
Volume 92, Issue 1, May 2010
ISSN 0304-3878
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92(1) 1–96
(2010)
JOURNAL OF
Development
ECONOMICS
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Contents lists available at ScienceDirect

Journal of Development Economics

journal homepage: www.elsevier.com/locate/econbase

Intellectual property rights, multinational firms and economic growth

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ARTICLE INFO

Article history:
Received 7 August 2007
Received in revised form 30 October 2008
Accepted 28 January 2009

Jel Classification:
F12
F23
F43
O31
O34

Keywords:
Intellectual property rights protection
International technology transfer
North–South trade
Multinational firms
Economic growth

ABSTRACT

This paper develops a model of North–South trade with multinational firms and economic growth in order to analyze formally the effects of stronger intellectual property rights (IPR) protection in developing countries. In the model, Northern firms invent new higher-quality products, multinational firms transfer manufacturing operations to the South and the Southern firms imitate products produced by multinational firms. It is shown that stronger IPR protection in the South (i.e., the adoption and implementation of the TRIPs agreement) leads to a permanent increase in the rate of technology transfer to the South within multinational firms, a permanent increase in R&D employment by Southern affiliates of Northern multinationals, a permanent decrease in the North–South wage gap, and a temporary increase in the Northern innovation rate.

1. Introduction

The purpose of the present paper is to develop a model of North–South trade with multinational firms and economic growth in order to analyze formally the effects of stronger intellectual property rights (IPR) protection in developing countries. The Trade-Related Intellectual Property (TRIPs) agreement, which was signed as part of the Uruguay round of multilateral trade negotiations in 1994, calls for the establishment of minimum standards of IPR protection by all World Trade Organization (WTO) members by 2006. The burden of policy adjustment, however, has fallen on the shoulders of developing countries because developed countries already have higher levels of IPR protection (Maskus, 2000). As a result, an intense debate has arisen about the effects of stronger IPR protection in developing countries.[2]

Advocates of stronger IPR protection argue that this reform promotes innovation in the global economy and benefits developing countries by fostering more rapid economic growth. They also claim that a strengthening of IPR accelerates the transfer of technology from developed countries (the North) to developing countries (the South), a further channel through which developing countries benefit. Opponents of stronger IPR protection counter that this reform leads to neither faster economic growth nor faster international technology transfer, but mainly results in the transfer of rents to multinational corporate patent holders headquartered in the world's most advanced countries especially the US.[3]

Recently, new evidence has become available that is directly relevant to this public policy debate. Taking advantage of considerably richer data than had been used by prior researchers, Branstetter et al. (2006) examined how technology transfer within US-based multinational firms has changed in response to a series of IPR reforms undertaken by sixteen countries over the 1982–1999 period.[4] They find that royalty payments for the use of intangible assets made by

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[2] In the working version of the paper, Dinopoulos and Kottaridi (2008) report that during the time period 1960–2000, IPR protection increased on average by 50% in a sample of developed countries and by 70% in a sample of developing countries, using a popular index of patent rights protection constructed by Ginarte and Park (1997). Furthermore, the average level of patent protection offered by developed countries was 33% higher than the corresponding level of patent protection offered by developing countries.

[3] For example, according to McCalman (2001), the implied income transfers caused by TRIPs-driven stronger IPR protection benefit the US, Germany, France, Italy, Sweden and Switzerland, and harm all other countries.

[4] Most, but not all, of the countries with major patent reforms that Branstetter et al. (2006) study are developing countries. Specifically, their sample consists of Argentina, Brazil, Chile, China, Columbia, Indonesia, Japan, Mexico, Philippines, Portugal, South Korea, Spain, Taiwan, Thailand, Turkey, and Venezuela.

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doi:10.1016/j.jdeveco.2009.01.007

affiliates to parent firms, which reflect the value of technology transfer, increase in the wake of stronger patent regimes. R&D spending by affiliates–usually viewed as a complement to technology imports from parent firms–also increases after IPR reform. The increases in affiliate royalties and R&D are concentrated among affiliates of firms that make extensive use of the US patent system prior to reforms and are therefore likely to value reforms the most. For these patent-intensive firms, there is a 34% increase in affiliate royalty payments and a 23% increase in affiliate R&D spending. Branstetter et al. (2006) conclude that improvements in IPR protection result in significant increases in technology transfer from US-based multinationals to their affiliates in reforming countries.[5]

This evidence represents a challenge to the existing theoretical literature on trade between the North and the South. In North–South trade models with multinational firms, stronger IPR protection in the South leads to an unambiguously lower rate of technology transfer in Glass and Saggi (2002), Sener (2006), and Glass and Wu (2007), the exact opposite of what Branstetter et al. (2006) find empirically.[6] The observed increase in the rate of technology transfer that results from stronger IPR protection is consistent with the implications of North–South trade models developed by Helpman (1993), Lai (1998), and Branstetter et al. (2007). However these papers all assume that international technology transfer within multinational firms is costless and thus cannot account for the observed increase in R&D spending by foreign affiliates of US multinationals. In these papers there is no R&D spending by affiliates, while several empirical studies have documented that R&D conducted by affiliates in developing countries is focused on the absorption of parent-firm technology and on its modification for local markets (Kuemmerle, 1999).

