta}$, and $q_N^* = v_H$ if $\theta > \hat{\theta}$.
(ii) Firm $S$ chooses $q_S^* = \hat{q}_S((1-\theta)v_H + \theta v_L)$ if $\theta \leq \hat{\theta}$, $q_S^* = v_L$ if $\theta \in (\hat{\theta}, \theta^*]$, and $q_S^* = \bar{q}_S$ if $\theta > \theta^*$.[16]

If the spillover rate $\theta$ is high enough to satisfy $\theta > \theta^*$, firm $N$ chooses home-production to avoid technology spillovers. Since there is no spillover, firm $S$ chooses $q_S^* = \bar{q}_S$ as in the case of $\theta = 0$ explained above. Firm $N$ then chooses $q_N^* = v_H$, which maximizes its profit $m_H[v_H q_N - (v_H - v_L)\bar{q}_S - \frac{1}{2}q_N^2 - t]$. Notice that the profit-maximizing level of firm $N$'s product quality under home-production, $q_N^* = v_H$, is equal to the socially optimal quality level because the net social benefit associated with the consumption of firm $N$'s product by type $H$ consumers is $m_H[v_H q_N - \frac{1}{2}q_N^2]$.

Firm $N$ chooses $q_N^* = v_H$ when $\theta > \hat{\theta}$, and strategically reduces its product quality to $(1-\theta)v_H + \theta v_L$ when $\theta \leq \hat{\theta}$. This strategic quality reduction, a central result of our analysis, can be explained as follows. Consider the equilibrium of the FDI subgame. Given firm $N$'s quality choice $q_N$, firm $S$ chooses $q_S$ to maximize $\pi_S(q_S) = m_L[v_L q_S - \frac{1}{2}q_S^2]$, subject to $q_S \leq \hat{q}_S(q_N) \equiv max(\bar{q}_S + \theta(q_N - \bar{q}_S), \bar{q}_S)$, where $\hat{q}_S(q_N)$ is increasing in $q_N$. Without the constraint $q_S \leq \hat{q}_S(q_N)$, firm $S$ would choose $q_S = v_L$ to maximize its profit $m_L[v_L q_S - \frac{1}{2}q_S^2]$. If $\hat{q}_S(q_N) \geq v_L$, the constraint is not binding because firm $S$ can choose $q_S = v_L$ even under the constraint. If $\hat{q}_S(q_N) < v_L$, the constraint is binding so that firm $S$ chooses $q_S = \hat{q}_S(q_N)$ to maximize its profit.

Let $q_S^*(q_N)$ denote firm $S$'s best response function. By anticipating firm $S$'s response to $q_N$, firm $N$ chooses $q_N$ to maximize its profit in the subsequent equilibrium, which is

$$\pi_N(q_N) \equiv m_H[v_H q_N - (v_H - v_L)q_S^*(q_N) - \frac{1}{2}q_N^2]. \tag{4.5}$$

We find that candidates for the profit-maximizing level of firm $N$'s product quality are $q_N = v_H$ and $q_N = (1-\theta)v_H + \theta v_L$. If firm $N$ does not impose a binding constraint on firm $S$'s quality choice in the equilibrium, firm $N$ chooses $q_N^* = v_H$, which maximizes $[v_H q_N - \frac{1}{2}q_N^2]$.

[16] We assume that if firm $N$ is indifferent between choosing $q_N = (1-\theta)v_H + \theta v_L$ and $q_N = v_H$ in the FDI subgame, firm $N$ chooses $q_N = (1-\theta)v_H + \theta v_L$.

In contrast, if firm $N$ does impose a binding constraint in the equilibrium, firm $N$ chooses $q_N^* = (1-\theta)v_H + \theta v_L$, which is lower than $v_H$, to reduce the amount of technology spillovers.

If the spillover rate $\theta$ is large enough so that $v_L < \hat{q}_S((1-\theta)v_H + \theta v_L) \Leftrightarrow \theta > \frac{v_L - \bar{q}_S}{v_H - v_L}$ holds, then the constraint is not binding at both candidates $q_N = (1-\theta)v_H + \theta v_L$ and $q_N = v_H$. In this case, firm $N$ chooses $q_N^* = v_H$ in equilibrium. In contrast, if $\theta$ is small enough so that $v_L \geq \hat{q}_S(v_H) \Leftrightarrow \theta \leq \frac{v_L - \bar{q}_S}{v_H - \bar{q}_S}$, then the constraint is binding at both candidates $q_N = (1-\theta)v_H + \theta v_L$ and $q_N = v_H$. In this case, firm $N$ chooses $q_N^* = (1-\theta)v_H + \theta v_L$ in equilibrium. We find that there exists a unique value $\dot{\theta} \in (0,1)$ such that in the equilibrium of the FDI subgame, firm $N$ chooses $q_N^* = v_H$ if $\theta > \dot{\theta}$ and $q_N^* = (1-\theta)v_H + \theta v_L$ if $\theta \leq \dot{\theta}$. We define $\hat{\theta} \equiv min\{\dot{\theta}, \theta^*\}$ to state this result in terms of the equilibrium of the entire game, leading to Proposition 3.

Finally, the following lemma is used to explore the impacts of quality-enhancing technology spillovers.

**Lemma 1.** $\hat{\theta} < \theta^* = 1$ if $t \geq \bar{t}$, and $\hat{\theta} = \theta^* < 1$ otherwise.

If $t \geq \bar{t}$, firm $N$ chooses FDI for all $\theta \in [0,1)$ (that is, $\theta^* = 1$) by Proposition 2. Lemma 1 tells us that firm $N$ chooses $q_N^* = v_H$ if $\theta$ is relatively large satisfying $\theta > \hat{\theta}$, and strategically reduces its product quality to $q_N^* = (1-\theta)v_H + \theta v_L$ if $\theta \leq \hat{\theta}$.

If $t < \bar{t}$, firm $N$ chooses FDI if $\theta$ is relatively small satisfying $\theta \leq \theta^*$, and chooses home-production otherwise (Proposition 2). Lemma 1 tells us that $\hat{\theta} = \theta^*$ holds in this case. Thus, whenever firm $N$ chooses FDI in equilibrium (that is, whenever $\theta \leq \theta^*$ holds), firm $N$ strategically reduces its product quality (that is, $\theta \leq \hat{\theta}$ holds). To see why $\hat{\theta} = \theta^*$ holds in this case, suppose $\hat{\theta} < \theta^* < 1$ holds. For any $\theta \in (\hat{\theta}, \theta^*]$, firm $N$ prefers FDI to home-production (because $\theta \leq \theta^*$), and $q_N^* = v_H$ and $q_S^* = v_L$ hold in the equilibrium (because $\theta > \hat{\theta}$). Firm $N$'s equilibrium profit is constant for all $\theta \in (\hat{\theta}, \theta^*]$, and is strictly greater than its profit under home-production. Since firm $N$'s equilibrium profit in the home-production subgame is constant for all $\theta$, firm $N$ should be strictly better off by choosing FDI over home-production for all $\theta > \hat{\theta}$; hence $\theta^* = 1$ should hold instead of $\theta^* < 1$. Thus, if $\theta^* < 1$, then $\hat{\theta} = \theta^*$ must hold.

In summary, we have shown that the game has a segmentation equilibrium if and only if the population of type $H$ consumers is relatively large. The segmentation equilibrium is the unique equilibrium: it is an FDI equilibrium if the spillover rate $\theta$ is relatively low, and an HP equilibrium otherwise. Importantly, FDI reduces the equilibrium quality of firm $N$'s product from the socially optimal level $v_H$ to a suboptimal level $(1-\theta)v_H + \theta v_L$ when $\theta$ is relatively low. Strategic quality reduction occurs because firm $N$ can reduce the amount of technology spillovers to firm $S$ by reducing its product quality; this, in turn, increases firm $N$'s profitability.

# 5 Impact of quality-enhancing technology spillovers

In this section we investigate the impact of quality-enhancing technology spillovers on firms' profits, Southern consumers, Southern welfare, and global welfare. We undertake comparative statics exercises on the spillover rate $\theta$, and identify and compare optimal spillover rates $\theta^S$ and $\theta^W$ that maximize Southern and global welfare, respectively. We then present an outline of comparative statics results of tariff rates.

## 5.1 Effects of spillover rates

Our comparative statics exercises on the spillover rate $\theta$ focus on cases in which the equilibrium of the game is a segmentation equilibrium for all $\theta \in [0, 1)$.[17] Let $\pi_N(\theta)$, $\pi_S(\theta)$, $CS(\theta)$, $W_S(\theta)$, and $W(\theta)$ denote the profits of the Northern and Southern firms, consumer surplus, Southern welfare, and global welfare in the equilibrium of the game, respectively. We present our results under two cases: the case of $t \geq \bar{t}$ (Case I) and $t < \bar{t}$ (Case II). See Proposition 2 for the definition of $\bar{t}$.

**Case I:** $t \geq \bar{t}$

Recall that $\hat{\theta} < \theta^* = 1$ holds if $t \geq \bar{t}$ by Lemma 1. Firm $N$ undertakes FDI for all $\theta \in [0, 1)$ and strategically reduces its product quality by choosing $q_N^* = (1-\theta)v_H + \theta v_L$ if and only if $\theta \leq \hat{\theta}$.

**Proposition 4.**
(i) $\pi_N(\theta)$ is strictly decreasing in $\theta$ for all $\theta \in [0, \hat{\theta}]$ and $\pi_N(\theta)|_{\theta \in (\hat{\theta}, 1)} = \pi_N(\hat{\theta})$ hold.
(ii) $\pi_S(\theta)$, $CS(\theta)$ and $W_S(\theta)$ are strictly increasing in $\theta$ for all $\theta \in [0, \hat{\theta}]$. Furthermore, $\pi_S(\theta)|_{\theta \in (\hat{\theta}, 1)} > \pi_S(\hat{\theta})$, $CS(\theta)|_{\theta \in (\hat{\theta}, 1)} > CS(\hat{\theta})$ and $W_S(\theta)|_{\theta \in (\hat{\theta}, 1)} > W_S(\hat{\theta})$ hold, where $\pi_S(\theta)$, $CS(\theta)$ and $W_S(\theta)$ are constant for all $\theta \in (\hat{\theta}, 1)$.

Figure 1 presents a diagrammatic representation of Proposition 4. When $\theta \in [0, \hat{\theta}]$, firm $N$ undertakes FDI and imposes a binding constraint on firm $S$'s quality choice by choosing $q_N^* = (1-\theta)v_H + \theta v_L$. Holding everything else constant, an increase in $\theta$ extends firm $S$'s upper bound quality level. Firm $N$ partially offsets this effect by reducing its product quality (that is, $q_N^* = (1-\theta)v_H + \theta v_L$ decreases as $\theta$ increases), but firm $S$'s equilibrium quality $q_S^* = \bar{q}_S + \theta(q_N^* - \bar{q}_S)$ is still increasing in $\theta$ for all $\theta \in [0, \hat{\theta}]$. The direct (positive) impact of an increase in the spillover rate on firm $S$'s equilibrium quality outweighs the indirect (negative) impact of firm $N$'s strategic quality reduction. Firm $N$'s equilibrium

[17] For any given $t > 0$, there exists a value $\hat{m}$ such that the equilibrium of the game is a segmentation equilibrium for all $\theta \in [0, 1)$ if and only if $m_H > \hat{m}$. The proof is presented after the proof of Proposition 1 in the Appendix.

