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International technology transfer and the technology gap

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Abstract

We build a quality ladders product cycle model that explores how the quality of technology transferred through foreign direct investment (FDI) is linked to innovation and imitation when the absorptive capacity of LDCs is limited. Successful imitation of low quality levels makes FDI involving high quality levels possible through reduction of the technology gap. A subsidy to imitation or a tax on low quality FDI production encourages imitation relative to innovation, thus releasing the constraint faced by foreign firms seeking to produce in the South. These forces that stimulate high-quality FDI raise Southern welfare through lower prices, faster innovation and higher wages. © 1998 Elsevier Science B.V.

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1. Introduction

Countries frequently rely on successful assimilation of foreign technology to achieve indigenous technological development. For example, in the initial phases

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of development, much of the R&D undertaken in Japan was absorptive, aimed at integrating foreign technologies (Blumenthal (1976)).[2] More recently, countries such as Mexico, Brazil, India, and China view foreign direct investment (FDI) by firms from technologically advanced countries as a vehicle of technology transfer. However, a common fear of many such developing countries is that local affiliates of foreign firms may not transfer the latest technologies from their parent firms.[3]

Empirical evidence indicates that such fears are not unfounded; multinational firms generally transfer technologies that, despite being more advanced than indigenous technologies, still lag behind the state-of-the-art (Mansfield and Romeo (1980)). What determines how much FDI from industrialized countries to developing countries transfers state-of-the-art technologies?

Multinationals often transfer older technologies to safeguard themselves against future competition. While strategic considerations play a role in determining the quality of technology transferred by multinationals in some situations, the limited absorptive capacity of such countries must act as a constraint on the ability of foreign firms to transfer state-of-the-art technologies in other situations. In a seminal work, Teece (1976) demonstrated that the costs of technology transfer are substantial and decline with the age of the technology being transferred (Kumar (1994) provides more recent evidence). In countries that lag significantly behind the technology frontier, difficulties inherent in transferring state-of-the-art technology likely outweigh strategic considerations. Countries that are too backward to host frontier technologies are plausibly also too backward to provide much threat of real competition.

In this paper, we build a general equilibrium model that accounts for the limited ability of developing countries to host FDI that transfers state-of-the-art technologies. Our model links the quality of technology transferred through FDI to the technology gap between the countries, as determined by the rate of imitation relative to innovation. Our paper is unique in determining the degree that technology transferred to LDCs through FDI from DCs lags behind the state-of-the-art in a setting where innovation and imitation respond to profit incentives and FDI from the advanced North to the lagging South occurs only slightly ahead of the Southern technology frontier. This limitation on FDI makes the quality of technology transferred through FDI for each product react to the size of the technology gap between the North and the South for that product.

Local R&D in the South (imitation), by shrinking the technology gap, permits FDI to transfer more advanced technologies while local R&D in the North (innovation), by expanding the technology gap, limits FDI to transferring more primitive technologies relative to the state-of-the-art. Thus the quality of technol-

[2] See Pack and Saggi (1997) for an overview of the relationship between imported technology and domestic technological development.

[3] See the United Nations' (1992) *World Investment Report*.

ogy transferred relative to the state-of-the-art depends upon the incentives for imitation relative to innovation. Specifically, the extent of high-quality FDI depends on such parameters influencing the incentives for imitation relative to innovation as the share of income spent on high quality levels, the cost disadvantage of multinationals relative to Southern firms, the resource requirement in innovation relative to imitation, and Northern resources relative to Southern resources.

What policies can the government of a potential host LDC implement to attract FDI from DCs that transfers state-of-the-art technologies? A host country can encourage high-quality FDI by encouraging domestic R&D activities that push forward the local technology frontier and thus make high-quality FDI more attractive to source country firms. This task can be accomplished either by a tax on low-quality multinational production or a subsidy to imitation. Are such policies welfare improving? Product market prices decline, the rate of innovation accelerates and the Southern wage rises with the extent of high-quality FDI in the South, so these policies do improve Southern welfare. Our welfare results show that the Southern government does indeed desire a higher quality mix of FDI, thus ruling out the possibility that policies promoting high-quality FDI might reduce Southern welfare through adversely affecting the rate of innovation.

Our work springs from the extended literature examining the relationship between international trade and the quality of products such as Segerstrom et al. (1990). We build on the quality ladders product cycle model of Grossman and Helpman (1991) to address the South's limited ability to host FDI. First, following Glass and Saggi (1995), Northern firms can locate production in the South through FDI. [4] Second, following Glass (1997), two different quality levels of each product sell in equilibrium due to consumer heterogeneity, so FDI can involve production of high or low quality levels, distinguishing whether the technology transferred through FDI lags behind the state-of-the-art. [5] Third, the South hosts high-quality FDI only if indigenous firms have the knowledge to produce the low quality level of that product. The setup of our model is appropriate for a country that lags sufficiently behind the technology frontier to have difficulty hosting state-of-the-art FDI. [6]

While Glass and Saggi (1995) and Glass (1997) do share some features with our current paper, the issues differ substantially. In Glass and Saggi (1995), we analyze how innovation responds to an increase in the flow of FDI from the North

[4] To simplify analysis, FDI occurs immediately after innovation, not after a lag.

[5] The South never catches up to the North for any product, as in the inefficient Southern followers equilibrium.

[6] For countries that slightly lag behind the technology frontier, a one quality level model such as Glass and Saggi (1995) would be more appropriate, as these countries should be able to host state-of-the-art FDI.

to the South when Southern firms can imitate both Northern firms and multinationals. In our current paper, we analyze how FDI promotes the ability of Southern firms to imitate, which in turn shrinks the technology gap and thus promotes the South's ability to host FDI that transfers superior technologies. Glass and Saggi (1995) is relevant to more advanced Southern countries, countries capable of imitating the state-of-the-art technology even in the absence of the knowledge spillovers from FDI. Our current paper is relevant to more backward Southern countries, countries incapable of imitating the state-of-the-art technology even in the presence of the knowledge spillovers from FDI. Glass (1997) analyzes how relative resources, relative R&D efficiency and R&D subsidies affect Southern market penetration, the quality mix of Southern production. In our current paper, we address how these forces, plus multinational cost disadvantage and multinational production taxes, affect the quality mix of FDI. Since FDI does not occur in Glass (1997) and only one quality level sells in Glass and Saggi (1995), neither of those papers determines the quality mix of FDI.

Our model generalizes the results of Flam and Helpman (1987), Stokey (1991) and Glass (1997), where Northern production involves a higher quality mix than Southern production, to determine the quality mix of multinational production. Like the existing models, we determine the size of the technology gap between the North and the South. Additionally, we link the quality of technology transferred through FDI to the magnitude of the technology gap. FDI transfers technology to the South that is on average below the Northern technology frontier but above the Southern technology frontier. Thus, multinational production occurs in a range of quality levels with an average quality level between pure Northern production and pure Southern production.

International technology transfer occurs through multiple channels in our model. First, innovation makes old technology obsolete—available as a knowledge base to attract low-quality FDI. As Northern firms innovate and push forward the quality frontier, the knowledge required for producing the previous low quality level becomes discarded technology, no longer capable of generating profits. [7] When innovation occurs in markets where a large technology gap limits FDI to low quality levels, the previous low quality level becomes discarded technology available to the South. [8] Consequently, the previous state-of-the-art becomes the

[7] That discarded technology acts as a form of technology transfer is argued in Glass (1997). Some very poorly developed countries may lack the ability to absorb even discarded technologies. For the purposes of this paper, we are interested in the group of LDCs that do attract FDI (and thus must be able to absorb discarded technologies), but FDI that transfers technology below the state-of-the-art.

[8] When innovation occurs in markets with high-quality FDI, the previous low-quality level becomes discarded technology but the technology was already produced by a Southern firm. No technology is transferred through FDI in that case as the new (relatively) low quality level produced through FDI is the same technology in absolute terms as the previous high quality level produced through FDI.

new low quality level and production in the South becomes attractive thanks to discarded technology providing the necessary knowledge foundation. Even though FDI remains limited to the low quality level (relative to the state-of-the-art), a better technology is transferred through FDI since the state-of-the-art has risen.