In this paper, we present a dynamic general equilibrium North–South trade model that is consistent with the above-mentioned empirical evidence. In the model, Northern firms engage in innovative R&D to develop new higher-quality products and once successful, they engage in adaptive R&D to learn how to transfer their manufacturing production from the high-wage North to the low-wage South. The profit flows earned by firms jump up when they are successful in transferring their production to the South and each production transfer is associated with a royalty payment from the foreign affiliate to its parent for the use of the parent firm's technology. When firms are successful in transferring their production to the South, they also become exposed to a positive rate of imitation by Southern firms. Stronger IPR protection in the South is modeled as a reduction in the rate at which Southern firms imitate the products that North-based multinational firms produce in the South.

The model has unique steady-state equilibrium with a constant rate of innovation and a constant rate of technology transfer in each industry. The steady-state rate of innovation does not depend on the scale of the economy and thus this model is not subject to the Jones (1995a) critique of early endogenous growth models.[7] Scale effects are ruled out by assuming that innovating becomes more difficult as products improve in quality and become more complex, as in Segerstrom (1998) and Li (2003).[8] Consequently, economic growth is semi-endogenous (policy choices do not affect the long-run economic growth rate) and because of this property, the model is particularly tractable.

We find that stronger IPR protection in the South (i.e., the adoption and implementation of the TRIPs agreement) leads to a permanent increase in the rate of technology transfer to the South within multinational firms and a permanent increase in adaptive R&D spending in the South by multinational firms. These two effects are connected because the increase in adaptive R&D spending is what drives the increase in the rate of technology transfer within multinational firms. Thus the model is consistent with the two main empirical findings in Branstetter et al. (2006, 2007), that patent reform is associated with increased royalty payments from foreign affiliates to their parent firms in the North and increased R&D spending by these foreign affiliates. Furthermore, we find that stronger IPR protection in the South leads to a temporary increase in the Northern innovation rate and a permanent decrease in the North–South wage gap. Thus this paper provides support for the argument that patent reform in developing countries promotes innovation in the global economy and also sheds light on why several developing countries have been growing faster than typical developed countries. Along the transition path leading to a new steady-state equilibrium with stronger IPR protection, the North–South wage gap can only permanently decrease if real wages grow faster in the South than in the North.

In addition to analyzing the equilibrium effects of stronger IPR protection, we also study the long-run welfare effects. In North–South trade models where patent reform permanently increases the economic growth rate (i.e., Lai, 1998; Branstetter et al., 2007; Glass and Wu, 2007), consumers must eventually be better off than they would have been without patent reform. Likewise, in North–South trade models where patent reform permanently decreases the economic growth rate (i.e., Glass and Saggi, 2002; Sener, 2006), consumers must eventually be worse off. In our model, by contrast, the long-run welfare effects are not unambiguous because patent reform does not permanently change the economic growth rate (growth is semi-endogenous). However, most of the long-run effects go in the direction of benefiting Southern consumers. When IPR protection is strengthened in the South, Southern consumers benefit from the faster rate of innovation, the faster rate of technology transfer, and the decrease in the North–South wage gap. The only consideration that goes against Southern consumers is that stronger IPR protection leads to less manufacturing production being transferred within the South from multinational firms with higher prices to Southern firms with lower prices. Thus this paper yields a generally optimistic picture concerning the long-run welfare effects of stronger IPR protection in developing countries.

In recent decades, structural changes in the global economy have significantly increased the effective size of the South. China's entry into the world trading system has augmented the Southern labor force by 760 million workers, the collapse of communism has added 260 million workers, and recently India has added another 440 million workers (Venables, 2006). As a final exercise, we explore the effects of increasing the initial size of the South and compare these effects with the corresponding effects of patent reform. We find that increasing the

[5] In a companion paper, Branstetter et al. (2007) introduce endogenous imitation of foreign affiliates in Lai's (1998) model of North-South trade with multinationals and increasing varieties and provide further evidence that US-based multinationals expand their activities in developing countries that have established stronger IPR protection.

[6] In addition, Parello (2008) finds that stronger IPR protection in the South has ambiguous effects on the rate of technology transfer within multinational firms.

[7] Jones (1995a) points out that since the 1950s the number of scientists and engineers in advanced countries has increased more than fivefold without generating any significant and persistent upward trend in the growth rate of total factor productivity (TFP). This evidence contradicts one of the main properties of early endogenous growth models, according to which an economy with a larger population (larger scale) should exhibit higher long-run TFP growth. With the exception of Sener (2006) and Parello (forthcoming), all of the above-mentioned North-South trade models have the counterfactual scale effect property.

[8] The Jones critique has stimulated the development of two classes of scale-free endogenous growth models. On the one hand, Jones (1995b), Kortum (1997), Segerstrom (1998) and Li (2003) have developed "semi-endogenous" growth models where the long-run TFP growth rate is proportional to the rate of population growth and is invariant to changes in policy-related parameters. On the other hand, Young (1998), Aghion and Howitt (1998, chapter 12), Dinopoulos and Thompson (1998), Peretto (1998), Howitt (1999) and Segerstrom (2000) have developed "fully-endogenous" growth models where long-run TFP growth is affected by policy-related parameters. See Dinopoulos and Thompson (1999), Jones (1999) and Dinopoulos and Sener (2007) for overviews of this literature.

initial size of the South has almost the same steady-state equilibrium effects: there is a permanent increase in the rate of technology transfer to the South within multinational firms, a permanent increase in adaptive R&D spending in the South by multinational firms, and a temporary increase in the Northern innovation rate. The only difference is that Southern market expansion has no effect on the North–South wage gap, whereas patent reform reduces the North–South wage gap. An increase in the initial size of the South unambiguously increases long-run Southern consumer welfare.