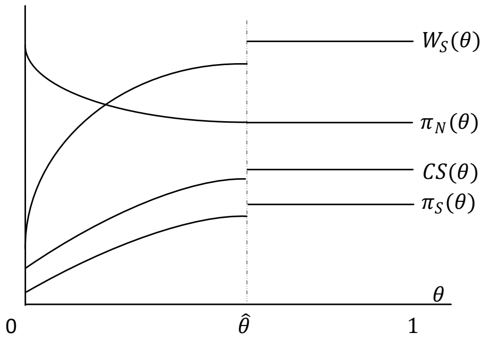


Figure 1: Effects of technology spillovers when $t \geq \bar{t}$.

profit $\pi_N(\theta)$ is strictly decreasing in $\theta$ for all $\theta \in [0, \hat{\theta}]$. In equilibrium, firm $S$ captures all surplus from type $L$ consumers by charging them $p_S = v_L q_S^*$, whereas firm $N$ leaves a rent of $(v_H - v_L)q_S^*$ to be captured by type $H$ consumers. Equilibrium consumer surplus is given by $CS(\theta) = m_H(v_H - v_L)q_S^*$. Since $q_S^*$ is strictly increasing in $\theta$, both $\pi_S(\theta)$ and $CS(\theta)$ are also strictly increasing in $\theta$ for all $\theta \in [0, \hat{\theta}]$.

When $\theta = \hat{\theta}$, firm $N$ is indifferent between choosing $q_N = (1 - \hat{\theta})v_H + \hat{\theta}v_L$ and $q_N = v_H$. Once $\theta$ exceeds $\hat{\theta}$, it becomes too costly for firm $N$ to impose a binding constraint on firm $S$'s quality choice, and firm $N$ chooses $q_N^* = v_H$ while firm $S$ chooses $q_S^* = v_L$ for all $\theta \in (\hat{\theta}, 1)$. Hence, $q_S^*|_{\theta=\hat{\theta}} < q_S^*|_{\theta\in(\hat{\theta},1)} = v_L$ for all $\theta \in (\hat{\theta}, 1)$, which implies that $\pi_S(\theta)|_{\theta\in(\hat{\theta},1)} > \pi_S(\hat{\theta})$ and $CS(\theta)|_{\theta\in(\hat{\theta},1)} > CS(\hat{\theta})$ hold, where $\pi_S(\theta)$ and $CS(\theta)$ are constant for all $\theta \in (\hat{\theta}, 1)$.

Let us consider Southern welfare. Note that the Southern government receives no tariff revenue for all $\theta \in [0, 1)$ in equilibrium because firm $N$ undertakes FDI for all $\theta \in [0, 1)$ in case I. Equilibrium Southern welfare is then given by $W_S(\theta) = \pi_S(\theta) + CS(\theta)$, and hence, $W_S(\theta)$ shares the same properties with $\pi_S(\theta)$ and $CS(\theta)$ as Proposition 4 (ii) tells us.

Next we turn to global welfare, which is the sum of the net social benefit associated with the consumption of firm $N$'s product, $m_H[v_H q_N - \frac{{q_N}^2}{2}]$, and firm $S$'s product, $m_L[v_L q_S - \frac{{q_S}^2}{2}]$. Hence, $q_N = v_H$ and $q_S = v_L$ are global welfare-maximizing levels of firm $N$'s product quality and firm $S$'s product quality, respectively. This leads us to Proposition 5.

**Proposition 5.** For any given $\theta' \in (\hat{\theta}, 1)$, $W(\theta') > W(\theta)$ holds for all $\theta \in [0, \hat{\theta}]$, where $W(\theta')$ is constant for all $\theta' \in (\hat{\theta}, 1)$.[18]

As mentioned above, firm $N$ chooses $q_N^* = v_H$ and firm $S$ chooses $q_S^* = v_L$ in the

[18] For the interval $[0, \hat{\theta}]$, we find that there exists a value $\tilde{\theta} \in [0, \hat{\theta}]$ such that $W(\theta)$ is strictly increasing in $\theta$ for all $\theta \in [0, \tilde{\theta}]$ and strictly decreasing in $\theta$ for all $\theta \in [\tilde{\theta}, \hat{\theta}]$. See Proposition 8 for an analogous property in case II.

equilibrium for all $\theta \in (\hat{\theta}, 1)$. In contrast, if $\theta \in [0, \hat{\theta}]$, firm $N$ strategically reduces its product quality to $(1-\theta)v_H + \theta v_L$, which in turn reduces firm $S$'s product quality as well. Hence, equilibrium global welfare achieves the maximum possible level when $\theta \in (\hat{\theta}, 1)$.

Finally, Propositions 4 (ii) and 5 together imply the following corollary.

**Corollary 1.** Let $\theta^S$ and $\theta^W$ denote the optimal spillover rates for Southern and global welfare, respectively. Then $\theta^S \in (\hat{\theta}, 1)$ and $\theta^W \in (\hat{\theta}, 1)$ hold.

In case I, the strategic reduction of firm $N$'s product quality reduces both Southern and global welfare. Southern and global welfare are both maximized when $\theta$ exceeds $\hat{\theta}$ so that it is too costly for firm $N$ to strategically reduce its product quality to impose a binding constraint on firm $S$'s choice of product quality.

**Case II:** $t < \bar{t}$

Recall that by Lemma 1, $\hat{\theta} = \theta^* < 1$ holds if $t < \bar{t}$. Firm $N$ undertakes FDI and strategically reduces its product quality by choosing $q_N^* = (1-\theta)v_H + \theta v_L$ if $\theta \leq \theta^*$, whereas it chooses HP and $q_N^* = v_H$ if $\theta > \theta^*$.

**Proposition 6.**
(i) $\pi_N(\theta)$ is strictly decreasing in $\theta$ for all $\theta \in [0, \theta^*]$, and $\pi_N(\theta) = \pi_N(\theta^*)$ for all $\theta \in (\theta^*, 1)$.
(ii) $\pi_S(\theta)$ and $CS(\theta)$ are strictly increasing in $\theta$ for all $\theta \in [0, \theta^*]$, and $\pi_S(\theta^*) > \pi_S(\theta)|_{\theta \in (\theta^*, 1)}$ and $CS(\theta^*) > CS(\theta)|_{\theta \in (\theta^*, 1)}$ hold, where $\pi_S(\theta)$ and $CS(\theta)$ are constant for all $\theta \in (\theta^*, 1)$.

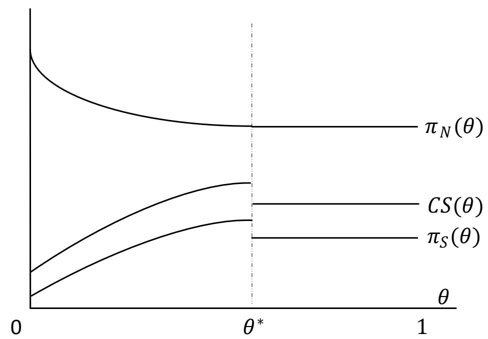


Figure 2: Effects of technology spillovers on $\pi_N(\theta)$, $\pi_S(\theta)$, and $CS(\theta)$ when $t < \bar{t}$.

Figure 2 presents a diagrammatic representation of Proposition 6. Given $\theta^* = \hat{\theta}$, the properties of $\pi_N(\theta)$, $\pi_S(\theta)$, and $CS(\theta)$ in the interval $[0, \theta^*]$ are the same as the ones presented in Proposition 4 for case I. That is, when $\theta \in [0, \theta^*]$, firm $N$ undertakes FDI and imposes a binding constraint on firm $S$'s quality choice by choosing $q_N^* = (1-\theta)v_H + \theta v_L$, but $q_S^*$ is still increasing in $\theta$ for all $\theta \in [0, \theta^*]$. Consequently, for all $\theta \in [0, \theta^*]$, $\pi_N(\theta)$ is strictly decreasing in $\theta$, whereas $\pi_S(\theta)$ and $CS(\theta)$ are strictly increasing in $\theta$.

When $\theta = \theta^*$, firm $N$ is indifferent between choosing FDI with $q_N = (1-\theta^*)v_H + \theta^* v_L$ and HP with $q_N = v_H$. Once $\theta$ exceeds $\theta^*$, it becomes too costly for firm $N$ to undertake FDI, and it chooses HP instead. This is the key difference between cases I and II. Since the tariff rate $t$ is relatively small in case II, home production becomes firm $N$'s optimal choice when $\theta$ exceeds $\theta^*$. Since there is no technology spillover under HP, firm $S$'s equilibrium quality level $q_S^*$ is reduced discontinuously from $\bar{q}_S + \theta^*(q_N^* - \bar{q}_S)$ to $\bar{q}_S$ once $\theta$ exceeds $\theta^*$. Then, $\pi_S(\theta)$ and $CS(\theta)$ are both discontinuously reduced when firm $N$ switches from FDI to HP, because $\pi_S(\theta)$ and $CS(\theta)$ are increasing in the level of firm $S$'s product quality. Therefore, we have that $\pi_S(\theta^*) > \pi_S(\theta)|_{\theta \in (\theta^*, 1)}$ and $CS(\theta^*) > CS(\theta)|_{\theta \in (\theta^*, 1)}$ hold, where $\pi_S(\theta)$ and $CS(\theta)$ are constant for all $\theta \in (\theta^*, 1)$.

Now we turn to Southern welfare. When $\theta \in [0, \theta^*]$, we have that $W_S(\theta) = \pi_S(\theta) + CS(\theta)$ since the Southern government receives no tariff revenue when firm $N$ chooses FDI. Proposition 6 (ii) tells us that $W_S(\theta)$ is strictly increasing in $\theta$ for all $\theta \in [0, \theta^*]$ and is maximized when $\theta = \theta^*$. Pick any $\theta = \theta' \in (\theta^*, 1)$ and compare $W_S(\theta^*)$ and $W_S(\theta')$. Note that when $\theta = \theta'$, firm $N$ chooses home production and the Southern government receives tariff revenue; that is, $W_S(\theta') = \pi_S(\theta') + CS(\theta')$+tariff revenue. Hence the comparison between $W_S(\theta^*)$ and $W_S(\theta')$ is not obvious even though we know $\pi_S(\theta^*) > \pi_S(\theta')$ and $CS(\theta^*) > CS(\theta')$ by Proposition 6 (ii). We find that $W_S(\theta^*) < W_S(\theta')$ if and only if the population of type $H$ consumers $m_H$ is relatively large, as formally stated in Proposition 7.

**Proposition 7 [Southern welfare].** $W_S(\theta)$ is strictly increasing in $\theta$ for all $\theta \in [0, \theta^*]$, and there exists a value $m^*$ such that $W_S(\theta^*) < (=, >)\ W_S(\theta)|_{\theta \in (\theta^*, 1)}$ if $m_H > (=, <)\ m^*$, where $m^* > \hat{m}$ holds under a range of parameterizations and $W_S(\theta)$ is constant for all $\theta \in (\theta^*, 1)$.

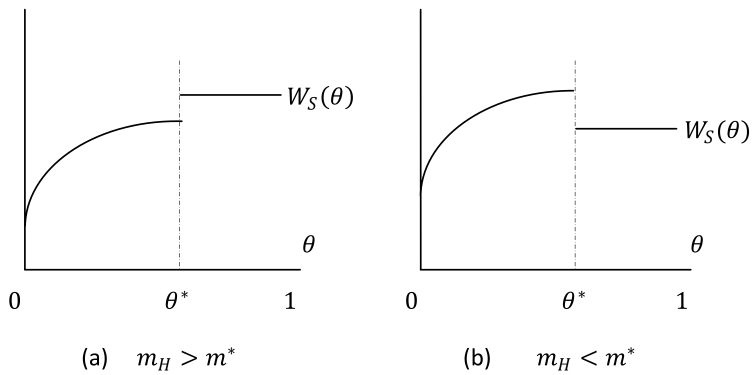


Figure 3: Effects of technology spillovers on $W_S(\theta)$ when $t < \bar{t}$.