Second, imitation upgrades the knowledge base in the South and consequently expands the South’s absorptive capacity so that FDI in high quality levels of products becomes feasible. Katrak (1989), Kokko (1994), and Siddharthan (1992) all provide empirical evidence showing technology transfer through FDI and domestic R&D investment are complementary activities. Shifting production to the South lowers production costs but not all the way down to the production costs of potential Southern rivals. The theory of FDI according to Markusen (1995) supports the idea that multinationals are disadvantaged relative to native firms due to operating in an unfamiliar environment. We link this cost disadvantage of multinationals to the difference between the technology to be transferred and the present technological ability of the host country. In situations where the Southern technology frontier is far behind the potential technology to be transferred through FDI, Northern firms find shifting their production to the South prohibitively expensive due to the magnitude of the technology gap. However, as the technology gap shrinks, multinational production using state-of-the-art technology in the South becomes attractive as production costs fall due to the lessened expenses from bridging the technology gap. In this manner, imitation investments by Southern firms promote technology transfer by providing the technological base needed to attract FDI.

Our model examines the dynamics of FDI and the interplay between FDI, imitation and technology transfer. We introduce dynamic links between imitation and technology transfer. In particular, our model specifies links between initial low quality FDI, low quality imitation, and subsequent high-quality FDI, thus capturing the dynamic externalities between multinationals and Southern firms. We explore the implications of FDI for Southern technological progress and the reverse implications of Southern technological progress for FDI. [9] Our paper adds significant value by modeling FDI as being more difficult when the technology gap is large and also modeling FDI as creating knowledge spillovers that enable the South to reduce the technology gap.

Keller (1996) argues that mere access to foreign technologies may not increase growth rates of LDCs. He makes the important point that if a country’s absorptive capacity (stock of human capital) remains unchanged, a switch to an outward orientation will not lead to a higher growth rate. Our paper complements Keller’s analysis by giving investment in imitation a role similar to human capital accumulation in Keller’s model. In our model, imitation investments by host country firms generate the necessary knowledge (or skill) foundation for FDI, and

[9] Findlay (1978) emphasized the contagion effects of FDI for Southern technological progress.

thus factors that promote imitation can promote a higher quality mix of FDI. While Keller's model stresses that a country's limited stock of human capital effectively constrains its ability to take advantage of foreign technologies, our model stresses that indigenous technological capability in an industry effectively constrains its ability to host foreign technology. [10] FDI directly transfers technology from the North to the South, but such transfers are cost effective for Northern firms only if the South is sufficiently advanced.

Blomström and Kokko (1995) find empirical evidence that the technology imports of multinationals respond positively to the investments of local firms. While such increased technology transfer may stem from increased local competition, investments by local firms in an industry may enhance that industry's technological capability, thus enabling multinationals to transfer improved technologies. When local firms provide their workers with the training needed to handle base technologies, multinationals then find less training is required to bring local workers up to the level needed to handle the best technologies available. When local firms provide key technological background that closes the technology gap between the countries, the ideal setting for a multinational wanting to transfer advanced technologies is not a complete absence of local firms.

Rodríguez-Clare (1996) argues that multinationals are beneficial to the host country when they generate linkage effects beyond those generated by the local firms displaced. In that framework, FDI transferring advanced technologies may involve more complex production activities that generate stronger linkage effects for the local economy thereby enhancing its appeal relative to FDI transferring less advanced technologies. We provide further reasoning behind the appeal of high-quality FDI to Southern economies: lower prices, faster innovation, and higher Southern wages. We also argue that local production may provide the fundamental background knowledge needed to transfer more advanced technologies in a cost effective manner, thus placing emphasis on the need to build a local technological foundation to attract a better mix of FDI.

The paper is organized as follows. After establishing the behavior of consumers and firms (Section 2) and finding the steady-state equilibrium (Section 3), we show that when FDI is limited to appropriate technologies, forces that promote imitation relative to innovation generate a higher quality mix of multinational production by closing the technology gap (Section 4). We then examine Southern policies that encourage high-quality FDI. A subsidy to local R&D or a tax on multinational production of low quality levels increases the extent of FDI in high quality levels of products. Finally, we explore the welfare implications of these policies and conclude. Proofs of results appear in Appendix A.

[10] Therefore, we take a more disaggregated view of the constraints on technology transfer relative to Keller. For example, a country may have a fair amount of human capital in the aggregate but may lack the technological sophistication in a particular product to be able to host high-quality FDI.

2. The economy

The economy is composed of two countries containing two types of consumers and many firms. Consumers differ in their valuation of quality so that high-type consumers purchase higher quality levels of each product than low-type consumers. Firms differ in their R&D abilities so that Northern firms innovate while Southern firms imitate. Firms in the North may produce in the South, where costs are lower, but only for appropriate technologies. Appropriate technologies are technologies for producing quality levels no more than one step ahead of the Southern technology frontier. In equilibrium, expected profits from the product market just compensate firms for their R&D costs, and the labor supply is fully employed in either R&D or production in each country.

2.1. Consumers

Consumers are each one of two types, $\omega \in \{A, B\}$ low and high, and live in one of two countries, $i \in \{N, S\}$ North and South. Consumers choose from a continuum of products indexed by $j \in [0, 1]$, available in a discrete number of quality levels indexed by m. Taste for quality improvement, λ^m, differs across types. Let $\lambda^B > \lambda^A > 1$, so that high-type consumers (B) value quality improvement more than low-type consumers (A).

Consumers of each type ω in each country i maximize lifetime utility subject to an intertemporal budget constraint. Consumers have additively separable intertemporal preferences given by lifetime utility

$$U_i^{\omega} = \int_0^{\infty} e^{-\rho t} \log u_i^{\omega}(t) \mathrm{d}t, \tag{2.1}$$

where ρ is the common subjective discount factor. [11] Instantaneous utility is

$$\log u_i^{\omega}(t) = \int_0^1 \log \left[\sum_m (\lambda^{\omega})^m x_{im}^{\omega}(j,t) \right] \mathrm{d}j, \tag{2.2}$$

where $(\lambda^{\omega})^m$ is the assessment by type ω consumers of quality level m and $x_m^{\omega}(j,t)$ is consumption by type ω consumers of quality level m of product j at time t. Consumers maximize lifetime utility subject to an intertemporal budget constraint. Since preferences are homothetic, aggregate demands for each group of

[11] For simplicity, the discount rate is common across countries. A higher discount rate in the South relative to the North could create a separate force reducing the extent of high-quality FDI by discouraging imitation relative to innovation due to requiring a higher rate of return for imitation to be undertaken.

consumers are found by maximizing lifetime utility subject to the aggregate intertemporal budget constraint

$$\int_0^\infty e^{-R(t)} E^\omega(t)\,\mathrm{d}t \le A^\omega(0) + \int_0^\infty e^{-R(t)} Y^\omega(t)\,\mathrm{d}t, \tag{2.3}$$

where $R(t)$ is the cumulative interest rate up to time t and $A^\omega(0) = f(\omega)A(0)$ is the aggregate value of any initial asset holdings by type ω consumers.[12] Aggregate income of type ω consumers is

$$Y^\omega(t) = \sum_i f(\omega) L_i w_i(t) \tag{2.4}$$

where $w_i(t)$ is the wage in country i at time t and L_i is the labor supply in country i. Thus $L_i w_i(t)$ is total labor income in country i at time t and $f(\omega)L_i w_i(t)$ is the share that goes to type ω consumers.[13] Aggregate spending of type ω consumers is

$$E^\omega(t) = \int_0^1 \left[\sum_m p_m(j,t)\, x_m^\omega(j,t) \right] \mathrm{d}j, \tag{2.5}$$

where $p_m(j,t)$ is the price of quality level m of product j at time t. Define aggregate spending by all consumers as $E = E^{\mathrm{A}} + E^{\mathrm{B}}$.

The consumers problem can be broken into three stages: allocation of lifetime wealth across time, allocation of expenditure at each instant across products, and allocation of expenditure at each instant for each product across available quality levels. In the first stage, consumers evenly spread lifetime spending for each product across time; in the second stage, consumers evenly spread spending at each instant across products. In the final stage, consumers allocate spending for each product at each instant to the quality level with the lowest quality adjusted price.