The rest of the paper is structured as follows: Section 2 offers an overview of the related literature. The model is presented in Section 3 and then solved for the unique steady-state equilibrium in Section 4. The equilibrium effects of stronger IPR protection are derived in Section 5 and the corresponding long-run welfare effects are derived in Section 6. Section 7 offers some concluding remarks and avenues for further research. Some algebraic derivations are relegated to Appendix A and the effects of Southern market expansion are contained in Appendix B.

2. Related literature

We begin by discussing papers in that earlier literature that focus on multinationals as the main mode of international technology transfer but obtain different findings about the effects of stronger IPR protection in the South.

Compared with the present paper, Glass and Wu (2007) find opposite effects of stronger IPR protection on innovation and foreign direct investment (FDI). Their model is similar to ours in many respects but they find that lowering the exogenous imitation rate causes a decline in the rates of FDI and innovation. The key difference is that, while we assume that there is free entry into innovative R&D races and all firms have access to the same technology, Glass and Wu assume that industry leaders are sufficiently more productive at innovating than follower firms so that all innovating R&D is done by industry leaders. Glass and Wu's assumption has strong implications because industry leaders engage in innovative R&D when they have the most to gain by innovating, namely, after their products have been imitated and they are not earning economic profits. In their model, no innovative R&D takes place in industries where Northern multinational firms produce: innovative R&D targets industries where products are produced by Southern firms under perfect competition.

In the steady-state equilibrium that Glass and Wu (2007) solve for, imitation must occur before further innovation, FDI must occur before imitation, and innovation must occur before FDI. Because the expected inflow of product lines into each of these three states must be balanced by the corresponding outflow, the model has the implication that the aggregate rates of innovation, FDI and imitation must be identical, so any policy that reduces the rate of imitation (such as stronger IPR protection) must also reduce the aggregate rates of innovation and FDI. This implication is not supported by the evidence reported in Branstetter et al. (2006). By contrast, in our model, because every industry is targeted by innovative R&D, the aggregate rates of innovation, FDI, and imitation are not identical and are allowed to move in different directions in response to policy changes.

Glass and Saggi (2002) analyze a richer model than Glass and Wu (2007) with costly imitation and costly FDI, but they make the same simplifying assumptions about innovative R&D. As they state on page 392, “For simplicity, we do not allow Northern innovation to target other Northern firms by making the necessary assumptions for such innovation to fail to earn the market rate of return”. When Glass and Saggi solve their model, they find that there are two types of equilibrium outcomes with FDI. In the case where there is imitation of multinationals by Southern firms but not imitation of Northern firms, they obtain the same results as in Glass and Wu (2007) and for the same reasons. Since the steady-state rates of imitation, FDI, and innovation must be identical, and stronger IPR protection must lower the rate of imitation, it reduces the aggregate rates of innovation and FDI. In the case where there is imitation of both multinationals and Northern firms, Glass and Saggi's model is more complicated but it continues to be true that stronger IPR protection leads to lower rates of imitation, innovation and FDI due to the innovative R&D targeting assumption.

In Dinopoulos and Segerstrom (2007), we develop a North–South trade model with costly innovation and imitation but no FDI. Instead of international technology transfer being 100% driven by FDI, in this companion paper we study the polar opposite case where 100% of technology transfer occurs through imitation (Southern firms copying the products of Northern firms). Whereas the present paper finds that an increase in IPR protection leads to a permanent decrease in the North–South wage gap and a temporary increase in the Northern innovation rate, Dinopoulos and Segerstrom (2007) find that an increase in IPR protection leads to a permanent increase in the North–South wage gap and a temporary decrease in the Northern innovation rate. Thus one could argue that even in quality-ladders growth models, the mode of international technology transfer makes a big difference. When technology transfer occurs through imitation of Northern products, stronger IPR protection slows the rate of technology transfer because it leads to a lower imitation rate of Northern products. This means that more production remains in the North, and the “excess” production increases the demand for Northern labor and the North–South wage gap. Northern firms respond to the higher costs of R&D by decreasing their R&D investment, and this leads to a decline in the rate of innovation. This global reallocation of resources is the exact opposite of what we find in the present paper where technology transfer occurs through FDI.

We view Dinopoulos and Segerstrom (2007) and this paper as complementing each other because both modes of technology transfer are important. In the real world, technology transfer from North to South occurs both within firms (FDI by multinational firms) and also across firms (imitation). In a more general model that combines elements of both papers, we conjecture that the effects of stronger IPR protection would depend on how important each mode of technology transfer is. If the share of technology transfer due to FDI is relatively high, we expect that the results of the present paper would apply: stronger IPR protection leading to a lower North–South wage gap and more innovation. If the share of technology transfer due to imitation of Northern products is relatively high, we expect that the results in Dinopoulos and Segerstrom (2007) would apply: stronger IPR protection leading to a higher North–South wage gap and less innovation. This conjecture is consistent with Lai's (1998) analysis in a model of growth through variety accumulation and deserves to be investigated formally in future research.