Figure 3 presents Proposition 7 diagrammatically. Notice that $\theta = \theta^*$ is the highest possible spillover rate under which firm $N$ undertakes FDI, and hence FDI is most likely to benefit the South in equilibrium when $\theta = \theta^*$. Proposition 7 tells us that even when $\theta = \theta^*$, FDI still hurts the South if the population of type $H$ consumers is relatively large (that is, $W_S(\theta^*) < W_S(\theta)|_{\theta \in (\theta^*, 1)}$ if $m_H > m^*$).

**Proposition 8 [Global welfare].** There exists a value $\tilde{\theta} \in (0, \theta^*]$ such that $W(\theta)$ is strictly increasing in $\theta$ for all $\theta \in [0, \tilde{\theta}]$ and strictly decreasing in $\theta$ for all $\theta \in [\tilde{\theta}, \theta^*]$, and $W(\tilde{\theta}) > W(\theta)|_{\theta \in (\theta^*, 1)}$ holds where $W(\theta)$ is constant for all $\theta \in (\theta^*, 1)$. Furthermore, there exists a value $m^{**}$ $(\leq m^*)$ such that $\tilde{\theta} < \theta^*$ holds if and only if $m_H > m^{**}$, where $m^{**} > \hat{m}$ holds under a range of parameterizations.

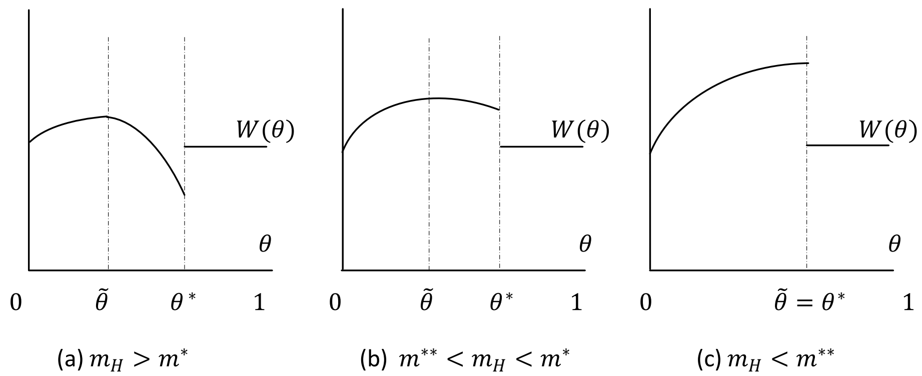


Figure 4: Effects of technology spillovers on $W(\theta)$ when $t < \bar{t}$.

We now turn to global welfare $W(\theta)$. Figure 4 presents Proposition 8 diagrammatically. It shows that $W(\theta)$ can be a non-monotone function of $\theta$ in the interval $[0, \theta^*]$. FDI always improves global welfare, when the globally optimal spillover rate is $\tilde{\theta}$ $(\leq \theta^*)$. Note that the logic behind Propositions 7 and 8 is explained after Corollary 2 below.

We can now compare the optimal spillover rates for Southern and global welfare. We have that $\theta^W = \tilde{\theta} \in (0, \theta^*]$ by Proposition 8. If $m_H > m^*$, we have that $\theta^S$ is any $\theta$ in the interval $(\theta^*, 1)$, implying $\theta^W < \theta^S$ by Proposition 7 (see Figure 4 (a)). Suppose instead that $m_H \leq m^*$, so that $\theta^S = \theta^*$. Proposition 8 tells us that $\theta^W = \tilde{\theta} < \theta^* = \theta^S$ if $m_H > m^{**}$ (see Figure 4 (b)), and $\theta^W = \theta^S = \theta^*$ otherwise (see Figure 4 (c)). Hence, we have Corollary 2.

**Corollary 2.** $0 < \theta^W < \theta^S$ holds if $m_H > m^{**}$, and $0 < \theta^W = \theta^S$ holds otherwise.

***Welfare consequences of strategic quality reduction***

Welfare results presented in Propositions 7 and 8, and Corollary 2 can be summarized as follows.

**Welfare implication I**

FDI reduces Southern welfare when $m_H$ is relatively large.

**Welfare implication II**

The globally optimal spillover rate is strictly higher than the Northern optimal rate, but strictly lower than the Southern optimal rate when $m_H$ is relatively large.

Strategic quality reduction is the driving force of these welfare results. Below, we explain the logic as well as the role played by strategic quality reduction. Let us start with Proposition 8. Recall that, when $\theta = 0$, firm $N$ chooses FDI with $q_N^* = v_H$ and firm $S$ chooses $q_S^* = \bar{q}_S$ since there are no technology spillovers. As the spillover rate increases from $\theta = 0$, firm $N$'s equilibrium product quality $q_N^* = (1-\theta)v_H + \theta v_L$ decreases because of strategic quality reduction, and firm $S$'s equilibrium product quality increases because of spillovers. Consequently, as $\theta$ increases, $q_N^*$ gets further away from the socially optimal level $v_H$ and this reduces the net social benefit associated with type $H$ consumers' consumption. At the same time, $q_S^*$ gets closer to the socially optimal level, $v_L$, and this increases the net social benefit associated with type $L$ consumers' consumption.

This is a new trade-off from technology spillovers. As discussed in Section 3, previous theoretical analyses of technology spillovers in North-South trade contexts have explored the trade-off between R&D incentives and spillovers. In our analysis, the trade-off arises not from R&D incentives but from strategic quality reduction. Proposition 8 tells us that when $\theta$ is relatively small, the positive effect of spillovers dominates the negative effect of strategic quality reduction so that $W(\theta)$ is increasing in $\theta$. It also says that when $m_H$ is relatively large, the strategic quality reduction effect starts to dominate the spillover effect when $\theta$ exceeds a threshold $\tilde{\theta}$ so that $W(\theta)$ is decreasing in $\theta$ for all $\theta \in [\tilde{\theta}, \theta^*]$. Once $\theta$ exceeds $\theta^*$, firm $N$ chooses HP with $q_N^* = v_H$ and firm $S$ chooses $q_S^* = \bar{q}_S$. Note that these equilibrium quality choices are identical to those when $\theta = 0$, implying that equilibrium global welfare is the same under $\theta = 0$ and $\theta \in (\theta^*, 1)$ ($W(0) = W(\theta)$ for all $\theta \in (\theta^*, 1)$). This, in turn, implies that $W(\theta)$ is maximized when $\theta = \tilde{\theta}$.

Proposition 7 says that $W_S(\theta^*) < W_S(\theta')$ ($\theta' \in (\theta^*, 1)$) if and only if $m_H > m^*$, implying that FDI may reduce Southern welfare. Strategic quality reduction, again, is the driving force of this result. The comparison between $W_S(\theta^*)$ and $W_S(\theta')$ is equivalent to the comparison between $W(\theta^*)$ and $W(\theta')$ because global welfare is Southern welfare plus firm $N$'s profit, and firm $N$ is indifferent between $\theta = \theta^*$ and $\theta = \theta'$ (that is, $W(\theta) = W_S(\theta) + \pi_N(\theta)$ and $\pi_N(\theta^*) = \pi_N(\theta')$). When $\theta = \theta^*$, firm $N$ chooses FDI and strategically reduces its product quality level to $(1-\theta^*)v_H + \theta^* v_L$ ($< v_H$) but firm $S$'s product quality $q_S^* = \bar{q}_S + \theta^*(q_N^* - \bar{q}_S)$

is greater than $\bar{q}_S$ because of technology spillovers (but still less than $v_L$). In contrast, when $\theta = \theta'$, firm $N$ chooses HP with $q_N^* = v_H$ and firm $S$ chooses $q_S^* = \bar{q}_S$ since there are no technology spillovers. Given this trade-off, we find that when the population of type $H$ consumers $m_H$ is relatively large, the former effect dominates the latter so that $W(\theta^*) < W(\theta')$ and $W_S(\theta^*) < W_S(\theta')$ hold.

When $m_H > m^*$, FDI reduces Southern welfare (Welfare implication I) and the globally optimal spillover rate, $\theta^W = \tilde{\theta}$, is strictly lower than the Southern optimal rate, $\theta^S \in (\theta^*, 1)$ (Welfare implication II, see Figure 4 (a)). To see that the driving force of these results is firm $N$'s strategic quality reduction, suppose that firm $N$ cannot strategically reduce its product quality and must choose $q_N = v_H$ for any given $\theta$. We find that there exists a value $\theta^{**} \in (0, 1]$ such that firm $N$ undertakes FDI if and only if $\theta \leq \theta^{**}$, where $\theta^{**} < 1$ holds when $t$ is relatively small. If $\theta^{**} < 1$, firm $S$'s equilibrium product quality is strictly increasing in $\theta$ for all $\theta \in [0, \theta^{**}]$ because of technology spillovers. This implies that equilibrium global welfare is maximized when $\theta = \theta^{**}$. Since firm $N$ is indifferent between $\theta = \theta^{**}$ and any $\theta \in (\theta^{**}, 1)$, equilibrium Southern welfare is also maximized when $\theta = \theta^{**}$. That is, FDI benefits the South when $\theta$ is equal to or sufficiently close to $\theta^{**}$, and $\theta^W = \theta^S = \theta^{**}$ holds. Hence, neither implication I nor II holds in the absence of strategic quality reduction.

## 5.2 Effects of tariff rates

In this subsection, we present an outline of comparative statics exercises on the tariff rate $t$, focusing on cases in which the equilibrium of the game is a segmentation equilibrium for all $t > 0$.[19] Let $\pi_N(t)$, $\pi_S(t)$, $CS(t)$, $W_S(t)$, and $W(t)$ denote the profits of the Northern and Southern firms, consumer surplus, Southern welfare, and global welfare in the equilibrium of the game, respectively. For expositional convenience, in this subsection we make a tie-breaking assumption that firm $N$ chooses HP if it is indifferent between HP and FDI.

When $t$ is relatively large, firm $N$ chooses FDI to avoid paying a tariff, and when $t$ is relatively small, firm $N$ chooses HP to avoid technology spillovers. This is formalized in Proposition 9.

**Proposition 9.** For any given $\theta \in [0, 1)$, there exists a value $\tilde{t}(\theta) \geq 0$ such that firm $N$ chooses HP if $t \leq \tilde{t}(\theta)$ and it undertakes FDI if $t > \tilde{t}(\theta)$ in the equilibrium of the game. Furthermore, $\tilde{t}(0) = 0$, $\tilde{t}(\theta)$ is strictly increasing in $\theta$ for all $\theta \in (0, \dot{\theta})$, and $\tilde{t}(\theta)$ is constant for all $\theta \in [\dot{\theta}, 1)$, where $\dot{\theta}$ is as defined in the Appendix.[20]

[19] For any given $\theta \in [0, 1)$, there exists a value $\tilde{m}$ such that the equilibrium of the game is a segmentation equilibrium for all $t > 0$ if and only if $m_H > \tilde{m}$. The proof is presented after the proof of Proposition 1 in the Appendix.

[20] In the proof of Proposition 1, we define $\dot{\theta} \equiv \frac{v_H - \bar{q}_S - \sqrt{(v_H - \bar{q}_S)^2 - 2(v_H - v_L)(v_L - \bar{q}_S)}}{v_H - v_L}$.