Introducing differences in valuation of quality across consumers permits more than one quality level of each product to sell in equilibrium. Both the approach taken here and the alternative approach of assuming indivisibility in consumption and differences in income generate multiple quality levels selling in equilibrium. Here we fix the price premium paid for a quality increment and let the quantity consumed adjust to achieve budget balance; Flam and Helpman (1987) fix the

[12] Individuals hold assets in the form of ownership in firms, but with a diversified portfolio, any capital losses appear as capital gains elsewhere, so only the initial value of assets enters the intertemporal budget constraint. Lack of perfect capital mobility could provide an additional reason for the South to favor a larger extent of high-quality FDI due to the greater value of Southern firms.

[13] For simplicity, the distribution of income across consumer types is identical across countries, even though most LDCs have a higher income share of low-type consumers. Allowing the distribution of consumer types to vary across countries would not alter any of our results since the taxes considered here are based on the location of production, not consumption.

quantity consumed and let the price premium adjust instead. Assuming indivisibility in consumption might appear to limit relevance to goods consumed in a fixed quantity. Further, any fixity of consumption would preclude general equilibrium adjustments occurring through labor demand for production, an undesirable trait when analyzing the incentives of innovation and imitation. [14]

Because consumers differ in their valuation of quality, the price that makes a consumer indifferent between one quality level and the quality level below varies across types: high-type consumers view a specific quality level offered at a given price as being a better value than do low-type consumers. Thus, when offered a menu of a low quality level for a low price and a high quality level for a high price, the two types of consumers need not agree on which quality level offers the best deal: for a range of prices, low-type consumers pick the low quality level while high-type consumers pick the high quality level. Provided a sufficient percentage of income is in the hands of high-type consumers, firms choose prices that cause high-type consumers to self-select by buying the high quality level, whereas low-type consumers buy the low quality level (see Section A.1).

The model focuses on the separating equilibrium, where consumers with different valuations of quality buy different quality levels of products. More than one quality level of each product must sell so FDI can be ranked by the technology transferred relative to the state-of-the-art. Having multiple quality levels of each product sell in equilibrium generates markets where Northern firms have a large lead over Southern firms and markets where Northern firms have only a small lead. The measure of markets where Southern firms have not yet copied the low quality level provides a concrete measure of the degree that the technologies Northern firms can transfer to the South are limited due to the technological backwardness of the South.

2.2. Firms

The firms problem can be broken down into two stages. First, when undertaking R&D, a firm chooses its intensity of R&D to maximize its expected value, given the R&D intensities of other firms. Once successful in R&D, the firm then chooses the price of its product to maximize its value, given prices and R&D intensities of other firms. R&D for Northern firms is innovation, designing higher quality levels, while R&D for Southern firms is imitation, copying quality levels designed by Northern firms. The technology frontier for each country and each product is the highest quality level of the product that can be produced by any native firm in that country.

[14] Flam and Helpman (1987) construct a static model, so incentives for innovation and imitation are not an issue there.

2.2.1. Production

Normalize the unit labor requirement in production to 1; further normalize all prices by the Southern wage. Thus the marginal cost of production is 1 for Southern firms and $w \equiv w_N / w_S = w_N$ for Northern firms. Let the marginal cost of production for a multinational be ζ for quality levels one step above the Southern technology frontier. Assume multinationals have a cost disadvantage relative to Southern firms, $\zeta > 1$, stemming from their lack of familiarity with the Southern environment and from employing their technologies in a foreign environment.

By the assumptions of two types of consumers and a separating equilibrium, two quality levels of each product sell at any point in time. By the assumption that Southern firms have access to discarded technology (technologies that no longer yield profits from production), the Southern technology frontier is at most two quality levels below the Northern technology frontier for any product. By the assumption that Southern firms imitating the state-of-the-art is prohibitively costly, the Southern technology frontier never catches up to the Northern frontier for any product; that is, Southern firms can never imitate the high quality level of any product. [15] Therefore, for some products, the North has a two-quality level lead over the South, while for other products, the North has only a one-quality level lead over the South. These assumptions lead to a simple version of the model that contains the essential features: in some markets, the technology gap is large enough to prevent high-quality FDI.

By assumption, for products where the North has a two-quality level lead over the South, only the low quality level is produced through FDI; where the North has only a one-quality level lead over the South, the high quality level is produced through FDI in the South. Transferring technology through FDI involves prohibitive costs if the host country is extremely technologically backward relative to the technology to be transferred. The underlying assumption is that $\zeta < w$ (in equilibrium) is the marginal cost of production for FDI one-quality level above the Southern technology frontier, while a much higher marginal cost of production $Z > w$ (in equilibrium) applies for FDI more than one-quality level above the Southern technology frontier. Since cost savings provide the incentive for Northern firms to undertake FDI, FDI then occurs only one-quality level above the Southern technology frontier.

Consider first markets where the North has a two-quality level lead over the South. Southern firms are sufficiently disadvantaged by their low quality in these markets that they cannot offer a price that covers costs and still attract customers. Thus the two active firms for each product are the two Northern firms that invented the current two highest quality levels for that product, where the

[15] The desire to attract high-quality FDI is most relevant to scenarios where the South cannot fully catch up to the North. If the South can catch up to the North, it is less likely that a large enough technology gap persists for enough products to limit state-of-the-art FDI significantly.

low-quality firm becomes a multinational to produce in the South through FDI but the high-quality firm does not, as the South is too technologically backward to host the state-of-the-art. The high-quality Northern firm engages in limit pricing against the low-quality multinational, charging a premium reflecting a high-type consumer's valuation of quality; the low-quality multinational in turn engages in limit pricing against inactive Southern firms with discarded technology one quality level below, charging a premium reflecting a low-type consumer's valuation of quality. The high-quality Northern firm charges price $p_N^H = \lambda^B \lambda^A$ and the low quality multinational charges price $p_M^L = \lambda^A$. The Northern firm has marginal cost of production w, while the multinational has marginal cost of production ζ. Instantaneous profits for the high-quality Northern firm are

$$\pi_N^H = E^B \left(1 - \frac{w}{\lambda^B \lambda^A}\right) \tag{2.6}$$

and instantaneous profits for the low-quality multinational are

$$\pi_M^L = E^A \left(1 - \frac{\zeta}{\lambda^A}\right) \tag{2.7}$$

where $E^B \equiv f(B)E$ and $E^A \equiv f(A)E$ are the shares of aggregate spending by high- and low-type consumers, respectively. We call these markets *low-quality FDI* markets since the magnitude of the technology gap limits FDI to low quality levels.

Now consider markets where the North has only a one-quality level lead over the South. Southern firms are somewhat disadvantaged in these markets: the Southern firm that imitated the low quality level can charge a price that covers costs and attract low-type consumers; however, the Southern firm is limited to the low end of the market. [16] Thus the two active firms for each product are the Northern firm (which becomes a multinational) that invented the current highest quality level and the Southern firm that imitated the next highest quality level. The high-quality multinational engages in limit pricing against the low-quality Southern firm, which in turn engages in limit pricing against the multinational at the same low-quality level. The high-quality multinational charges price $p_M^H = \lambda^B \zeta$ and the low-quality Southern firm charges price $p_S^L = \zeta$. The multinational has marginal cost of production ζ, while the Southern firm has marginal cost of production 1. Instantaneous profits for the high-quality multinational are

$$\pi_M^H = E^B \left(1 - \frac{1}{\lambda^B}\right) \tag{2.8}$$

[16] As in Glass (1997), the equilibrium concept is subgame perfection in the repeated-play game, where tit-for-tat strategies support market segmentation as value maximizing for both firms (when the share of income spent on high quality levels $f(B)$ is sufficiently large).

and instantaneous profits for a low-quality Southern firm are

$$\pi_S^L = E^A\left(1 - \frac{1}{\zeta}\right) \tag{2.9}$$

We call these markets *high-quality FDI* markets since the technology gap is small enough for the South to host FDI at high quality levels.