A paper by Sener (2006) has taken a step in this direction. He presents a quality ladders growth model where there is costly innovation, costly FDI, costly imitation of products produced in the North, and costly imitation of products produced by Northern firms located in the South. Unlike the simplifying R&D targeting assumption of Glass and Saggi (2002) and Glass and Wu (2007), Sener allows firms engaging in innovative R&D to target all Northern industries. Unfortunately, Sener's model is too complicated to solve analytically and, when he solves it numerically, he only studies a benchmark parameterization where the imitation rate of products produced in the North is roughly twice as high as the imitation rate of products produced by Northern multinationals in South. In this case, roughly 50% of technology transfer is due to imitation. Sener reports that stronger IPR protection leads to a higher North–South wage gap and less innovation, the same result as in Dinopoulos and Segerstrom (2007). He also finds that stronger IPR protection leads to less FDI.[9] We conjecture that if he had studied cases where imitation of foreign

[9] See Sener (2006, Tables 2a, 2b) where he reports a decline in ϕ.

affiliates is more important than imitation of Northern firms and FDI is the dominant mode of technology transfer, he would have confirmed the results of the present paper. An important benefit of studying polar extreme cases is that one can obtain analytical (as opposed to numerical) solutions that are robust to parameter choices and thus arrive at clear economic insights.

In all aforementioned papers that focused on the nexus of IPR protection and FDI, innovation takes the form of increasing product quality. Helpman (1993), Lai (1998) and Branstetter et al. (2007) have developed North–South trade models where innovation takes the form of increasing product variety. In Helpman's (1993) model of FDI, both innovation and imitation rates are exogenously given and costless FDI results in the equalization of wages between Northern and Southern workers. In Lai (1998) and Branstetter et al. (2007), the presence of endogenous innovation together with imitation only of foreign affiliates generates a positive North–South wage gap. In these models, stronger IPR protection in the South leads to more FDI, more innovation, and a lower North–South wage gap, just like in the present paper. One substantial difference between the present paper and the papers by Lai (1998) and Branstetter et al. (2007) is that they assume that FDI is costless, so their models cannot account for the observed increase in R&D spending by foreign affiliates in response to patent reform. Aside for the issue of R&D spending, we are not surprised that they obtain the same results as in the present paper: all our results in Theorem 2 continue to hold in the special case of costless FDI ($\alpha = 0$).

While all of the above-mentioned models of North–South trade treat stronger IPR protection as a reduction in the rate of imitation (either of Northern firms or foreign affiliates), there is a strand of literature that abstracts from FDI as the dominant mode of international technology transfer and explores other approaches to modeling of IPR protection. Yang and Maskus (2001) model stronger IPR protection as a policy that facilitates the process of technology licensing from North to South. They find that stronger IPR protection raises the economic return to licensing and accelerates the rate of long-run growth. Stronger IPR protection has an ambiguous effect on the demand for Northern labor and the North–South wage gap. If licensing shifts a sufficiently large fraction of production from North to South, the North–South wage gap declines. Dinopoulos and Kottaridi (2008) model stronger IPR protection as an increase in the duration of so-called "utility" patents which are granted to Southern imitators. They find that stronger IPR protection reduces the North–South wage gap and increases the long-run rates of innovation and growth. Dinopoulos et al. (2008) model stronger IPR protection as an increase in the length of global patents granted to Northern firms. They find that longer global patents have an ambiguous effect on the rate of innovation and the North–South wage gap. The ambiguity stems from the nature of knowledge spillovers and the fraction of industries with active patents. Gancia and Bonfiglioli (2007) model stronger IPR protection as an exogenous fraction of profits earned by successful Southern imitators that is repatriated to Northern firms. They find that stronger IPR protection benefits open economies more than closed economies by shifting the direction of technical change and innovation in the North's favor.

Having reviewed the related literature, we conclude that neither the nature of innovation (increasing quality or expanding variety) nor the removal of scale effects seems to be important in driving our results. For example, while we study the case where innovations are improvements in product quality and scale effects are not present, Lai (1998) and Branstetter et al. (2007) obtain closely related results using models where innovations increase the number of product varieties and scale effects are present. However, the mode of technology transfer (imitation versus FDI) is crucial in determining the impact of stronger IPR protection, as the comparison of the present paper with Dinopoulos and Segerstrom (2007) reveals. Also, our assumption that there is free entry into innovative R&D races (with all firms having access to the same R&D technology) plays an important role in driving our results, as the comparison of the present paper with Glass and Wu (2007) or Glass and Saggi (2002) reveals. Their pessimistic findings about the effects of stronger IPR protection are not supported by recent evidence on the behavior of US-based multinationals (Branstetter et al., 2006). In contrast, the results of our paper are consistent with this evidence and offer an optimistic view of the TRIPs agreement including its long-run welfare implications.