When the spillover rate $\theta$ is zero, firm $N$ is strictly better off by undertaking FDI for all $t > 0$, implying $\tilde{t}(0) = 0$. As $\theta$ increases, FDI becomes the less attractive option for firm $N$, and this implies that the threshold $\tilde{t}(\theta)$ is increasing in $\theta$.

When $t \in [0, \tilde{t}(\theta)]$, firm $N$ chooses HP and $q_N^* = v_H$, whereas firm $S$ chooses $q_S^* = \bar{q}_S$ because no technology spills over from firm $N$ to firm $S$ under HP. Notice that equilibrium quality levels $q_N^*$ and $q_S^*$ are constant for all $t \in [0, \tilde{t}(\theta)]$, implying that equilibrium global welfare $W(t) = m_H(v_H q_N^* - \frac{q_N^{*2}}{2}) + m_L(v_L q_S^* - \frac{q_S^{*2}}{2})$ is constant for all $t \in [0, \tilde{t}(\theta)]$. Also, $\pi_N(t)$ is strictly decreasing in $t$ and $W_S(t)$ is strictly increasing in $t$ for all $t \in [0, \tilde{t}(\theta)]$ because firm $N$ pays more tariff to the Southern government as $t$ increases, and firm $N$ is indifferent between HP and FDI when $t = \tilde{t}(\theta)$. Equilibrium Southern welfare $W_S(t)$ is therefore maximized when $t = \tilde{t}(\theta)$.

Once $t$ exceeds $\tilde{t}(\theta)$, firm $N$ switches from HP to FDI, and a further increase in $t$ does not affect equilibrium profits and welfare. Upon choosing FDI, firm $N$ undertakes strategic quality reduction if the spillover rate is low enough, satisfying $\theta \leq \dot{\theta}$ (see the proof of Proposition 1). Then, taking any $t' > \tilde{t}(\theta)$ and comparing Southern and global welfare under $t = \tilde{t}(\theta)$ and $t = t'$, we obtain the following result.

**Proposition 10.**
(i) If $\theta > \dot{\theta}$, $W(t') > W(\tilde{t}(\theta))$ and $W_S(t') > W_S(\tilde{t}(\theta))$ hold.
(ii) If $\theta \leq \dot{\theta}$, there exists a value $\hat{m}^*$ such that $W(t') > (=, <)\ W(\tilde{t}(\theta))$ and $W_S(t') > (=, <)\ W_S(\tilde{t}(\theta))$ hold if $m_H < (=, >)\ \hat{m}^*$, where $\hat{m}^* > \tilde{m}$ holds under a range of parameterizations.

Suppose $\theta > \dot{\theta}$. We have that $q_N^* = v_H$ and $q_S^* = v_L$ under FDI with $t = t'$, whereas $q_N^* = v_H$ and $q_S^* = \bar{q}_S$ under HP with $t = \tilde{t}(\theta)$. That is, firm $N$'s product quality is at the socially optimal level under both HP and FDI; firm $S$'s product quality is also at the socially optimal level under FDI, but below the socially optimal level under HP. Hence we have $W(t') > W(\tilde{t}(\theta))$, which implies $W_S(t') > W_S(\tilde{t}(\theta))$ because firm $N$ is indifferent between $t = t'$ and $t = \tilde{t}(\theta)$.

Next suppose $\theta \leq \dot{\theta}$. We have that $q_N^* = (1-\theta)v_H + \theta v_L$ and $q_S^* = \bar{q}_S + \theta(q_N^* - \bar{q}_S)$ $(< v_L)$ under FDI with $t = t'$, whereas $q_N^* = v_H$ and $q_S^* = \bar{q}_S$ under HP with $t = \tilde{t}(\theta)$. Firm $N$'s product quality is below the socially optimal level under FDI due to strategic quality reduction; firm $S$'s product quality is below the socially optimal level under both FDI and HP, but higher under FDI because of technology spillovers. Given that firm $N$'s product is consumed by high valuation consumers, and firm $S$'s product by low valuation consumers, global and Southern welfare are both higher under HP when $m_H$ is relatively large, implying Proposition 10 (ii).

Proposition 10 tells us that FDI induced by a higher tariff rate hurts the South when the spillover rate is relatively low and the population of high valuation consumers is relatively large. It can be shown, as in the previous subsection, that strategic quality reduction is the driving force of this negative welfare effect of FDI.

# 6 Discussion

## 6.1 Policy implications

We discuss policy implications of our findings based on the assumption that stronger IPR protection in the South reduces the rate of technology spillovers (see, for example, Cohen and Levinthal, 1989; Žigić, 1998; McCalman, 2005; Naghavi, 2007; Belderbos et al., 2008; for papers that make similar assumptions). Lower technology spillover rates and/or higher tariff rates in the South can induce Northern firms to undertake FDI in the South. Would induced FDI benefit the South? FDI can potentially benefit Southern firms and consumers through technology spillovers, but the Southern government loses its tariff revenue under FDI. The total effect of FDI on the South is therefore not obvious in general. We find that FDI hurts the South, in the sense that Southern welfare is lower under FDI than under home-production, when the population of high-valuation consumers is relatively large. Our analysis therefore suggests that when Southern governments formulate IPR protection and trade policy, they should carefully assess the impact of quality-enhancing technology spillovers accompanied by FDI, especially when Northern firms are expected to strategically reduce their product quality upon FDI.

An equally important policy implication of our analysis is that we have identified cases in which the spillover rate that maximizes global welfare is positive but lower than the level that maximizes Southern welfare. Suppose there is a social planner who can set the spillover rate in the South. If Northern welfare were the only concern, the social planner would set the spillover rate at zero, whereas if Southern welfare were the only concern, she would choose a positive spillover rate that maximizes Southern welfare. Should the social planner support the North by choosing a zero spillover rate or support the South by choosing the Southern optimal rate if she was to maximize the sum of the Northern and the Southern welfare? There is no single answer to this question in the literature. Deardoff (1992) shows that extending patent protection from the innovating country to the imitating country reduces global welfare if the innovating country is large. Lai and Qiu (2003) find that harmonizing Southern IPR with that of the North could improve global welfare. We find that the social planner should support neither the North nor the South in a broad range of parameterizations in our model. This is because the globally optimal spillover rate is strictly positive, but lower than the Southern optimal rate when the population of high-valuation consumers is relative large.[21]

[21]If the social planner can choose both the spillover rate and the tariff rate, she would choose a high enough tariff rate to induce firm $N$ to undertake FDI, and choose a high enough spillover rate to induce firm

Trade-Related Aspects of Intellectual Property Rights (the TRIPS agreement), administered by the WTO, is by far the most influential agreement on international IPR issues, and establishes minimum standards of protection for several categories of intellectual property. However, as pointed out by Grossman and Lai (2004), IPR remains a highly contentious issue in international relations. Many developing countries believe that the TRIPS agreement was forced upon them by their economically more powerful trading partners and that the move to harmonize patents and other IPR policies serves the interests of the North at the expense of their own.[22]

An important question that arises from this context, as noted by Lai and Qiu (2003) is, "What are the welfare consequences of strengthening IPR protection in the South for the South, the North, and the world?" Our finding suggests that the WTO has an active role to play in reconciling North-South conflicts on IPR protection, because the globally optimal strength of IPR protection can be strictly in-between the Northern optimal and the Southern optimal in our model.

## 6.2 Quality-enhancing versus cost-reducing technology spillovers

Strategic quality reduction is the new result that arises from our analysis of quality-enhancing technology spillovers. Would a similar phenomenon occur if a Northern firm had superior technology in terms of production costs rather than product quality? This subsection explores this question using an international Cournot duopoly model with cost-reducing technology spillovers. The model, outlined below, has a logical structure similar to our quality-enhancing spillover model.

Northern firm (firm $N$) and Southern firm (firm $S$) compete in the Southern market with a homogenous good. Firm $N$ chooses either home-production (HP) or FDI, while firm $S$ produces in the South. Firm $N$ has superior technology in the sense that its lowest possible constant marginal cost is zero, whereas firm $S$'s lowest possible cost without technology spillovers is $c_0 > 0$. There are no fixed costs of production. Consider the following three stage game. In stage 1, firm $N$ chooses its production location HP or FDI, and its constant marginal cost $c_N$, subject to $c_N \geq 0$. In stage 2, firm $S$ chooses its constant marginal cost $c_S$ with the following constraint. If firm $N$ chose HP, $c_S \geq c_0$ must hold, whereas if firm $N$ chose FDI, $c_S \geq min(c_0 - \theta(c_0 - c_N), c_0)$ must hold where $\theta \in [0, 1)$. Once chosen, production costs become public knowledge. In stage 3, firms $N$ and $S$ compete against each other by choosing quantities, and their profits realize.

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$N$ not to undertake strategic quality reduction. By doing so, the social planner can induce firm $N$ to choose $q_N = v_H$ and firm $S$ to choose $q_S = v_L$ as Proposition 4 suggests, thereby maximizing the global welfare. Also, the Southern government would make the same choice to maximize Southern welfare.

[22]Similarly, Lai and Qiu (2003) point out that it is often argued that the agreement "forces" the South to harmonize its IPR standards with those of the North.

Notice that $\theta$ represents the rate of cost-reducing technology spillovers in this model. If firm $N$ chooses the lowest possible cost $c_N = 0$ upon FDI, then firm $S$'s lowest possible cost is reduced by $\theta(c_0 - 0) = \theta c_0$ from $c_0$ down to $(1-\theta)c_0$. Firm $N$ can set $c_N$ strictly above zero, the minimum possible level, in order to reduce technology spillovers to firm $S$. This action, referred to as *strategic cost increase* in what follows, is a logically comparable action to strategic quality reduction in our quality-enhancing spillovers model.

We have analyzed this model under a general downward-sloping demand function with several regularity conditions and found that firm $N$ does not strategically increase its cost in equilibrium.[23] Specifically, we have found that there exists a value $\theta^* \in (0,1)$ such that firm $N$ chooses FDI in the equilibrium if $\theta \leq \theta^*$ and HP if $\theta > \theta^*$, where firm $N$ chooses the minimum possible cost $c_N = 0$ for all $\theta \in [0,1)$ not only in the HP equilibrium but also in the FDI equilibrium.[24]

Strategic cost increase does not occur in this cost-reducing spillovers model, but strategic quality reduction occurs in our quality-enhancing spillovers model. To understand the difference, consider firm $N$'s strategic cost increase from $c_N = 0$ to $c_N = z > 0$ in the FDI subgame. Firm $N$'s cost increase works in the direction of reducing its profitability. At the same time, the cost increase itself reduces the amount of technology that spills over to firm $S$, resulting in an increase of firm $S$'s equilibrium cost by $\theta z$. Firm $S$'s cost increase, however, is less than that of firm $N$ because spillovers are not perfect. Firm $N$'s cost increase therefore decreases the gap between the costs of firms $N$ and $S$, intensifying competition between the two firms. Hence, the spillover effect also works in the direction of reducing firm $N$'s profitability, so firm $N$ can never increase its profitability by the strategic cost increase.

Let us now consider firm $N$'s strategic quality reduction in the FDI subgame of our quality-enhancing spillovers model. Recall that firm $N$'s profit in the segmentation equilibrium is $m_H[v_H q_N - (v_H - v_L)q_S - \frac{1}{2}q_N^2]$ (see equation 4.3). Firm $N$'s strategic quality reduction from $q_N = v_H$ to $q_N = (1-\theta)v_H + \theta v_L$ works in the direction of decreasing its profitability in the sense that $q_N = v_H$ maximizes the value of $(v_H q_N - \frac{1}{2}q_N^2)$. At the same time, it reduces the amount of technology that spills over to firm $S$, thereby decreasing firm $S$'s equilibrium quality. The spillover effect of strategic quality reduction works in the direction of increasing firm $N$'s profitability because a decrease in firm $S$'s product quality decreases the rent, $(v_H - v_L)q_S$, that firm $N$ must give type $H$ consumers to ensure they purchase from firm $N$. In contrast, as mentioned above, the spillover effect is negative for firm $N$'s profitability in the cost-reducing model. This is the key difference between the

[23]Details of the model and its analysis are presented in the Supplementary note.