Northern firms target all markets for innovation and Southern firms target only low-quality FDI markets (since targeting high quality levels is too difficult). A Northern firm successful at innovation gains the value of a high-quality Northern firm v_N^H; a Southern firm successful at imitation gains the value of a low-quality Southern firm v_S^L. Let v_M^L denote the value of a low-quality multinational and v_M^H denote the value of a high-quality multinational.

To find the value of producing firms, discount the flow of instantaneous profits for each type of producing firm to account for the chance that the profit stream will be terminated due to innovation or imitation. Low-quality FDI markets are targeted by both imitation and innovation. For a high-quality Northern firm, subsequent innovation (ι) makes the firm a low-quality multinational, while subsequent imitation (μ) makes the firm a high-quality multinational.

$$v_N^H = \frac{\pi_N^H + \iota v_M^L + \mu v_M^H}{\rho + \iota + \mu} \tag{2.10}$$

For a low-quality multinational, subsequent innovation or imitation pushes the firm out of the market.

$$v_M^L = \frac{\pi_M^L}{\rho + \iota + \mu} \tag{2.11}$$

High-quality FDI markets are targeted by innovation only. For a high-quality multinational, subsequent innovation makes the firm a low-quality multinational.

$$v_M^H = \frac{\pi_M^H + \iota v_M^L}{\rho + \iota} \tag{2.12}$$

For the low-quality Southern firm, subsequent innovation pushes the firm out of the market.

$$v_S^L = \frac{\pi_S^L}{\rho + \iota} \tag{2.13}$$

By repeated substitution, the value terms can be eliminated from the right-hand side of Eqs. (2.10) and (2.12), leaving the value of a high-quality Northern firm and the value of a low-quality Southern firm as the discounted streams of expected instantaneous profits. These values indicate the reward to successful innovation and imitation. These rewards must offset the costs of innovation and imitation for innovation and imitation to occur in equilibrium.

2.2.2. Innovation and imitation

To produce a quality level of a product, a firm must first design it. Firms are willing to endure the costs of developing higher quality levels because they earn profits in the product market if successful. The potential for quality improvement is unbounded; however, both innovation and imitation must proceed one quality level at a time. While Northern firms push forward the quality frontier of existing products through innovation, Southern firms pursue the quality frontier through imitation.

R&D races occur simultaneously for all products. A Northern firm undertaking innovation intensity ι for a time interval dt requires $\gamma a \iota dt$ units of labor at cost $w\gamma a \iota dt$ and leads to success with probability ιdt; for a Southern firm, undertaking imitation intensity μ for a time interval dt requires $a\mu dt$ units of labor at cost $a\mu dt$ and leads to success with probability μdt. Innovation is more difficult than imitation, and thus requires relatively more resources: $\gamma > 1$.

Assume the South is at worst just out of each product market. Such a situation occurs if knowledge of the design of quality levels no longer produced (discarded technology) leaks out to Southern firms. A technology becomes discarded when any firm that invented or imitated that quality level no longer earns any profits from producing it; therefore, no firm would have any reason to protect its design. Otherwise, no Southern firm could ever imitate even the low-quality level once enough innovations occur uninterrupted by imitation because the South would lack the base technological knowledge needed to imitate even low quality levels.

The South is limited to imitating *appropriate technologies*, quality levels within one step of their present capabilities. The underlying assumption is that the unit labor requirement a applies to imitation one quality level above current capabilities but a substantially higher unit labor requirement $A > a$ applies to imitation of the state-of-the-art quality level, so that imitation costs exceed the expected reward to imitation of the state-of-the-art (in equilibrium): $A > v_S^H$. The South may lack infrastructure or other public investments necessary to make imitation of the state-of-the-art cost effective. Additionally, subsequent imitation would be undertaken by follower firms, firms that lack the background information of leader firms that imitate low quality levels. [17] Finally, multinationals may more actively protect state-of-the-art technologies than other inferior (less valuable) technologies, thus reducing the spillovers to potential imitators. [18]

Each firm chooses its intensity of R&D to maximize its expected value, given the R&D intensities of the other firms. To maximize their value, firms engage in

[17] See Grossman and Helpman (1991) for the distinction between leaders and followers and Glass (1997) for application of the leaders and followers distinction to imitation.

[18] If the South could catch up to the North for some products, Southern firms would push multinationals out of the market due to their lower costs. Assuming the South cannot completely catch up to the North for any product eliminates a market structure with no FDI. Since we focus on the quality of technology transferred through FDI, this simplification should not alter our results.

positive rates of innovation or imitation whenever the expected gains are no less than their costs. To generate finite rates of innovation and imitation, the expected gains must not exceed their cost. Northern firms target all markets at intensity ι, earning the reward v_N^H if successful.

$$v_N^H \leq w\gamma a, \iota > 0 \Leftrightarrow v_N^H = w\gamma a \tag{2.14}$$

Southern firms target low-quality FDI markets at intensity μ, earning the reward v_S^L if successful.

$$v_S^L \leq a, \mu > 0 \Leftrightarrow v_S^L = a \tag{2.15}$$

Resource constraints and steady-state conditions complete the model.

3. Steady-state equilibrium

Having established the purchasing decisions of consumers and the R&D and pricing decisions of firms, we now constrain R&D according to resource availability. Further, we impose conditions for a steady-state equilibrium and establish key linkages between variables of interest in a steady-state equilibrium.

3.1. Resource constraints

Let η be the extent of high-quality FDI (percentage of markets with high-quality multinational production), and thus $1-\eta$ the extent of low-quality FDI. In the labor markets, the fixed supply of labor is allocated between R&D and production. In the North, labor demand for innovation is $\gamma a \iota$, while labor demand for production is $(1-\eta)$ $[(E^B)/(\lambda^B \lambda^A)]$; in the South, labor demand for imitation is $a\mu(1-\eta)$ while labor demand for production is $(1-\eta)(E^A/\lambda^A) + \eta[(E^B/(\lambda^B \zeta)) + (E^A/\zeta)]$. For equilibrium in the labor market, the total demand for labor must equal the total supply of labor in each country:

$$\gamma a \iota + (1-\eta)\left[\frac{E^B}{\lambda^B \lambda^A}\right] = L_N \tag{3.1}$$

$$a\mu(1-\eta) + (1-\eta)\left[\frac{E^A}{\lambda^A}\right] + \eta\left[\frac{E^B}{\lambda^B \zeta} + \frac{E^A}{\zeta}\right] = L_S \tag{3.2}$$

The resource constraints limit the amount of R&D and production performed in each country.

3.2. Constant measures

For any product, whether FDI occurs at high or low quality levels changes over time as innovation or imitation occurs; however, the measure of products where FDI shifts from high quality to low quality due to innovation must equal the measure of products where FDI shifts from low quality to high quality due to imitation for the extent of high-quality FDI to remain constant at the aggregate level.

$$\iota\eta = \mu(1-\eta) \tag{3.3}$$

This condition is especially useful for deriving relationships between variables of interest in the steady-state equilibrium.

Since innovation targets all markets, the rate of innovation is the intensity of innovation ι (see Fig. 1). Since imitation targets only low-quality FDI markets, the rate of imitation is the intensity of imitation times the extent of low-quality FDI: $\mu(1-\eta)$. Using Eq. (3.3) the rate of imitation relative to the rate of innovation equals the extent of high-quality FDI.

$$I \equiv \frac{\mu(1-\eta)}{\iota} = \frac{\iota\eta}{\iota} = \eta \tag{3.4}$$

Thus, forces that increase the rate of imitation relative to innovation also increase the extent of high-quality FDI.