3. The model

3.1. Overview

We consider a global economy consisting of two regions: a high-wage North and a low-wage South. Labor is the only factor of production and grows at an exogenous rate over time in both regions. It is employed in three distinct activities, manufacturing of final consumption goods, innovative R&D, and adaptive R&D. All innovative R&D is done in the North and all adaptive R&D is done in the South. There is free trade between the two regions.

In this global economy, firms can hire Northern workers to engage in innovative R&D with the goal of learning how to produce higher-quality products. A successful firm earns global monopoly profits from producing and selling the state-of-the-art quality product in its industry. We call such a firm a *Northern quality leader* because all production is located in the North. A Northern quality leader can hire Southern workers to engage in adaptive R&D with the aim to transferring its manufacturing operations to the low-wage South. When successful in adaptive R&D, a firm earns even higher global monopoly profits because of the lower wage-costs in the South. We call such a firm a *foreign affiliate* because production takes place in the South but a fraction of its profits is repatriated back to its Northern stockholders. Adaptive R&D can be interpreted as an index of FDI (foreign direct investment) because it represents the cost that Northern quality leaders incur to transfer their technology to foreign affiliates, and, even when financed by Southern savings, Northern quality leaders control the amount of adaptive R&D in order to maximize their global profits. In what follows, we will use the time index to denote variables and functions that grow over time in the steady-state equilibrium. When the context is clear, we will omit time arguments from variables that are constant over time in the steady-state equilibrium.

3.2. Households

The global economy is populated by a fixed measure of identical households that are modeled as dynastic families. The typical member of a household lives forever and is endowed with one unit of labor, which is supplied inelastically. The size of each household grows exponentially at a fixed rate $g_L > 0$, which equals the world population growth rate.[10] Assuming that the initial size of each household is unity, the size of each household at time t is $e^{g_L t}$. Let $\bar{L}_N$ and $\bar{L}_S$ denote the initial number of households in the North and the South respectively, and let $\bar{L} = \bar{L}_N + \bar{L}_S$ be the initial number of households in the world. Then $\bar{L}_N(t) = \bar{L}_N e^{g_L t}$ denotes the Northern labor supply at time t, $L_S(t) = \bar{L}_S e^{g_L t}$ denotes the Southern labor supply, and $L(t) = \bar{L}e^{g_L t} = L_N(t) + L_N(t)$ denotes the global labor supply.

There is a continuum of industries indexed by $\theta \in [0,1]$ producing final consumption goods. In each industry θ, firms are distinguished by the quality of the products they produce. Higher values of the index j denote higher quality products, and j is restricted to taking on integer values. At time $t = 0$, the state-of-the-art quality product in each industry is $j = 0$, that is, some firm in each industry knows how to produce a $j = 0$ quality product and no firm knows how to produce

[10] Helpman (1993), Lai (1998), Glass and Saggi (2002), and Glass and Wu (2007) among others have analyzed the case of $g_L = 0$.

any higher quality product. To learn how to produce higher quality products, Northern firms in each industry participate in innovative R&D races. In general, when the state-of-the-art quality product in an industry is j, the next winner of an innovative R&D race becomes the sole producer of a $j+1$ quality product.

Each household is modeled as a dynastic family that maximizes discounted lifetime utility

$$U \equiv \int_0^\infty e^{-(\rho - g_L)t} \ln u(t) dt \tag{1}$$

where $\rho > g_L$ is the constant subjective discount rate and

$$u(t) = \left\{ \int_0^1 \left[\sum_j \delta^j d(j, \theta, t) \right]^{(\sigma-1)/\sigma} d\theta \right\}^{\sigma/(\sigma-1)} \tag{2}$$

is the per-capita utility at time t. Eq. (2) is a standard quality-augmented Dixit–Stiglitz utility function, where $d(j,\theta,t)$ is the per-capita quantity demanded of a j quality product in industry θ at time t, parameter $\delta > 1$ captures the size of the quality increment generated by each innovation and parameter $\sigma > 1$ is the constant elasticity of substitution. The assumption $\sigma > 1$ implies that products across industries are gross substitutes.

Following Dinopoulos and Segerstrom (2007), we solve the consumer problem in three steps. The first step is to solve the within-industry static optimization problem. Letting $p(j,\theta,t)$ denote the price of the j quality product in industry θ at time t, each household allocates its budget within each industry by buying the product with the lowest quality-adjusted price $p(j,\theta,t)/\delta^j$. If two products have the same quality-adjusted price, we assume that consumers buy only the higher-quality product. The second step is to solve the across-industry static optimization problem

$$\max_{d(.)} \int_0^1 \left[\delta^{j(\theta,t)} d(\theta, t) \right]^{(\sigma-1)/\sigma} d\theta \ \text{ subject to } \int_0^1 p(\theta, t) d(\theta, t) d\theta = c(t),$$

where $j(\theta,t)$ is the quality index of the product with the lowest quality-adjusted price in industry θ at time t, $p(\theta,t)$ is the price of this product, $d(\theta,t)$ is the corresponding quantity demanded, and c is the individual consumer's expenditure at time t. Solving this static optimization problem using standard optimal control techniques yields the individual consumer's demand function

$$d(\theta, t) = q(\theta, t) p(\theta, t)^{-\sigma} \frac{c}{P(t)^{1-\sigma}} \tag{3}$$

for the product with the lowest quality-adjusted price in industry θ at time t, where $q(\theta,t) = \delta^{j(\theta,t)(\sigma-1)}$ is an alternative measure of product quality, and $P(t)$ is a quality-adjusted price index defined by

$$P(t) \equiv \left[\int_0^1 q(\theta, t) p(\theta, t)^{1-\sigma} d\theta \right]^{1/(1-\sigma)}. \tag{4}$$

The quantity demanded for each of the remaining products in each industry is zero.