[24]We also investigated the welfare consequences of cost-reducing technology spillovers under linear demand functions. We found that FDI always improves Southern welfare in the sense that equilibrium Southern welfare is greater when $\theta = \theta^*$ than when $\theta = \theta' \in (\theta^*, 1)$. Also, the globally optimal spillover rate is either equal to the Southern optimal level ($\theta^*$) or the Northern optimal level (0). Hence, neither Welfare implication I or II (see Subsection 5.2) holds true in this case.

two models. Since the spillover effect is positive for firm $N$ in the quality-enhancing model, strategic quality reduction increases firm $N$'s profitability if the spillover effect dominates the negative direct effect.

## 7 Conclusion

When Northern firms undertake FDI in the South, the superior technology they bring to their Southern operations spills over to Southern firms. Technology spillovers accompanied by FDI often enable Southern firms to enhance product quality. This paper has contributed to the theoretical literature on technology spillovers in North-South trade contexts by exploring a model that incorporates quality-enhancing spillovers in an international duopoly model of vertical product differentiation. We have found that the Northern firm, when it chooses to undertake FDI, strategically reduces its product quality in a broad range of parameterizations to reduce the amount of technology that spills over to the Southern firm.

Strategic quality reduction, which is often observed in reality, leads to the following trade-off regarding welfare consequences of technology spillovers. As the rate of technology spillovers increases, the Northern firm strategically lowers its product quality, reducing the net social benefit associated with high-valuation consumers' consumption. At the same time, an increase in the spillover rate increases the Southern firm's product quality because more technology spills over despite the strategic quality reduction. This effect increases the social benefit associated with low-valuation consumers' consumption.

Previous theoretical analyses have explored the trade-off between R&D incentives and technology spillovers, given that innovating firms' R&D incentives decrease as the spillover rate increases. In our analysis, the trade-off arises not from R&D incentives but from strategic quality reduction. We have demonstrated the importance of this new trade-off by showing that strategic quality reduction drives the following two policy implications of quality-enhancing technology spillovers: (i) FDI may reduce Southern welfare, and (ii) the globally optimal spillover rate is strictly higher than the Northern optimal rate, but can be strictly lower than the Southern optimal rate. Finally, we have considered an international Cournot duopoly model with cost-reducing technology spillovers that has a logical structure similar to our quality-enhancing spillover model. We have found that strategic cost increase, a phenomenon similar to strategic quality reduction, never occurs in equilibrium.

## Appendix

**Proof of Proposition 1.**
The proof is structured as follows. First, we assume that the game has a segmentation SPNE and

find the segmentation SPNE quality and profit for each firm. Second, we identify the necessary and sufficient conditions for a segmentation SPNE to exist. Finally, we show that the segmentation SPNE is the unique equilibrium of the game.

Suppose the game has a segmentation SPNE. In the segmentation SPNE, (A.1)-(A.4) must hold.

$$v_H q_N - p_N \geq 0 \tag{A.1}$$

$$v_L q_S - p_S \geq 0 \tag{A.2}$$

$$v_H q_N - p_N \geq v_H q_S - p_S \tag{A.3}$$

$$v_L q_S - p_S \geq v_L q_N - p_N. \tag{A.4}$$

(A.2) and (A.3) imply $v_H q_N - p_N \geq v_H q_S - p_S \geq 0$, which in turn implies (A.1) holds and can be excluded. If (A.2) does not hold with equality, we can increase both $p_N$ and $p_S$ by a small amount, $\epsilon$, without affecting other constraints: this contradicts the supposition that $p_N$ and $p_S$ are equilibrium prices. Thus, (A.2) holds with equality. Similarly, if (A.3) does not hold with equality, we can increase $p_N$ by a small amount, $\epsilon$, without affecting other constraints, reaching a contradiction. So, (A.3) holds with equality, which in turn implies that (A.4) holds and can be excluded. We end up with only two constraints being held with equality, (A.2) and (A.3). Thus, $p_S = v_L q_S$, and $p_N = v_L q_S + v_H(q_N - q_S)$.

We now turn to find the level of quality and profit for each firm in the segmentation equilibrium of each subgame. Suppose the game has a SPNE in the HP subgame. Then, the problem facing firm $N$ is given by:

$$\max_{q_N} m_H[v_H q_N - (v_H - v_L)q_S - \frac{{q_N}^2}{2} - t], \tag{A.5}$$

and firm $S$ solves its problem:

$$\max_{q_S} m_L[v_L q_S - \frac{{q_S}^2}{2}] \tag{A.6}$$

$$\text{subject to: } q_S \leq \bar{q}_S.$$

The solutions are given by $q_N = v_H$ and $q_S = \bar{q}_S$. Firms $N$ and $S$ obtain profits $\pi_N^{HP} = m_H[v_L \bar{q}_S - v_H \bar{q}_S + \frac{v_H^2}{2} - t]$, and $\pi_S^{HP} = m_L[v_L \bar{q}_S - \frac{\bar{q}_S^2}{2}]$.

Suppose that the game has a SPNE in the FDI subgame. Let $q_S(q_N)$ denote the response function for firm $S$. Then, $q_S(q_N) = v_L$ if $\hat{q}_S(q_N) = \bar{q}_S + \theta(q_N - \bar{q}_S) \geq v_L$, and $q_S(q_N) = \bar{q}_S + \theta(q_N - \bar{q}_S)$ otherwise. Anticipating this, firm $N$ solves its problem:

$$\max_{q_N} m_H[v_H q_N - (v_H - v_L)q_S(q_N) - \frac{{q_N}^2}{2}]. \tag{A.7}$$

The solution to firm $N$'s problem depends on the value of $\theta$. One possibility is that firm $N$ chooses $q_N = (1-\theta)v_H + \theta v_L \equiv q'_N$ which satisfies $\hat{q}_S(q'_N) = \bar{q}_S + \theta(q'_N - \bar{q}_S) < v_L$. In this case, firm $S$ chooses $q_S = \hat{q}_S(q'_N)$. Another possibility is that firm $N$ chooses $q_N = v_H$, which satisfies $\hat{q}_S(v_H) = \bar{q}_S + \theta(v_H - \bar{q}_S) > v_L$ and firm $S$ chooses $q_S = v_L$ (see more on the discussion under the Proposition 3 which rules out other possibilities).

Following the first possibility, the level of profit for firms $N$ and $S$ are $\pi_N^{FDI} = m_H[-(1-\theta)(v_H - v_L)\bar{q}_S + \frac{((1-\theta)v_H+\theta v_L)^2}{2}]$ and $\pi_S^{FDI} = m_L[v_L(1-\theta)\bar{q}_S + \theta[(1-\theta)v_H + \theta v_L] - \frac{((1-\theta)\bar{q}_S+\theta[(1-\theta)v_H+\theta v_L])^2}{2}]$. The second possibility yields $\pi_N^{FDI} = m_H[\frac{v_H^2}{2} + v_L^2 - v_H v_L]$ and $\pi_S^{FDI} = m_L[\frac{v_L^2}{2}]$. Thus, the first possibility will arise in equilibrium when $m_H[-(1-\theta)(v_H - v_L)\bar{q}_S + \frac{((1-\theta)v_H+\theta v_L)^2}{2}] \geq m_H[\frac{v_H^2}{2} + v_L^2 - v_H v_L] \Leftrightarrow \theta \leq \frac{v_H - \bar{q}_S - \sqrt{(v_H-\bar{q}_S)^2 - 2(v_H-v_L)(v_L-\bar{q}_S)}}{v_H - v_L} \equiv \dot{\theta}$, where $\dot{\theta} \in (0,1)$ holds. If, on the other hand, $\theta > \dot{\theta}$, the second possibility will arise in equilibrium.

**Claim 1.** Suppose the game has a segmentation SPNE in which firm $N$ chooses HP in stage 1, then $m_H > max\{\tilde{m}_{H1}, \tilde{m}_{H2}\}$ and $t < \dot{t}$ must hold, where
(i) $\dot{t} \equiv (v_H - v_L)(v_L - \bar{q}_S)$ if $\theta > \dot{\theta}$, and $\dot{t} \equiv \theta(v_H - v_L)[v_H - \bar{q}_S - \theta\frac{v_H - v_L}{2}]$ if $\theta \leq \dot{\theta}$;
(ii) $\tilde{m}_{H1} \equiv m_L \frac{\frac{(v_L-\bar{q}_S)^2}{2} - t}{\frac{v_H^2}{2} - \bar{q}_S(v_H - v_L) - \frac{(v_L-\bar{q}_S)^2}{2}}$ if $t < \frac{(v_L-\bar{q}_S)^2}{2}$, and $\tilde{m}_{H1} \equiv 0$ otherwise; and
(iii) $\tilde{m}_{H2} \equiv m_L \frac{\frac{(1-\theta)(v_L-\bar{q}_S)^2}{2(1+\theta)}}{v_L\bar{q}_S + \frac{v_H^2}{2} - v_H\bar{q}_S - \frac{(1-\theta)(v_L-\bar{q}_S)^2}{2(1+\theta)} - t}$ if $t < \dot{t}$ and $\tilde{m}_{H2} \equiv 0$ otherwise.

*Proof.* First, consider firm $N$'s deviation by choosing FDI in stage 1 and selling its product to type $H$ consumers in stage 2. If $\theta > \dot{\theta}$, it follows that firm $N$ will not deviate if and only if $\pi_N^{FDI}|_{\theta > \dot{\theta}} < \pi_N^{HP} \Leftrightarrow m_H[v_L^2 + \frac{v_H^2}{2} - v_H v_L] < m_H[v_L\bar{q}_S + \frac{v_H^2}{2} - v_H\bar{q}_S - t] \Leftrightarrow t < (v_H - v_L)(v_L - \bar{q}_S) \equiv \bar{t}$. If $\theta \leq \dot{\theta}$, it follows that firm $N$ will not deviate if and only if $\pi_N^{FDI}|_{\theta \leq \dot{\theta}} < \pi_N^{HP} \Leftrightarrow m_H[-(v_H - v_L)\bar{q}_S(1-\theta) + \frac{((1-\theta)v_H+\theta v_L)^2}{2}] < m_H[v_L\bar{q}_S + \frac{v_H^2}{2} - v_H\bar{q}_S - t] \Leftrightarrow t < \theta(v_H - v_L)[v_H - \bar{q}_S - \theta\frac{v_H - v_L}{2}] \equiv \hat{t}$. By defining $\dot{t}$ by $\dot{t} = \bar{t}$ if $\theta > \dot{\theta}$ and $\dot{t} = \hat{t}$ if $\theta \leq \dot{\theta}$, it can be concluded that firm $N$ will not deviate if and only if $t < \dot{t}$.