Technology is transferred between countries through FDI and between firms through imitation. Imitation of low quality levels allows the South to host high-quality FDI: technology for producing high quality levels flows into the South through FDI at the rate $\mu(1-\eta)$, equal to the rate of imitation. Innovation in markets with low-quality FDI brings a higher quality level produced in the South through FDI in absolute terms: technology for producing low quality levels

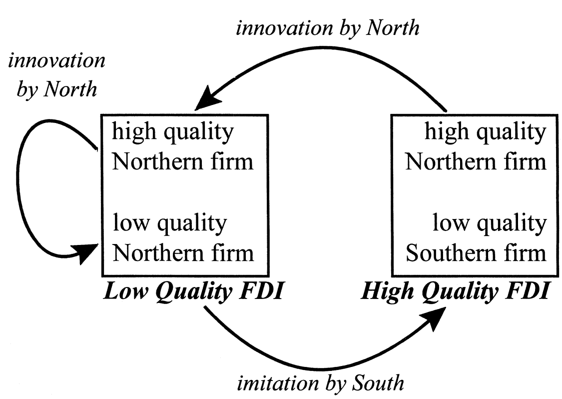

Fig. 1. Flow chart.

flows into the South through FDI at the rate $\iota(1-\eta)$.[19] Using Eq. (3.3), the aggregate flow of technology transferred to the South through FDI equals the rate of innovation.

$$F \equiv \iota(1-\eta) + \mu(1-\eta) = \iota(1-\eta) + \iota\eta = \iota \tag{3.5}$$

Thus, forces that increase the rate of innovation increase the aggregate flow of technology transferred to the South through FDI.

In low-quality FDI markets, the South is two quality levels below the Northern technology frontier, while in high-quality FDI markets, the South is only one quality level below the Northern technology frontier. Therefore, the average technology gap is negatively related to the extent of high-quality FDI, and using Eq. (3.4), the average technology gap is also negatively related to the rate of imitation relative to innovation.

$$G = 2(1-\eta) + \eta = 2 - \eta = 2 - I \tag{3.6}$$

Thus forces that increase the rate of imitation relative to innovation I shrink the technology gap G and expand the extent of high-quality FDI η. After collecting the key equations into a system, we find what forces have this effect.

3.3. Solution

The equations reduce to a system of four equations in four unknowns. The resource constraints (Eqs. (3.1) and (3.2)) form two equations. The return to R&D equations (Eqs. (2.14) and (2.15)), with producing firm values (Eqs. (2.10), (2.11), (2.12) and (2.13)) and profits (Eqs. (2.6), (2.7), (2.8) and (2.9)) included, form the remaining two equations. The system (see Section A.2) determines aggregate spending, the relative wage, the rate of innovation and the extent of high-quality FDI given the parameters. The solution is a combination of the endogenous variables such that resources are fully employed in each country and R&D yields no excess returns.

The relative wage is exclusively determined as the value of the marginal product of labor in producing innovations by the innovation valuation condition. The imitation valuation condition can be solved for aggregate spending E and inserted into the remaining resources constraints, leaving a system of two equations that determine the rate of innovation ι and the extent of high-quality FDI η, as in Fig. 2. The Northern resource constraint is upward sloping: a higher ι requires a higher η to free up resources from production for use in innovation. The Southern resource constraint is downward sloping: a higher ι requires a lower η.

[19] Innovation in a high-quality FDI market leads to low-quality FDI, which is the same technology in absolute terms (just at a larger lag relative to the state-of-the-art).

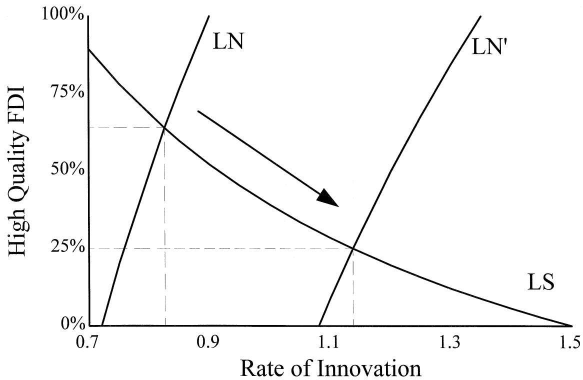

Fig. 2. Increase in relative resource supply.

Now we turn to determining the effects of various parameters on the endogenous variables to find what forces lead to a greater extent of high-quality FDI. While the extent of high-quality FDI remains constant in a steady-state equilibrium, different parameters lead to different steady-state solutions, with potentially different extent of high-quality FDI.

4. Technology transfer and the technology gap

In this section we explore how the extent of high-quality FDI, the rate of innovation and aggregate spending depend on the parameters of the model and draw some policy implications. Southern governments are often concerned with catching up to the North. What parameters decrease the technology gap between the North and the South? Southern governments are also often concerned with attracting FDI that transfers technologies closer to the technology frontier. What parameters increase the extent of high-quality FDI?

A smaller steady-state technology gap implies a larger extent of high-quality FDI (and vice versa), so these two questions share the same answer. By Eq. (3.6), the extent of high-quality FDI is tied to the rate of imitation relative to innovation, so any force increasing the rate of imitation relative to innovation increases the extent of high-quality FDI (by shrinking the technology gap). We start with parameters that contract the extent of high-quality FDI. Proofs for all propositions appear in Section A.2.

4.1. Relative resources

Define $\psi \equiv L_N / L_S$ as Northern resources relative to Southern resources. Larger Northern resources relative to Southern resources is a force pushing against imitation relative to innovation. Resources are needed to conduct R&D, so larger Northern relative to Southern resources supports a larger rate of innovation relative to imitation.

Proposition 1. *The extent of high-quality FDI decreases, the rate of innovation increases and aggregate spending increases with larger resources in the North relative to resources in the South* ψ.

Fig. 2 illustrates this effect. An increase in ψ means Northern firms can expand their innovative activity for a given η so the Northern resource constraint shifts right. The Southern resource constraint is unaffected. Thus the equilibrium shifts along the downward sloping Southern resource constraint to smaller η and larger ι.[20]

4.2. High-quality income share

Let $\phi \equiv f(B) = 1 - f(A)$ denote the share of income spent on high-quality levels. The model displays an interesting relationship between the size of the market for high-quality products and the extent of high-quality FDI. One might think that more extensive demand for high-quality products would increase the extent of high-quality FDI; however, such logic fails to account for the incentives for innovation relative to imitation. A larger market for high quality levels increases the rewards to innovation relative to imitation. With innovation occurring faster relative to imitation, the Southern technology frontier falls farther behind, and consequently FDI is limited to the lower quality levels for more products.

Proposition 2. *The extent of high-quality FDI decreases, the rate of innovation decreases and aggregate spending increases with a larger share of income spent on high quality levels* ϕ.

The South's ability to host FDI is limited to low quality levels when a large technology gap separates the Northern and Southern technology frontiers. The technology gap is larger when innovation is faster relative to imitation. Thus, a larger market for high quality levels of products implies a smaller extent of high-quality FDI due to the increase in incentives for innovation relative to imitation. Now we turn to forces that expand the extent of high-quality FDI.

[20] Graphical analysis of other forces that contract the extent of high-quality FDI markets is complicated by effects on E that shift both resource constraints.

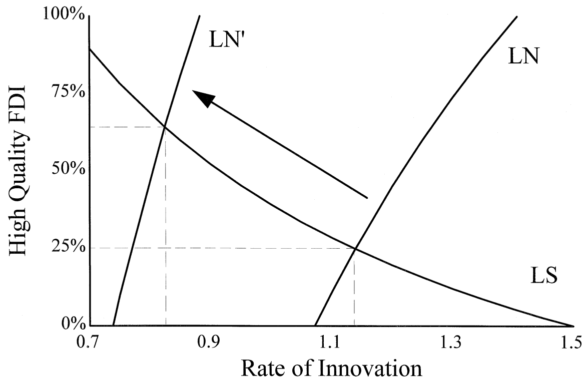

Fig. 3. Increase in relative innovation difficulty.

4.3. Relative resource requirement in innovation

A larger resource requirement in innovation relative to imitation is a force pushing towards imitation relative to innovation. Since the resource requirement in production is normalized to 1 in each country, the resource requirements in R&D indicate the opportunity costs of R&D, the number of units of output forgone to increase R&D activity. Intuitively, the higher the opportunity cost of innovation relative to imitation, the smaller the rate of innovation relative to imitation, and hence the smaller the technology gap and the larger the extent of high-quality FDI.

Proposition 3. *The extent of high-quality FDI increases, the rate of innovation decreases and aggregate spending decreases with a larger resource requirement in innovation relative to imitation* γ.