The third and final step is to determine the allocation of consumer income between consumption and savings that are used to finance various R&D investments. Substituting Eq. (3) into Eq. (2) and inserting the resulting expression into Eq. (1), one can express the per-capita utility $u(t)$ as a function of per-capita consumer expenditure c. Maximizing the resulting expression for Eq. (1) subject to the standard intertemporal budget constraint yields the well-known differential equation

$$\frac{\dot{c}}{c} = r - \rho, \tag{5}$$

where $r(t)$ is the market interest rate at time t. Eq. (5) implies that in a steady-state equilibrium with constant per-capita consumption expenditure c, the market interest rate r must be equal to the subjective discount rate ρ.

3.3. Product markets

We begin the analysis of product markets by describing manufacturing production. In each industry, we assume that one unit of labor produces one unit of output regardless of the quality level or the geographic location of production. Thus, in any industry where manufacturing operations are located in the North, the Northern quality leader faces constant marginal and average cost equal to the Northern wage rate w_N. Likewise, in any industry where manufacturing production takes place in the South, the foreign affiliate has constant unit-production cost equal to the Southern wage rate w_S.

We solve the model for a steady-state equilibrium where the wage rates w_N and w_S are both constant over time. We also restrict attention to the range of parameter values that generate the following inequalities in the steady-state equilibrium: $w_N > w_S > w_N/\delta$. The first inequality implies that the North has a higher wage rate than the South and the unit production cost of a foreign affiliate is lower than that of a Northern quality leader. Then manufacturing production shifts to the South when a Northern industry leader is successful in adaptive R&D. The second inequality implies that the quality improvement is sufficiently large so that a typical Northern quality leader has lower quality-adjusted unit production costs than a foreign affiliate producing a product one step below in the quality ladder. As a result, Northern quality leaders can drive foreign affiliates producing lower quality products out of business even though the latter have a wage-based cost advantage.

We assume that firms are price setters in each industry. To understand what this assumption implies, consider a Northern firm that wins an R&D race and becomes the only firm in the world that knows how to produce the state-of-the-art quality product in its industry. This firm faces a competitor that can produce a product with quality one step below, with manufacturing production located in either the North or the South depending on the past history of that industry. It is profit-maximizing for the new quality leader to either engage in limit pricing (as in Grossman and Helpman, 1991) or charge the unconstrained monopoly price. In either case, the closest competition cannot compete and is priced out of business. We restrict attention to equilibrium behavior where the closest competitor chooses to immediately exit the market and then the new quality leader charges the unconstrained monopoly price, as in Howitt (1999).[11]

A Northern quality leader earns the flow of global profits $\pi_N(t) = (p_N - w_N)[d_N(t)L_N(t) + d_S(t)L_S(t)]$, where p_N is the price charged, $d_N(t)$ is the per-capita quantity demanded by Northern consumers and $d_S(t)$ is the per-capita quantity demanded by Southern consumers. At each instant in time, each Northern quality leader maximizes the flow of global monopoly profits with respect to p_N taking into account Eq. (3) which is used to determine $d_N(t)$ and $d_S(t)$. It is straightforward to verify that the unconstrained monopoly price is $p_N = [\sigma/(\sigma - 1)]w_N$, that is, each Northern quality leader charges the standard monopoly markup of price over marginal cost. Likewise, after a Northern quality leader has succeeded in transferring its production to its foreign affiliate, the foreign affiliate earns a flow of global monopoly profits $\pi_F(t) = (p_F - w_S)[d_N(t)L_N(t) + d_S(t)L_S(t)]$, where p_F is the price

[11] In the case of drastic innovations ($\delta > 1$ is sufficiently large), the new quality leader charges the unconstrained monopoly price and drives the incumbent quality-leader out of business. In the case of non-drastic innovations ($\delta > 1$ is small), the new quality leader charges the limit price initially and immediately reverts to the unconstrained monopoly price once it learns that the incumbent firm has gone out of business. In the presence of positive costs of reentering the market, the above mentioned trigger strategy allows each new quality leader to charge the unconstrained monopoly price except for an instance in time when innovation occurs.

charged. By charging the unconstrained monopoly price $p_F=[\sigma/(\sigma-1)]w_S$, each foreign affiliate maximizes the flow of global profits.

Each foreign affiliate faces the risk that its technology becomes public knowledge. Following Helpman (1993) and Lai (1998), we model this risk by assuming that, at each instant in time, there is an exogenous instantaneous probability $\bar{I}_S$ that a foreign affiliate's product is copied by a competitive fringe of Southern firms. All copied products are produced in the South at a price $p_S=w_S$. A reduction in the rate of copying $\bar{I}_S$ will be later interpreted as a strengthening of IPR protection in the South.[12] The above analysis implies that $p_N>p_F>p_S$, that is, as a product shifts from being produced by a Northern quality leader to its foreign affiliate and then to a Southern firm, the equilibrium price of the product declines. This price pattern is consistent with Vernon's (1966) description of the product life cycle, in which multinational firms play a central role.