Second, consider firm $N$'s deviation by choosing HP in stage 1 and selling its product to type $L$ consumers in stage 2. The price and quality level chosen by firm $N$ must satisfy $v_L q_N - p_N \geq v_L q_S - p_S$ for any quality and price level chosen by firm $S$. Thus, $p_N = v_L q_N - v_L q_S + p_S$, and since $v_L q_N - v_L q_S + p_S < v_H q_N - v_H q_S + p_S \Leftrightarrow v_H q_N - p_N > v_H q_S - p_S$, it follows that type $H$ consumers also buy firm $N$'s product unless $q_N < q_S$ holds. As shown below, firm $N$ chooses $q_N = v_L > \bar{q}_S$ in this case; thus it can be concluded that firm $N$ sells its product to all consumers, and firm $S$ sells nothing (making a zero profit).

Firm $S$'s profit when it sells its product to type $L$ consumers in the segmentation SPNE of the HP subgame is $m_L[v_L q_S - \frac{{q_S}^2}{2}]$. Given firm $S$'s constraint on its choice of quality, it chooses $q_S = \bar{q}_S$ to maximize its profit. Thus, $p_N = v_L q_N - v_L\bar{q}_S + \frac{\bar{q}_S^2}{2}$ must hold under deviation. This gives firm $N$ a profit of $(m_H+m_L)(v_Lq_N - v_L\bar{q}_S + \frac{\bar{q}_S^2}{2} - \frac{{q_N}^2}{2} - t)$ (deviation profit), which could be maximized at $q_N = v_L$. Then, firm $N$'s best deviation profit is $\pi_N^{HP'} = (m_H+m_L)(\frac{(v_L-\bar{q}_S)^2}{2} - t)$. If $t \geq \frac{(v_L-\bar{q}_S)^2}{2}$, the best deviation profit is non-positive. If $t < \frac{(v_L-\bar{q}_S)^2}{2}$, $\pi_N^{HP'} < \pi_N^{HP} \Leftrightarrow (m_H + m_L)(\frac{(v_L-\bar{q}_S)^2}{2} - t) < m_H[\frac{v_H^2}{2} - \bar{q}_S(v_H-v_L) - t] \Leftrightarrow m_H > m_L\frac{\frac{(v_L-\bar{q}_S)^2}{2}-t}{\frac{v_H^2}{2}-\bar{q}_S(v_H-v_L)-\frac{(v_L-\bar{q}_S)^2}{2}} \equiv \tilde{m}_{H1}$. Note that $\frac{v_H^2}{2} - \bar{q}_S(v_H-v_L) - \frac{(v_L-\bar{q}_S)^2}{2} = \frac{(v_H-\bar{q}_S)^2}{2} - \frac{(v_L-\bar{q}_S)^2}{2} + v_L\bar{q}_S + \frac{\bar{q}_S^2}{2} > 0$.

Third, consider firm $N$'s deviation by choosing FDI in stage 1 and selling its product to type $L$ consumers in stage 2. Then, it chooses a $[quality, price]$ menu, $[q_N, p_N]$, satisfying: $v_Lq_N - p_N \geq v_Lq_S(q_N) - p_S$. In this case, similar to the logic presented above, type $H$ consumers also buy firm $N$'s product so that it sells to all consumers. It is straightforward to show that in this case, $q_S = \hat{q}_S(q_N) < q_N$ must hold. This is because if firm $S$ chooses $q_S = v_L$, then $p_N = v_Lq_N - \frac{v_L^2}{2}$ so that firm $N$'s deviation profit is $\pi_N = (m_H+m_L)(v_Lq_N - \frac{v_L^2}{2} - \frac{{q_N}^2}{2}) \leq 0$: this is a contradiction . As firm $S$ makes zero profit, the price it charges equals the unit cost, $p_S = \frac{q_S^2}{2}$. Thus, firm $N$'s profit is $(m_H+m_L)(v_Lq_N - v_L\hat{q}_S(q_N) + \frac{\hat{q}_S^2(q_N)}{2} - \frac{{q_N}^2}{2})$, which is maximized at $q_N = \frac{v_L+\theta\bar{q}_S}{1+\theta}$. Hence, firm $N$'s best deviation profit is $\pi_N^{FDI'} = (m_H+m_L)\frac{(1-\theta)(v_L-\bar{q}_S)^2}{2(1+\theta)}$. Then, $\hat{q}_S(q_N) = \frac{\bar{q}_S+\theta v_L}{1+\theta} < v_L$. It follows that $\pi_N^{FDI'} < \pi_N^{HP} \Leftrightarrow (m_H+m_L)\frac{(1-\theta)(v_L-\bar{q}_S)^2}{2(1+\theta)} < m_H[v_L\bar{q}_S + \frac{v_H^2}{2} - v_H\bar{q}_S - t] \Leftrightarrow m_H > m_L\frac{\frac{(1-\theta)(v_L-\bar{q}_S)^2}{2(1+\theta)}}{v_L\bar{q}_S+\frac{v_H^2}{2}-v_H\bar{q}_S-\frac{(1-\theta)(v_L-\bar{q}_S)^2}{2(1+\theta)}-t} \equiv \tilde{m}_{H2}$. Note that $v_L\bar{q}_S + \frac{v_H^2}{2} - v_H\bar{q}_S - \frac{(1-\theta)(v_L-\bar{q}_S)^2}{2(1+\theta)} - t > 0$ holds since $\frac{(1-\theta)(v_L-\bar{q}_S)^2}{2(1+\theta)} + t < \frac{(v_L-\bar{q}_S)^2}{2} + (v_H-v_L)(v_L-\bar{q}_S)$ and $v_L\bar{q}_S + \frac{v_H^2}{2} - v_H\bar{q}_S > \frac{(v_L-\bar{q}_S)^2}{2} + (v_H - v_L)(v_L-\bar{q}_S) \Leftrightarrow \frac{(v_H-v_L)^2}{2} + \frac{(v_L)^2}{2} - \frac{(v_L-\bar{q}_S)^2}{2} > 0$ always holds.

Finally, suppose firm $N$ chooses HP and $q_N = v_H$ in stage 1. Consider firm $S$'s deviation by selling its product to type $H$ consumers in stage 2. Its $[quality, price]$ menu, $[q_S, p_S]$, must satisfy $v_Hq_S - p_S \geq v_H^2 - p_N \Leftrightarrow p_S = v_Hq_S - v_H^2 + p_N$. Since $v_Hq_S - v_H^2 + p_N < v_Lq_S - v_Lv_H + p_N \Leftrightarrow v_Lq_S - p_S > v_Lv_H - p_N$, type $S$ consumers also buy firm $S$'s product, so that firm $S$ sells its product to all consumers and firm $N$ sells nothing, making a zero profit. Since firm $N$'s average cost is $\frac{v_H^2}{2} + t$, when firm $N$ makes zero profit, $p_N = \frac{v_H^2}{2} + t$ must hold. Thus, in this case firm $S$ chooses $p_S = v_Hq_S - \frac{v_H^2}{2} + t$, obtaining profit $(m_H+m_L)(t - \frac{(v_H-q_S)^2}{2})$, which can be maximized at $q_S = \bar{q}_S$. The best deviation profit for firm $S$ is $\pi_S^{HP'} = (m_H+m_L)(t - \frac{(v_H-\bar{q}_S)^2}{2})$. This profit is negative because of condition $t < \dot{t}$ above ($\frac{(v_H-\bar{q}_S)^2}{2} > (v_H-v_L)(v_L-\bar{q}_S) > t$) so that firm $S$ will not deviate. Q.E.D.

**Claim 2.** Suppose the game has a segmentation SPNE in which firm $N$ chooses FDI in stage 1; then, $m_H > max\{\tilde{m}_{H3}, \tilde{m}_{H4}\}$ and $t \geq \dot{t}$ must hold, where

(i) $\tilde{m}_{H3} \equiv \frac{\frac{m_L(1-\theta)(v_L-\bar{q}_S)^2}{2(1+\theta)}}{\frac{v_H^2}{2}-v_Hv_L+v_L^2-\frac{(1-\theta)(v_L-\bar{q}_S)^2}{2(1+\theta)}}$ if $\theta > \dot{\theta}$, and $\tilde{m}_{H3} \equiv \frac{\frac{m_L(1-\theta)(v_L-\bar{q}_S)^2}{2(1+\theta)}}{-(1-\theta)(v_H-v_L)\bar{q}_S+\frac{((1-\theta)v_H+\theta v_L)^2}{2}-\frac{(1-\theta)(v_L-\bar{q}_S)^2}{2(1+\theta)}}$ if $\theta \leq \dot{\theta}$;

(ii) $\tilde{m}_{H4} \equiv \frac{m_L \frac{(v_L-\bar{q}_S)^2}{2}-t}{v_L^2-v_Hv_L-\frac{\bar{q}_S^2}{2}+v_H\bar{q}_S+t}$ if $\theta > \dot{\theta}$, $t < \frac{(v_L-\bar{q}_S)^2}{2}$; $\tilde{m}_{H4} \equiv \frac{m_L \frac{(v_L-\bar{q}_S)^2}{2}-t}{-(v_H-v_L)\bar{q}_S(1-\theta)+\frac{((1-\theta)v_H+\theta v_L)^2}{2}-\frac{(v_L-\bar{q}_S)^2}{2}+t}$ if $\theta \leq \dot{\theta}$, $t < \frac{(v_L-\bar{q}_S)^2}{2}$; and $\tilde{m}_{H4} \equiv 0$ otherwise.

*Proof.* First, consider firm $N$'s deviation by choosing HP in stage 1 and selling its product to type $H$ consumers in stage 2. Then, following the proof of Claim 1, firm $N$ will not deviate if and only if $t \geq \dot{t}$.

Second, consider firm $N$'s deviation by choosing FDI in stage 1 and selling its product to type $L$ consumers in stage 2. Then, its best deviation profit, $\pi_N^{FDI'}$, can be found in the proof for Claim 1. If $\theta > \dot{\theta}$, firm $N$ will not deviate if and only if $\pi_N^{FDI'} < \pi_N^{FDI}|_{\theta>\dot{\theta}} \Leftrightarrow (m_H+m_L)\frac{(1-\theta)(v_L-\bar{q}_S)^2}{2(1+\theta)} < m_H[\frac{v_H^2}{2}-v_Hv_L+v_L^2] \Leftrightarrow m_H > m_L\frac{\frac{(1-\theta)(v_L-\bar{q}_S)^2}{2(1+\theta)}}{\frac{v_H^2}{2}-v_Hv_L+v_L^2-\frac{(1-\theta)(v_L-\bar{q}_S)^2}{2(1+\theta)}} \equiv \tilde{m}_{H3a}$. Note that $\frac{v_H^2}{2}-v_Hv_L+v_L^2-\frac{(1-\theta)(v_L-\bar{q}_S)^2}{2(1+\theta)} > \frac{v_H^2}{2}-v_Hv_L+v_L^2-\frac{(v_L-\bar{q}_S)^2}{2} > 0 \Leftrightarrow \frac{(v_H-v_L)^2}{2}+\frac{v_L^2}{2}-\frac{(v_L-\bar{q}_S)^2}{2} > 0$ always holds.