Fig. 3 illustrates this effect. An increase in γ means Northern firms must contract their innovative activity for a given η so the Northern resource constraint shifts left. The Southern resource constraint is unaffected. Thus the equilibrium shifts back up along the downward sloping Southern resource constraint to larger η and smaller ι. [21]

4.4. Multinational cost disadvantage

As the cost disadvantage of multinationals increases, the rate of imitation relative to innovation rises. The higher costs for a multinational decrease the profits during those phases where production in the South is possible and thus decrease the incentives for innovation relative to imitation.

[21] Graphical analysis of other forces that expand the extent of high-quality FDI markets is complicated by effects on E that shift both resource constraints.

Proposition 4. *The extent of high-quality FDI increases, the rate of innovation increases and aggregate spending decreases with a larger cost disadvantage of multinationals relative to Southern firms* ζ.

In addition, since Southern firms successful in imitation compete against multinationals at the same quality level, Southern firms price at the multinational's cost to keep the multinational out of the market. The higher price for successful imitators leads to higher profits that increased incentives for imitation. Further, the high-quality multinational then charges a premium over the low-quality Southern firm's price to reflect the extra willingness of high-type consumers to pay for quality. When the cost disadvantage of multinationals increases, the price of both quality levels in high-quality FDI markets rises, and thus production levels fall. The resources freed from production in the South are then available for imitation, adding another force in this direction. Together, the reduced relative innovation incentives, increased imitation incentives, and expanded resources for imitation lead to a faster rate of imitation relative to innovation, a smaller technology gap and thus a larger extent of high-quality FDI.

4.5. Tax on low-quality multinational production

What government policies might help close the technology gap and thus encourage high-quality FDI? The constraint facing Northern firms is the limited ability of the South to host FDI due to the technology gap between the North and the South. The technology gap reflects the rate of innovation relative to imitation. Thus to encourage high-quality FDI, policies must shrink the technology gap by raising the rate of imitation relative to innovation.

Let τ denote the (specific) production tax on low-quality FDI. A production tax on low-quality FDI effectively increases a multinational's production costs by τ, reducing profits for low-quality multinationals. A production tax on low-quality FDI also raises the price charged by low-quality Southern firms since successful imitators limit price against low-quality multinationals, thus raising profits for Southern firms and increasing the incentives for imitation. The tax also raises the price charged by high-quality multinationals since high-quality multinationals engage in limit pricing against low-quality Southern firms. The higher prices reduce consumption quantities, which frees up relatively more resources for imitation.

Proposition 5. *The extent of high-quality FDI increases, the rate of innovation increases and aggregate spending decreases with a larger low-quality multinational production tax* τ.

Imitation is profitable due to the production cost advantage of Southern firms relative to multinationals. A production tax acts like a greater cost disadvantage of multinationals in encouraging high-quality FDI by shrinking the technology gap through raising the rate of imitation relative to innovation.

4.6. Subsidy to Southern imitation

Similarly, a subsidy to Southern imitation also encourages high-quality FDI by shrinking the technology gap. Let σ denote the subsidy to Southern imitation. A subsidy to imitation places a term $(1-\sigma)$ on the cost of imitation in the imitation valuation condition (Eq. (2.15)), as the Southern government pays a portion of Southern firms' imitation costs.

Proposition 6. *The extent of high-quality FDI increases, the rate of innovation increases and aggregate spending decreases with a larger Southern imitation subsidy* σ.

The technological backwardness of the South limits its ability to host high-quality FDI; a subsidy to imitation spurs imitation relative to innovation and releases the constraint on Northern firms wanting to produce high quality levels in the South. The effect of a subsidy to imitation resembles the effect of increased relative resources requirement in innovation; however, a subsidy to R&D only affects the R&D valuation conditions, not the resource constraints, since no change in the resources demanded for a given R&D intensity occurs.

4.7. Welfare

Now that we have determined the Southern government can raise the extent of high-quality FDI, we determine whether the Southern government would want to do so, if its policy objective is to maximize Southern welfare. How is Southern welfare affected by changes in the extent of high-quality FDI, the rate of innovation, and aggregate spending?

By the law of large numbers, the expected number of innovations arriving in time period t is $\overline{m}=\iota t$. Instantaneous utility (2.2) is

$$\log u_i^{\omega}(t)=\log E_i-\log \bar{p}^{\omega}+\overline{m}^{\omega}\log \lambda^{\omega} \tag{4.1}$$

where the average price paid by low-type consumers is

$$\bar{p}^{\mathrm{A}}=(1-\eta)\lambda^{\mathrm{A}}+\eta\zeta=\lambda^{\mathrm{A}}-\eta(\lambda^{\mathrm{A}}-\zeta), \tag{4.2}$$

the average price paid by high-type consumers is

$$\bar{p}^{\mathrm{B}}=(1-\eta)\lambda^{\mathrm{B}}\lambda^{\mathrm{A}}+\eta\lambda^{\mathrm{B}}\zeta=\lambda^{\mathrm{B}}\left[\lambda^{\mathrm{A}}-\eta(\lambda^{\mathrm{A}}-\zeta)\right] \tag{4.3}$$

the average quality level consumed by low-type consumers is one level below the state-of-the-art, $\overline{m}^{\mathrm{A}}=\overline{m}-1$, and the average quality level consumed by high-type consumers is the state-of-the-art, $\overline{m}^{B}=\overline{m}$. An increased extent of high-quality FDI lowers the average price paid by low-type consumers $\partial\overline{p}^{A}/\partial\eta=-(\lambda^{A}-\zeta)<0$, lowers the average price paid by high-type consumers $\partial\overline{p}^{B}/\partial\eta=-\lambda^{B}(\lambda^{A}-\zeta)<0$ and does not affect the average quality level consumed by either type consumer (holding fixed the highest quality level available).

Lifetime utility (2.1) for type ω consumers is

$$U_i^{\omega}=\frac{\log E_i+\left(\frac{\iota}{\rho}-1\right)\log\lambda^{\omega}-\log\left[\lambda^{A}-\eta(\lambda^{A}-\zeta)\right]}{\rho} \tag{4.4}$$

For both types of consumers, the first term indicates utility rises with aggregate spending due to the larger quantity consumed, the second term indicates utility rises with the rate of innovation due to the higher quality consumed (magnitude differs across types) and the third term indicates utility rises with the extent of high-quality FDI due to lower prices. The first term also indicates utility rises for Northern consumers with the relative wage and falls for Southern consumers with aggregate spending. [22] Any force that decreases E while concurrently increasing ι and η does increase Southern welfare. Accordingly, a reduction in the share of income spent on high quality levels ϕ, an increase in the cost disadvantage of multinationals relative to Southern firms ζ, an increase in the low-quality multinational production tax τ or an increase in the Southern imitation subsidy σ do increase Southern welfare. This welfare analysis supports the observation that Southern governments are actively seeking means of attracting FDI that transfers a better mix of technologies: their efforts, if successful, do raise Southern welfare.

5. Conclusion

This paper develops a model of FDI from DCs to LDCs, where multiple quality levels sell of each product. Firms from the developed country can shift their production to the less developed country where costs are lower, only for quality levels slightly above the current Southern technology frontier for that product. Where multiple quality levels sell, in some markets a large technology gap limits FDI to low quality levels, while in other markets a small technology gap permits FDI at high quality levels. The paper shows how the quality of technology transferred through FDI is linked (through the technology gap) to the rate of imitation relative to innovation by studying parameters that determine how much FDI occurs to produce using the best technology available.

[22] Aggregate spending is normalized by the Southern wage, so an increase in aggregate spending implies a reduction in the Southern wage.

The larger the market for high quality levels of products or the larger the resources in the North relative to the South, the smaller the extent of high-quality FDI. However, the larger the resources required for innovation relative to imitation or the larger the cost disadvantage of multinationals relative to Southern firms, the larger the extent of high-quality FDI. The host country can shrink the technology gap and thus encourage high-quality FDI by imposing a tax on low-quality FDI production or providing a subsidy to imitation. Encouraging domestic R&D activities that push forward the technology frontier releases the constraints faced by Northern firms wanting to produce using advanced technologies in the South. Such policies improve Southern welfare by raising Southern wages, lowering prices and accelerating innovation.