The next step in the analysis is to derive expressions for the equilibrium values of global monopoly profits. We first introduce additional notation which simplifies the exposition. Denote with $E(t)=c_NL_N(t)+c_SL_S(t)$ global consumption expenditure and let $c=[c_N\bar{L}_N+c_S\bar{L}_S]/\bar{L}$ denote per-capita global consumption expenditure. In addition, denote with $Q(t)\equiv\int_0^1 q(\theta,t)d\theta$ the average quality level across all industries at time t. Using Eq. (3), one can then define per-capita global demand for a product with average quality $Q(t)$ produced by a Northern quality leader

$$y_N=Q(t)p_N^{-\sigma}\frac{c}{P(t)^{1-\sigma}}, \tag{6}$$

by a foreign affiliate

$$y_F=Q(t)p_F^{-\sigma}\frac{c}{P(t)^{1-\sigma}}, \tag{7}$$

and by Southern firms

$$y_S=Q(t)p_S^{-\sigma}\frac{c}{P(t)^{1-\sigma}}. \tag{8}$$

We solve the model for a steady-state equilibrium where y_N, y_F and y_S are all constant over time. We can then write the flow of global monopoly profits earned by a Northern quality leader as

$$\pi_N(\theta,t)=\frac{w_N}{(\sigma-1)}\frac{q(\theta,t)}{Q(t)}y_NL(t). \tag{9}$$

Eq. (9) states that the flow of global profits earned by a Northern quality leader increases in its per-unit profit margin $w_N/(\sigma-1)$, its relative quality $q(\theta,t)/Q(t)$, and the global demand for its product $y_NL(t)$. Similar considerations apply to the flow of global monopoly profits earned by a foreign affiliate, which can be expressed as

$$\pi_F(\theta,t)=\frac{w_S}{(\sigma-1)}\frac{q(\theta,t)}{Q(t)}y_FL(t). \tag{10}$$

A foreign affiliate has marginal cost w_S and a typical market size $y_F L(t)$.[13] Southern firms producing copied products under perfect competition earn zero economic profits.

3.4. Innovation, adaptation and imitation

The flow of monopoly profits provides an incentive for Northern firms to engage in innovative R&D aimed at discovering new higher-quality products. Northern quality leaders can increase the flow of monopoly profits by transferring their manufacturing facilities to the South, but to do so their foreign affiliates must engage in adaptive R&D, as in Glass and Saggi (2002). Both types of investment activities are costly and involve uncertain returns.

If a Northern firm i in industry θ at time t hires $\ell_{Ni}(\theta,t)$ Northern workers to engage in innovative R&D, then it is successful in discovering the next higher-quality product in industry θ with instantaneous probability

$$I_{Ni}(\theta,t)=\frac{\ell_{Ni}(\theta,t)}{\gamma q(\theta,t)}, \tag{11}$$

where $\gamma>0$ is an innovative-R&D productivity parameter. The term $q(\theta,t)$ captures the notion that the productivity of R&D labor declines as the complexity of each product (measured by its quality level) increases. Following Segerstrom (1998) and in particular Li (2003), we assume increasing R&D difficulty to remove the counterfactual scale effect growth property that is shared by all early endogenous growth models. This assumption generates semi-endogenous growth.

The returns to innovative R&D are independently distributed across firms, industries and over time. Therefore, the industry-wide instantaneous probability of innovation (or the intensity of the Poisson process that governs the arrival of innovations) is $I_N(\theta,t)=\sum_i I_{Ni}(\theta,t)$. If the foreign affiliate of a Northern quality leader in industry θ at time t hires $\ell_F(\theta,t)$ Southern workers to engage in adaptive R&D, then the Northern firm is successful in shifting its production to the foreign affiliate with instantaneous probability

$$I_F(\theta,t)=\frac{\ell_F(\theta,t)}{\alpha q(\theta,t)}, \tag{12}$$

where $\alpha>0$ is an adaptive R&D productivity parameter. Thus a Northern quality leader is more likely to be successful in transferring its manufacturing production to the South when it employs more adaptive-R&D workers. The term $q(\theta,t)$ captures the notion that it is more difficult to transfer the production of more complex products.[14]

Our modeling of adaptive R&D attempts to capture the substantial resource costs and inherent uncertainty associated with international technology transfer, including the training of foreign workers, learning about local customs, culture and regulations, etc. Fors (1997) reports that in a sample of Swedish multinationals, the average amount of R&D performed abroad was about 25% of total R&D expenditure per firm. Norback (2001) uses regression analysis to establish that Swedish multinationals that have established R&D labs in a foreign country are more likely to transfer technology and production to such a country.