If $\theta \leq \dot{\theta}$, firm $N$ will not deviate if and only if $\pi_N^{FDI'} < \pi_N^{FDI}|_{\theta\leq\hat{\theta}} \Leftrightarrow (m_H+m_L)\frac{(1-\theta)(v_L-\bar{q}_S)^2}{2(1+\theta)} < m_H[-(1-\theta)(v_H-v_L)\bar{q}_S+\frac{((1-\theta)v_H+\theta v_L)^2}{2}] \Leftrightarrow m_H > m_L\frac{(1-\theta)(v_L-\bar{q}_S)^2}{2(1+\theta)}/(-(1-\theta)(v_H-v_L)\bar{q}_S+\frac{((1-\theta)v_H+\theta v_L)^2}{2}-\frac{(1-\theta)(v_L-\bar{q}_S)^2}{2(1+\theta)}) \equiv \tilde{m}_{H3b}$. Note that $(-(1-\theta)(v_H-v_L)\bar{q}_S+\frac{((1-\theta)v_H+\theta v_L)^2}{2}-\frac{(1-\theta)(v_L-\bar{q}_S)^2}{2(1+\theta)}) > 0$ holds because $-(1-\theta)(v_H-v_L)\bar{q}_S+\frac{((1-\theta)v_H+\theta v_L)^2}{2} = \frac{(\theta[v_H-v_L])^2}{2}+\frac{(v_H)^2}{2}-q_S(q_N)(v_H-v_L) > \frac{(\theta[v_H-v_L])^2}{2}+\frac{(v_H)^2}{2}-v_L(v_H-v_L) = \frac{(\theta[v_H-v_L])^2}{2}+\frac{(v_H-v_L)^2}{2}+\frac{v_L^2}{2} > \frac{(v_L-\bar{q}_S)^2}{2} > \frac{(1-\theta)(v_L-\bar{q}_S)^2}{2(1+\theta)}$ always holds. Let $\tilde{m}_{H3} = \tilde{m}_{H3a}$ if $\theta > \dot{\theta}$ and $\tilde{m}_{H3} = \tilde{m}_{H3b}$ if $\theta \leq \dot{\theta}$.

Third, consider firm $N$'s deviation by choosing HP in stage 1 and selling its product to type $L$ consumers in stage 2. Its best deviation profit, $\pi_N^{HP'}$, can be found in the proof for Claim 1. If $\theta > \dot{\theta}$, firm $N$ will not deviate if and only if $\pi_N^{HP'} < \pi_N^{FDI}|_{\theta>\dot{\theta}} \Leftrightarrow (m_H+m_L)(\frac{(v_L-\bar{q}_S)^2}{2}-t) < m_H[v_L^2+\frac{v_H^2}{2}-v_Hv_L]$, which is always true if $t \geq \frac{(v_L-\bar{q}_S)^2}{2}$. If $t < \frac{(v_L-\bar{q}_S)^2}{2}$, we need $m_H > m_L\frac{\frac{(v_L-\bar{q}_S)^2}{2}-t}{v_L^2-v_Hv_L-\frac{\bar{q}_S^2}{2}+v_H\bar{q}_S+t} \equiv \tilde{m}_{H4a}$. Note that $v_L^2-v_Hv_L-\frac{\bar{q}_S^2}{2}+v_H\bar{q}_S+t > v_L^2-v_Hv_L-\frac{\bar{q}_S^2}{2}+v_H\bar{q}_S+(v_H-v_L)(v_L-\bar{q}_S) = v_L\bar{q}_S-\frac{\bar{q}_S^2}{2} > 0$.

If $\theta \leq \dot{\theta}$, firm $N$ will not deviate if and only if $\pi_N^{HP'} < \pi_N^{FDI}|_{\theta\leq\dot{\theta}} \Leftrightarrow (m_H+m_L)(\frac{(v_L-\bar{q}_S)^2}{2}-t) < m_H[(v_H-v_L)\bar{q}_S(1-\theta)+\frac{((1-\theta)v_H+\theta v_L)^2}{2}]$, which is always true if $t \geq \frac{(v_L-\bar{q}_S)^2}{2}$. If $t < \frac{(v_L-\bar{q}_S)^2}{2}$, we need $m_H > m_L\frac{\frac{(v_L-\bar{q}_S)^2}{2}-t}{-(v_H-v_L)\bar{q}_S(1-\theta)+\frac{((1-\theta)v_H+\theta v_L)^2}{2}-\frac{(v_L-\bar{q}_S)^2}{2}+t} \equiv \tilde{m}_{H4b}$. Note that $-(1-\theta)(v_H-v_L)\bar{q}_S+\frac{((1-\theta)v_H+\theta v_L)^2}{2}-\frac{(v_L-\bar{q}_S)^2}{2} > 0$ holds because $-(1-\theta)(v_H-v_L)\bar{q}_S+\frac{((1-\theta)v_H+\theta v_L)^2}{2} = \frac{(\theta[v_H-v_L])^2}{2}+\frac{(v_H)^2}{2}-q_S(q_N)(v_H-v_L) > \frac{(\theta[v_H-v_L])^2}{2}+\frac{(v_H)^2}{2}-v_L(v_H-v_L) = \frac{(\theta[v_H-v_L])^2}{2}+\frac{(v_H-v_L)^2}{2}+\frac{v_L^2}{2} > \frac{(v_L-\bar{q}_S)^2}{2}$ always holds. Let $\tilde{m}_{H4} = \tilde{m}_{H4a}$ if $\theta > \dot{\theta}$ and $\tilde{m}_{H4} = \tilde{m}_{H4b}$ if $\theta \leq \dot{\theta}$.

Finally, suppose firm $N$ chooses FDI and segmentation SPNE quality level $q_N$ in stage 1. Recall that there are two possibilities: $q_N = v_H$ if $\theta > \dot{\theta}$ and $q_N = q'_N$ if $\theta \leq \dot{\theta}$. Consider firm $S$'s deviation by selling its product to type $H$ consumers in stage 2. Then, firm $S$ chooses a $[quality, price]$ menu, $[q_S(q_N), p_S]$, satisfying $v_H q_S(q_N) - p_S \geq v_H q_N - p_N$ for any $p_N$ firm $N$ chooses. Thus, $p_S = v_H q_S(q_N) - v_H q_N + p_N$. Since $v_H q_S(q_N) - v_H q_N + p_N < v_L q_S(q_N) - v_L q_N + p_N \Leftrightarrow v_L q_S - p_S > v_L q_N - p_N$, firm $S$ sells its product to all consumers and firm $N$ sells nothing (making a zero profit). Firm $N$'s marginal cost is $\frac{{q_N}^2}{2}$. Hence, for firm $S$ to sell to all consumers, $p_S = v_H q_S(q_N) - v_H q_N + \frac{{q_N}^2}{2}$ must hold, and firm $S$'s deviation profit is $\pi'_S = (m_H + m_L)(-\frac{(q_N - q_S)(2v_H - q_N - q_S)}{2}) < 0$, so that firm $S$ will not deviate. Q.E.D.

**Claim 3.** Suppose $m_H > max\{\tilde{m}_{H1}, \tilde{m}_{H2}\}$ and $t < \dot{t}$ hold, or $m_H > max\{\tilde{m}_{H3}, \tilde{m}_{H4}\}$ and $t > \dot{t}$ hold. Then the game has a segmentation equilibrium, which is the unique equilibrium of the game.

*Proof.* Claim 1 and its proof imply that, if $m_H > max\{\tilde{m}_{H1}, \tilde{m}_{H2}\}$ and $t < \dot{t}$ hold, then the segmentation equilibrium of the HP subgame is the unique SPNE of the game. Claim 2 and its proof imply that, if $m_H > max\{\tilde{m}_{H3}, \tilde{m}_{H4}\}$ and $t > \dot{t}$ hold, then the segmentation SPNE of the FDI subgame is the unique SPNE of the game. These two sets of conditions can never happen simultaneously, and this implies the result. Q.E.D.

Finally, by defining $\tilde{m}_H$ as follows

$$\tilde{m}_H = \begin{cases} max(\tilde{m}_{H1}, \tilde{m}_{H2}) & \text{if } t < \dot{t} \\ max(\tilde{m}_{H3}, \tilde{m}_{H4}) & \text{if } t \geq \dot{t}. \end{cases}$$

we obtain Proposition 1. Q.E.D.

**Proof of the results presented in footnotes 17 and 19.**
Footnote 17: Since $\tilde{m}_{H1}$ is independent of $\theta$, $\tilde{m}_{H2}$ and $\tilde{m}_{H3}$ are decreasing in $\theta$, and $\tilde{m}_{H4}$ is weakly increasing in $\theta \in [0, \theta^*]$, it follows that for any given $t$, if $m_H > max\{\lim_{\theta \to 0} \tilde{m}_{H2}, \lim_{\theta \to 0} \tilde{m}_{H3}, \lim_{\theta \to \theta^*} \tilde{m}_{H4}\} \equiv \hat{m}$, then the game has a segmentation SPNE for all $\theta \in [0, 1)$. This result and the proof of Proposition 1 imply that segmentation SPNE is the unique equilibrium of the game.

Footnote 19: Since $\tilde{m}_{H1}$ and $\tilde{m}_{H4}$ are decreasing in $t$, $\tilde{m}_{H2}$ is increasing in $t \in [0, \bar{t}]$, and $\tilde{m}_{H3}$ is independent of $t$, it follows that for any given $\theta \in [0, 1)$, if $m_H > max\{\lim_{t \to 0} \tilde{m}_{H1}, \lim_{t \to 0} \tilde{m}_{H4}, \lim_{t \to \bar{t}} \tilde{m}_{H2}\} \equiv \tilde{m}(\theta)$, then the game has a segmentation SPNE for all $t > 0$. This result and the proof of Proposition 1 imply that segmentation SPNE is the unique equilibrium of the game. Q.E.D.

**Proof of Proposition 2.**
Consider the segmentation SPNE of the game. From the proof of Proposition 1, if $\theta > \dot{\theta} \equiv \frac{v_H - \bar{q}_S - \sqrt{(v_H - \bar{q}_S)^2 - 2(v_H - v_L)(v_L - \bar{q}_S)}}{v_H - v_L}$ then the segmentation SPNE of the game is an FDI equilibrium if $t \geq \bar{t} \equiv (v_H - v_L)(v_L - \bar{q}_S)$ and it is an HP equilibrium if $t < \bar{t}$. If $\theta \leq \dot{\theta}$ then the segmentation SPNE of the game is an FDI equilibrium if $t \geq \hat{t} \Leftrightarrow \theta \leq \frac{v_H - \bar{q}_S - \sqrt{(v_H - \bar{q}_S)^2 - 2t}}{v_H - v_L} \equiv \theta_1$, and it is an HP equilibrium if $t < \dot{t} \Leftrightarrow \theta > \theta_1$. Notice that $\theta_1 > (=, <) \dot{\theta} \Leftrightarrow t > (=, <) \bar{t}$. If $t \geq \bar{t}$ then it follows that firm $N$ chooses FDI for all $\theta \in [0, 1)$ (since $\theta_1 \geq \dot{\theta}$). If $t < \bar{t}$ then, since $\theta_1 < \dot{\theta}$, it follows that firm

$N$ chooses FDI if $\theta \leq \theta_1$ and it chooses HP if $\theta > \theta_1$. It can be verified that $\theta_1(t)$ is increasing in $t$. Finally, by defining $\theta^*$ by $\theta^* = \theta_1$ if $t < \bar{t}$ and $\theta^* = 1$ if $t \geq \bar{t}$, we obtain Proposition 2. Q.E.D.

**Proof of Proposition 3.**
From the proof of Propositions 1 and 2, we have that if $t \geq \bar{t}$ then firm $N$ chooses FDI for all $\theta \in [0, 1)$. In this case, when $\theta \leq \dot{\theta}$ then firm $N$ chooses $q_N = q'_N$ (firm $S$ chooses $q_S = \hat{q}_S(q'_N)$), and when $\theta > \dot{\theta}$ then firm $N$ chooses $q_N = v_H$ (firm $S$ chooses $q_S = v_L$). If, on the other hand, $t < \bar{t}$, then firm $N$ chooses FDI if $\theta \leq \theta_1$ and it chooses HP if $\theta > \theta_1$. In this case, under FDI, firm $N$ chooses $q_N = q'_N$ (firm $S$ chooses $q_S = \hat{q}_S(q'_N)$). Note that when firm $N$ chooses HP then $q_N = v_H$ and $q_S = \bar{q}_S$ hold. Finally, by defining $\hat{\theta}$ by $\hat{\theta} = \theta_1$ if $t < \bar{t}$ and $\hat{\theta} = \dot{\theta}$ if $t \geq \bar{t}$, we obtain Proposition 3. Q.E.D.