This paper provides a contrasting view to the common depiction of imitation as exclusively the foe of FDI. In situations where a substantial technology gap persists between source and host countries, imitation can provide the technological foundation needed to make state-of-the-art technology transfer through FDI more attractive from the viewpoint of Northern firms.

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Appendix A

A.1. Condition for separation

Under pooling, all Northern firms become multinationals as the technology gap is exactly one quality level for all products due to only one quality level selling in equilibrium and discarded technology. Each firm would charge price $p^{\mathrm{P}} = \lambda$ and have marginal cost of production ζ and instantaneous profits

$$\pi^{\mathrm{P}} = E\left(1 - \frac{\zeta}{\lambda}\right)$$

which lead to a present discounted value

$$v^{\mathrm{P}} = \frac{\pi^{P}}{\rho + \iota}$$

For separation to emerge in low-quality FDI markets, by charging the price $p_N^H = \theta\lambda^2$ with marginal cost of production ζ, the firm must earn instantaneous profits π_N^H that lead to a present discounted value, taking as given the R&D intensities of other firms under pooling (only targeted by innovation)

$$v_N^S = \frac{\pi_N^H}{\rho + \iota}$$

that exceeds the reward to innovation under pooling. For $v_N^S > v^P$, must have enough income spent on high quality levels

$$\phi > \frac{\lambda - \zeta}{\lambda - \frac{1}{\theta}\left(\frac{w}{\lambda}\right)} < 1$$

as $\zeta > 1$ and $w < \theta\lambda$ in equilibrium (necessary for imitation to occur and Northern production to be profitable). Similarly, for separation to emerge in high-quality FDI markets, must also have enough income spent on high quality levels

$$\phi > \frac{\lambda - \zeta}{\lambda - \frac{1}{\theta}\left(\frac{w}{\lambda}\right)} < 1$$

since $\theta > 1$ by the definition of high-type consumers, so income shares spent on high quality do exist that generate a separating equilibrium. A separating equilibrium is more likely (occurs for a wider range of income shares spent on high quality levels) the larger the cost disadvantage of multinationals ζ and the larger the premium high-type consumers pay θ (heterogeneity in consumer types).

A.2. Proofs of results

Let $\lambda \equiv \lambda^A > 1$ represent the base quality increment and $\theta \equiv \lambda^B/\lambda^A > 1$ represent the quality premium in the view of high-type consumers. All consumers agree that new innovations are at least λ-times better than the previous innovation, but some consumers have an extra idiosyncratic taste for quality. The model reduces to three equations in the three unknowns $\{E, \iota, \eta\}$:

$$\gamma a \iota + \left[\frac{\phi(1-\eta)}{\theta\lambda^2}\right] E = \psi L$$

$$a \iota \eta + \left[\frac{\theta\zeta(1-\phi) + \eta[\phi + \theta(\lambda - \zeta)(1-\phi)]}{\theta\lambda\zeta}\right] E = L$$

$$(1-\phi)\left(1 - \frac{1}{\zeta}\right) E = a(\rho + \iota)$$

with w determined separately by the innovation valuation condition (using the solution from the reduced system). Then solve the imitation valuation condition for aggregate spending

$$E=\frac{a(\rho+\iota)}{(1-\phi)\left(1-\frac{1}{\zeta}\right)}$$

and substitute into the resource constraints, leaving a system of two equations in the two unknowns, $\{\eta,\iota\}$, as drawn in Fig. 2.

$$\gamma a\iota+\left(\frac{\phi(1-\eta)}{\theta\lambda^2}\right)\left[\frac{a(\rho+\iota)}{(1-\phi)\left(1-\frac{1}{\zeta}\right)}\right]=\psi L$$

$$a\iota\eta+\left(\frac{\theta\zeta(1-\phi)+\eta[\phi+\theta(\lambda-\zeta)(1-\phi)]}{\theta\lambda\zeta}\right)\left[\frac{a(\rho+\iota)}{(1-\phi)\left(1-\frac{1}{\zeta}\right)}\right]=L$$

An increase in ψ shifts the Northern resource constraint down so that η smaller for a given ι; an increase in γ shifts the Northern resource constraint up so that η larger for a given ι.

A.2.1. Proof of Proposition 1

The derivatives with respect to ψ are generated by

$$\begin{bmatrix} b_{11} & -b_{12} \\ b_{21} & b_{22} \end{bmatrix}\begin{bmatrix} \mathrm{d}\iota \\ \mathrm{d}\eta \end{bmatrix}=\begin{bmatrix} Ld\psi \\ 0 \end{bmatrix}$$

where

$$b_{11}\equiv\left[\frac{a}{\theta\lambda(1-\phi)(\zeta-1)}\right]\left[\frac{\gamma\theta\lambda^2(1-\phi)(\zeta-1)+\zeta\phi(1-\eta)}{\lambda}\right]>0$$

$$b_{12}\equiv\left[\frac{a}{\theta\lambda(1-\phi)(\zeta-1)}\right]\left[\frac{\zeta\phi(\rho+\iota)}{\lambda}\right]>0$$

$$b_{21}\equiv\left[\frac{a}{\theta\lambda(1-\phi)(\zeta-1)}\right][\theta\zeta(1-\phi)[\eta(\lambda-1)+1]+\eta\phi]>0$$

$$b_{22}\equiv\left[\frac{a}{\theta\lambda(1-\phi)(\zeta-1)}\right][\theta(1-\phi)[\zeta\iota(\lambda-1)+\rho(\lambda-\zeta)] +\phi(\rho+\iota)]>0.$$

Consequently, the determinant of the matrix is positive

$$D \equiv b_{11} b_{22} - (-b_{12}) b_{21} = b_{11} b_{22} + b_{12} b_{21} > 0.$$

An increase in relative resources increases the rate of innovation

$$\frac{\partial \iota}{\partial \psi} = \frac{L b_{22}}{D} > 0$$

decreases the extent of high-quality FDI

$$\frac{\partial \eta}{\partial \psi} = -\frac{L b_{21}}{D} < 0$$

and increases aggregate spending

$$\frac{\partial E}{\partial \psi} = \frac{a \zeta L b_{22}}{(\zeta - 1)(1 - \phi) D} > 0.$$

To simplify expressions, L from the Southern resource constraint and ψ from the Northern resource constraint have been inserted after calculating the following derivatives.

A.2.2. Proof of Proposition 2

An increase in the share of income spent on high quality levels decreases the rate of innovation

$$\frac{\partial \iota}{\partial \phi} = -\frac{\left[\theta(1-\phi)(1-\eta)\left[\zeta\iota(\lambda-1) + \rho(\lambda-\zeta)\right] + \phi(\rho+\iota)\right] a b_{12}}{\phi\theta\lambda(1-\phi)^2(\zeta-1) D}$$

decreases the extent of high-quality FDI

$$\frac{\partial \eta}{\partial \phi} = -\frac{\left[\gamma\eta\lambda(\zeta-1) + \zeta^2(1-\eta)\left[\eta(\lambda-1)+1\right]\right] a b_{12}}{\zeta\theta\lambda(1-\phi)(\zeta-1) D}$$

and increases aggregate spending

$$\frac{\partial E}{\partial \phi} = \frac{\left[\theta(1-\phi)\left[\zeta\iota(\lambda-1) + \rho(\lambda-\zeta)\right]\left[\lambda^2\gamma\theta(\zeta-1) - \zeta(1-\eta)\right] + N_\phi\right] a^2 b_{12}}{\phi\theta\lambda(1-\phi)^2(\zeta-1)^2 D} > 0$$

where $N_\phi \equiv \phi(\rho+\iota)[\lambda^2\gamma\theta(\zeta-1) + \zeta[\theta\zeta\eta(\lambda-1) + \theta\zeta - 1]]0.$

A.2.3. Proof of Proposition 3

An increase in the relative resource requirement in innovation decreases the rate of innovation

$$\frac{\partial \iota}{\partial \gamma} = -\frac{a \iota b_{22}}{D} < 0$$

increases the extent of high-quality FDI

$$\frac{\partial\eta}{\partial\gamma} = \frac{a\iota b_{21}}{d} > 0$$

and decreases aggregate spending

$$\frac{\partial E}{\partial\gamma} = -\frac{a^2\zeta\iota b_{22}}{(\zeta-1)(1-\phi)D} < 0.$$