**Proof of Lemma 1.**
The proof of Propositions 3 implies the result. Q.E.D.

**Proof of Propositions 4, 5.**
First note that firm $N$ chooses to undertake FDI in the equilibrium for all $\theta \in [0, 1)$ in this case. Proposition 3 implies that, if $\theta > \hat{\theta}$, firm $N$ chooses $q_N = v_H$ and firm $S$ chooses $q_S = v_L$ in the equilibrium, so that $\pi_N(\theta)$, $\pi_S(\theta)$, $CS(\theta)$, $W_S(\theta)$ are all independent of $\theta$. Suppose $\theta \leq \hat{\theta}$. Proposition 3 then implies that firm $N$ chooses $q_N = q'_N$ and firm $S$ chooses $q_S = \hat{q}_S(q'_N)$ in the equilibrium. Then, $q'_N < v_H$ and $\hat{q}_S(q'_N) < v_L$ imply that $W(\theta') > W(\hat{\theta})$, $CS(\theta') > CS(\hat{\theta})$, $\pi_S(\theta') > \pi_S(\hat{\theta})$ and $W_S(\theta') > W_S(\hat{\theta})$, where $\theta' > \hat{\theta}$. We also find that $\frac{\partial \pi_S(\theta)}{\partial \theta}$, $\frac{\partial CS(\theta)}{\partial \theta}$, $\frac{\partial W_S(\theta)}{\partial \theta}$, and $\frac{\partial q_S}{\partial \theta}$ all take positive values for all $\theta \in [0, \hat{\theta}]$, if and only if, $v_H - \bar{q}_S - 2\theta(v_H - v_L) > 0$ holds for all $\theta \in [0, \hat{\theta}]$. For all $t \geq \bar{t}$, we have that $\hat{\theta} < \frac{v_H - \bar{q}_S}{2(v_H - v_L)} \Leftrightarrow 3(v_H - \bar{q}_S)^2 > 8(v_H - v_L)(v_L - \bar{q}_S)$ always holds, and hence $v_H - \bar{q}_S - 2\theta(v_H - v_L) > 0$ holds for all $\theta \in [0, \hat{\theta}]$. We also find that $\frac{\partial \pi_N}{\partial \theta}$ and $\frac{\partial q_N}{\partial \theta}$ both take negative values for all $\theta \in [0, \hat{\theta}]$, given $v_L - v_H < 0$. These results together imply Propositions 4 and 5. Q.E.D.

**Proof of Proposition 6.**
If $\theta > \theta^*$, firm $N$ chooses HP and $q_N = v_H$ and firm $S$ chooses $q_S = \bar{q}_S$ in the equilibrium, so that $\pi_N(\theta)$, $\pi_S(\theta)$, $CS(\theta)$, $W_S(\theta)$ are all independent of $\theta$. Suppose $\theta \leq \theta^*$. Then firm $N$ chooses FDI and $q_N = q'_N$ and firm $S$ chooses $q_S = \hat{q}_S(q'_N)$ in the equilibrium. Then, $\hat{q}_S(q'_N) > \bar{q}_S$ implies that $CS(\theta') < CS(\hat{\theta})$ and $\pi_S(\theta') < \pi_S(\hat{\theta})$ hold, where $\theta' > \hat{\theta}$. Furthermore, as in the proof of Propositions 4 and 5, we find that $\frac{\partial \pi_S(\theta)}{\partial \theta}$, $\frac{\partial CS(\theta)}{\partial \theta}$, $\frac{\partial W_S(\theta)}{\partial \theta}$, and $\frac{\partial q_S}{\partial \theta}$ all take positive values for all $\theta \in [0, \theta^*]$, and $\frac{\partial \pi_N(\theta)}{\partial \theta}$ and $\frac{\partial q_N}{\partial \theta}$ both take negative values for all $\theta \in [0, \theta^*]$. These results together imply Proposition 6. Q.E.D.

**Proof of Proposition 7.**
We have that $W(\theta^*) = m_H(q''_N v_H - \frac{{q''_N}^2}{2}) + m_L(\hat{q}_S(q''_N)v_L - \frac{\hat{q}_S(q''_N)^2}{2})$ and $W(\theta') = m_H(\frac{v_H^2}{2}) + m_L(v_L\bar{q}_S - \frac{\bar{q}_S^2}{2})$, where $\theta' > \theta^*$ and $q''_N = (1 - \theta^*)v_H + \theta^* v_L$. Given $\pi_N(\theta') = \pi_N(\theta^*)$, we have that $W_S(\theta') > W_S(\theta^*) \Leftrightarrow W(\theta') > W(\theta^*)$. We the find that $W_S(\theta') > W_S(\theta^*) \Leftrightarrow m_H(\frac{v_H^2}{2} - (v_H - v_L)\bar{q}_S -$

$t) + m_L(v_L\bar{q}_S - \frac{\bar{q}_S^2}{2}) + m_H(v_H - v_L)\bar{q}_S + m_H t > m_H(q_N'' v_H - \frac{{q_N''}^2 - (v_H - v_L)\hat{q}_S(q_N'')}{2}) + m_L(\hat{q}_S(q_N'')v_L - \frac{\hat{q}_S(q_N'')^2}{2}) + m_H(v_H - v_L)\hat{q}_S(q_N'') \Leftrightarrow m_H > \frac{(v_H - v_L)(\hat{q}_S(q_N'') - \bar{q}_S) + (v_L\hat{q}_S(q_N'') - \frac{\hat{q}_S(q_N'')^2}{2}) - (v_L\bar{q}_S - \frac{\bar{q}_S^2}{2})}{t} \equiv m_1$. It follows that for small enough $t$, $m_1 > \hat{m}$ holds. From Proposition 6 and by defining $m^*$ by $m^* = max\{m_1, \hat{m}\}$, we obtain the result. Q.E.D.

**Proof of Proposition 8.**
For all $\theta \leq \theta^*$, $W(\theta) = m_H\big(q_N' v_H - \frac{{q_N'}^2}{2}\big) + m_L\big(\hat{q}_S(q_N')v_L - \frac{\hat{q}_S(q_N')^2}{2}\big)$. Thus, we have that $\frac{\partial W(\theta)}{\partial \theta} = -m_H\theta(v_H - v_L)^2 + m_L(v_L - \hat{q}_S(q_N'))\frac{\partial \hat{q}_S(q_N')}{\partial \theta}$, which takes a positive value when $\theta = 0$. Furthermore, $\frac{\partial^2 W(\theta)}{\partial \theta^2} = -m_H(v_H - v_L)^2 - m_L\big((\frac{\partial \hat{q}_S(q_N')}{\partial \theta})^2 + (v_L - \hat{q}_S(q_N')(v_H - v_L)\big) < 0$. Hence, $W(\theta)$ is concave in $\theta$ for all $\theta \in [0, \theta^*]$ and can be maximized at some $\tilde{\theta} \leq \theta^*$, where $\theta = \tilde{\theta}$ leads to $\frac{\partial W(\theta)}{\partial \theta} = 0$. It is useful to note that for $\theta = 0$ (FDI) and $\theta = \theta' \in (\theta^*, 1)$ (HP), since firm $N$ chooses $q_N = v_H$ and firm $S$ chooses $q_S = \bar{q}_S$, we have that $W(0) = W(\theta')$. Thus $\theta = \tilde{\theta}$ maximizes global welfare for all $\theta \in [0, 1)$.

If $m_H > m^*$ then $W(\theta^*) < W(\theta')$ for all $\theta' \in (\theta^*, 1)$ by Proposition 7 (recall that since $\pi_N(\theta^*) = \pi_N(\theta')$, $W_S(\theta^*) < W_S(\theta') \Leftrightarrow W(\theta^*) < W(\theta')$. This implies that $\tilde{\theta} < \theta^*$ holds. If $m_H < m^*$ then $\tilde{\theta} < \theta^* \Leftrightarrow \frac{\partial W(\theta)}{\partial \theta}(\theta = \theta^*) < 0 \Leftrightarrow m_H > m_L\frac{[v_L - (\bar{q}_S + \theta^*(v_H - v_L))][v_H - \bar{q}_S - 2\theta^*(v_H - v_L)]}{{\theta^*}^2(v_H - v_L)^2} \equiv m_2$. We also find that $m_2 > \hat{m}$ holds for small enough $t$. By defining $m^{**}$ by $m^{**} = m^*$ when $m_H \geq m^*$, and $m^{**} = max\{m_3, \hat{m}\}$ ($m_3 \equiv min\{m_2, m^*\}$) when $m_H < m^*$, we obtain the result. Q.E.D.

**Proof of Proposition 9.**
From the proof of Proposition 1, if $\theta \geq \dot{\theta} = \frac{v_H - \bar{q}_S - \sqrt{(v_H - \bar{q}_S)^2 - 2(v_H - v_L)(v_L - \bar{q}_S)}}{v_H - v_L}$ then firm $N$ chooses FDI when $t > \bar{t}$, and it chooses HP when $t \leq \bar{t}$. If, on the other hand, $\theta < \dot{\theta}$ then firm $N$ chooses FDI when $t > \hat{t}(\theta)$, and it chooses HP when $t \leq \hat{t}(\theta)$. It can be verified that $\frac{\partial \hat{t}(\theta)}{\partial \theta} = (v_H - v_L)((v_H - \bar{q}_S) - \theta(v_H - v_L)) > 0$ for all $\theta \in [0, 1)$. Finally, by defining $\tilde{t}(\theta)$ by $\tilde{t}(\theta) = \bar{t}$ if $\theta \geq \dot{\theta}$ and $\tilde{t}(\theta) = \hat{t}(\theta)$ if $\theta < \dot{\theta}$, we obtain Proposition 9. Q.E.D.

**Proof of Proposition 10.**
If $\theta \geq \dot{\theta}$, firms $N$ and $S$ choose their socially optimal quality under segmentation SPNE in the FDI subgame ($t = t'$), implying that $W(t') > W(\tilde{t}(\theta))$. If $\theta < \dot{\theta}$, we have that $W(t') = m_H(v_H q_N' - \frac{{q_N'}^2}{2}) + m_L(v_L\hat{q}_S(q_N') - \frac{\hat{q}_S(q_N')^2}{2})$, and $W(\tilde{t}(\theta)) = m_H(\frac{v_H^2}{2}) + m_L(v_L\bar{q}_S - \frac{\bar{q}_S^2}{2})$. Thus, $W(t') > W(\tilde{t}(\theta)) \Leftrightarrow m_H < m_L\frac{(q_N' - \bar{q}_S)(2v_L - \hat{q}_S(q_N') - \bar{q}_S)}{\theta(v_H - v_L)^2} \equiv m_3$. Note that $W_S(t') > W_S(\tilde{t}(\theta)) \Leftrightarrow W(t') > W(\tilde{t}(\theta))$ since $\pi_N(t') = \pi_N(\tilde{t}(\theta))$. We also find that $m_3 > \tilde{m}$ holds for small enough $\theta$. By defining $\hat{m}_H^*$ by $\hat{m}_H^* = max\{m_3, \tilde{m}\}$, we obtain the result. Q.E.D.

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