A.2.4. Proof of Proposition 4

An increase in the cost disadvantage of multinationals relative to Southern firms increases the rate of innovation

$$\frac{\partial\iota}{\partial\zeta} = \frac{\left[\phi(\rho+\iota)\left[\eta(\zeta-1)+1\right] + \theta\lambda(1-\phi)\left[\zeta\iota+\rho\left[\eta(\zeta-1)+1\right]\right]\right]ab_{12}}{\zeta\theta\lambda(1-\phi)(\zeta-1)^2 D}$$

$$> 0$$

increases the extent of high-quality FDI

$$\frac{\partial\eta}{\partial\zeta} = \frac{\left[\gamma\theta\lambda^2(1-\phi)\left[\eta\phi+\theta(1-\phi)\left[\eta(\lambda-1)+1\right]\right] + \phi^2\eta(1-\eta)\right]ab_{12}}{\zeta\phi\theta\lambda(1-\phi)(\zeta-1)D}$$

and decreases aggregate spending

$$\frac{\partial E}{\partial\zeta} = -\frac{\left[\gamma\theta^2\lambda^2(1-\phi)^2\left[\zeta\iota(\lambda-1)+\rho(\lambda-\zeta)\right] + N_\zeta\right]a^2 b_{12}}{\zeta\phi\lambda(1-\phi)^2(\zeta-1)^2 D}$$

where $N_\zeta \equiv \phi(\rho+\iota)[\gamma\theta\lambda^2(1-\phi)-\phi\zeta\eta]$.

A.2.5. Proof of Proposition 5

With a tax on low-quality multinational production, the three equations become

$$\gamma a\iota + \left[\frac{\phi(1-\eta)}{\theta\lambda^2}\right]E = \psi L$$

$$a\iota\eta + \left[\frac{\theta(\zeta+\tau)(1-\phi) + \eta\left[\phi+\theta(\lambda-\zeta-\tau)(1-\phi)\right]}{\theta\lambda(\zeta+\tau)}\right]E = L$$

$$(1-\phi)\left(1-\frac{1}{\zeta+\tau}\right)E=a(\rho+\iota)$$

with w determined as before. The expression for aggregate spending from the imitation valuation condition becomes

$$E=\frac{a(\rho+\iota)}{(1-\phi)\left(1-\frac{1}{\zeta+\tau}\right)}$$

The reduced system becomes

$$\gamma a\iota+\left(\frac{\phi(1-\eta)}{\theta\lambda^2}\right)\left[\frac{a(\rho+1)}{(1-\phi)\left(1-\frac{1}{\zeta+\tau}\right)}\right]=\psi L$$

$$a\iota\eta+\left(\frac{\theta(\zeta+\tau)(1-\phi)+\eta[\phi+\theta(\lambda-\zeta-\tau)(1-\phi)]}{\theta\lambda(\zeta+\tau)}\right)$$

$$\times\left[\frac{a(\rho+\iota)}{(1-\phi)\left(1-\frac{1}{\zeta+\tau}\right)}\right]=L$$

An increase in the tax on low-quality FDI increases the rate of innovation

$$\frac{\partial\iota}{\partial\tau}=\frac{[\phi(\rho+\iota)[1+\eta(\zeta+\tau-1)]+\theta\lambda(1-\phi)[\iota(\zeta+\tau)+\rho[1+\eta(\zeta+\tau-1)]]]ab_{12}^{\tau}}{\theta\lambda(1-\phi)(\zeta+\tau)(\zeta+\tau-1)^2D^{\tau}}>0$$

increases the extent of high-quality FDI

$$\frac{\partial\eta}{\partial\tau}=\frac{[\gamma\theta\lambda^2(1-\phi)[\theta(1-\phi)[\eta(\lambda-1)+1]+\phi\eta]+\phi^2\eta(1-\eta)]ab_{12}^{\tau}}{\theta\lambda\phi(1-\phi)(\zeta+\tau)(\zeta+\tau-1)D^{\tau}}>0$$

and increases aggregate spending

$$\frac{\partial E}{\partial\tau}=-\frac{[\gamma\theta^2\lambda^2(1-\phi)^2[(\zeta+\tau)\iota(\lambda-1)+\rho(\lambda-\zeta-\tau)]+N_{\tau}]a^2b_{12}^{\tau}}{(\zeta+\tau)\phi\theta\lambda(1-\phi)^2(\zeta+\tau-1)^2D^{\tau}}$$

where $N_{\tau}\equiv\phi(\rho+\iota)[\gamma\theta\lambda^2(1-\phi)-\phi(\zeta+\tau)\eta]>0$ and $b_{12}^{\tau}=[(\zeta+\tau)(\zeta\text{-}1)]/[\zeta(\zeta+\tau\text{-}1)]b_{12}$. In the limit as the tax rate goes to zero $\tau\to 0$, these effects approach the effects of an increase in multinational cost disadvantage.

A.2.6. Proof of Proposition 6

With a subsidy to imitation, the three equations become

$$\gamma a\iota + \left[\frac{\phi(1-\eta)}{\theta\lambda^2}\right]E = \psi L$$

$$a\iota\eta + \left[\frac{\theta\zeta(1-\phi) + \eta[\phi + \theta(\lambda-\zeta)(1-\phi)]}{\theta\lambda\zeta}\right]E = L$$

$$(1-\phi)\left(1-\frac{1}{\zeta}\right)E = a(\rho+\iota)(1-\sigma)$$

with w determined separately by the innovation valuation condition using the solution from the reduced system). The expression for aggregate spending from the imitation valuation condition becomes

$$E = \frac{a(\rho+\iota)(1-\sigma)}{(1-\phi)\left(1-\frac{1}{\zeta}\right)}$$

The reduced system becomes

$$\gamma a\iota + \left(\frac{\phi(1-\eta)}{\theta\lambda^2}\right)\left[\frac{a(\rho+\iota)(1-\sigma)}{(1-\phi)\left(1-\frac{1}{\zeta}\right)}\right] = \psi L$$

$$a\iota\eta + \left(\frac{\theta\zeta(1-\phi) + \eta[\phi + \theta(\lambda-\zeta)(1-\phi)]}{\theta\lambda\zeta}\right) \times \left[\frac{a(\rho+\iota)(1-\sigma)}{(1-\phi)\left(1-\frac{1}{\zeta}\right)}\right] = L$$

An increase in the subsidy to Southern imitation increases the rate of innovation

$$\frac{\partial\iota}{\partial\sigma} = \frac{[\iota\theta\lambda(1-\phi)(\zeta-1)(1-\eta) + (1-\sigma)(\rho+\iota)[\phi+\theta\lambda(1-\phi)]]ab_{12}^{\sigma}}{\theta\lambda(1-\phi)(\zeta-1)(1-\sigma)D^{\sigma}} > 0$$

increases the extent of high-quality FDI

$$\frac{\partial\eta}{\partial\sigma} = \frac{\left(\gamma\lambda[\theta(1-\phi)[\zeta(1-\eta)+\eta\lambda]] + \phi\eta^2\zeta + \eta\left(\gamma\lambda^2 - \phi\zeta\right)\right)ab_{12}^{\sigma}}{\phi\zeta(1-\sigma)D\sigma} > 0$$

and decreases aggregate spending

$$\frac{\partial E}{\partial \sigma} = -\frac{\left[\gamma\theta\lambda(1-\phi)\left[\iota\lambda(\zeta-1)+(\rho+\iota)(\lambda-\zeta)(1-\sigma)\right]+N_\sigma\right]a^2 b_{12}^{\sigma}}{\phi(1-\phi)(\zeta-1)(1-\sigma)D^{\sigma}}$$

$$< 0.$$

where $N_\sigma \equiv \phi(1-\sigma)(\rho+\iota)(\gamma\lambda+\zeta\eta) > 0$ and $b_{12}^{\sigma} = (1-\sigma)b_{12}$.

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