All firms maximize expected discounted profits and there is free entry into each innovative R&D race. Consider first the incentive of Northern challenger firm i to engage in innovative R&D in industry θ at time t. The expected benefit from engaging in innovative R&D is $v_N(\theta,t)I_{Ni}(\theta,t)dt$, where $v_N(\theta,t)$ is the expected discounted profits that the Northern firm would earn from innovating (i.e., the market value of being a Northern quality leader) and $I_{Ni}(\theta,t)dt$ is the firm's probability of innovating during the infinitesimal time interval dt. During this time interval, firm i also incurs the innovative R&D cost $w_N\ell_{\mathrm{N}i}(\theta,t)dt=w_NI_{Ni}(\theta,t)\gamma q(\theta,t)dt$ using Eq. (11). Free entry into each

[12] This interpretation can be justified as follows: assume that once a product is produced in the South, its technology can be imitated instantaneously and without any costs by Southern firms in the absence of Southern IPR protection. Further assume that with instantaneous probability $\bar{I}_S$ the Southern government refrains from perfect IPR protection (allows “illegal” imitation) in each industry. Then $\bar{I}_S$ captures the flow of products manufactured by foreign affiliates that do not obtain effective IPR protection.

[13] Due to special assumptions about product market competition, Northern quality leaders and foreign affiliates earn identical profit flows in Parello (2008). In this paper, profit flows always jump up when a Northern quality leader succeeds in transferring its production to a foreign affiliate.

[14] This assumption differentiates the present model from earlier North-South trade models with FDI, in particular, Helpman (1993), Lai (1998), Glass and Saggi (2002), and Glass and Wu (2007).

R&D race implies that the expected benefit from innovative R&D must be equal to the corresponding R&D cost. This yields the following zero-profit condition for innovative R&D:

$$v_N(\theta,t) = w_N \gamma q(\theta,t). \tag{13}$$

Next consider the incentives that the foreign affiliate of a Northern quality leader has to engage in adaptive R&D in industry θ at time t. If successful, the expected discounted profit flow earned by the firm increases by $[v_F(\theta,t) - v_N(\theta,t)]$, where $v_F(\theta,t)$ is the market value of the foreign affiliate after R&D success. Thus, the expected benefit from engaging in adaptive R&D is $[v_F(\theta,t) - v_N(\theta,t)]I_F(\theta,t)dt$, where $I_F(\theta,t)dt$ is the multinational firm's probability of successfully transferring its production to the low-wage South during the infinitesimal time interval dt. The corresponding cost of conducting adaptive R&D during this time interval is $w_S \ell_F(\theta,t)dt = w_S \alpha I_F(\theta,t)q(\theta,t)dt$ using Eq. (12). Because the net benefit of adaptive R&D is linear in $I_F(\theta,t)$, the foreign affiliate engages in a positive amount of adaptive R&D if and only if the following equilibrium condition holds:

$$v_F(\theta,t) - v_N(\theta,t) = w_S \alpha q(\theta,t). \tag{14}$$

Multinational firms already earn positive global profit flows, and this needs to be taken into account when evaluating their incentives to engage in adaptive R&D. Eq. (14) implies that what matters for adaptive R&D is not the expected discounted profits a firm could earn from moving its production to the South v_F but the gain in expected discounted profits $v_F - v_N$. When technology transfer occurs, each foreign affiliate pays its parent firm the royalty payment v_N for the use of its technology in the South, since the adaptive R&D accounts for the increment in the firm's value $v_F - v_N$ which is less that the foreign affiliate's market value v_F. Since foreign affiliates transfer a fraction of their profits as royalty payments to Northern stockholders for the use of Northern technology, a fraction of the operating profits from affiliates are repatriated to the North. We solve the model for a steady-state equilibrium where both I_N and I_F are constant over time and do not vary across industries.

3.5. The stock market

Consumer savings finance all types of R&D investments through a global stock market. At each instant in time there are two types of firms that have positive stock-market value: Northern quality leaders (who produce in the North) and foreign affiliates (who produce in the South). Although it is not important for the equilibrium analysis, for the welfare analysis we need to specify exactly who finances R&D and consequently ends up owning the firms. We will analyze the case in which all innovative R&D is financed by Northern consumers and all adaptive R&D is financed by Southern consumers.[15] This assumption determines the distribution of financial assets between North and South and it is consistent with the Feldstein and Horioka (1980) finding that domestic savings finance domestic investment.

Since the returns to R&D investments are independent across firms and over time, consumers can completely diversify the idiosyncratic risk by holding a diversified portfolio of stocks. At each instant in time, the rate of return from holding any of the above-mentioned stocks must be the same as the rate of return from holding a risk-free bond: the market interest rate r.

[15] An alternative asset distribution arises if one assumes that Southern consumers do not save. In this case, Northern savings finance both types of R&D, all profits of foreign affiliates are repatriated to Northern stockholders, and per-capita consumption of a typical Southern consumer equals her wage income (see Eq. (39)). Theorems 2 and 3 hold in this case as well.

Using the no-profitable arbitrage condition we can derive expressions for the stock-market valuation of each type of firm. The relevant no-arbitrage condition for holding a stock issued by an incumbent Northern quality leader is

$$\frac{\pi_N - w_S \alpha q I_F}{v_N} + I_N\left[\frac{0 - v_N}{v_N}\right] + I_F\left[\frac{v_F - v_N}{v_N}\right] = r,$$

where industry arguments of functions have been omitted. The LHS of the above equation equals the expected rate of return on a stock issued by Northern quality leader and the RHS equals the market interest rate r. By investing in the stock, the investor receives the dividend $(\pi_N - w_S \alpha q I_F)/v_N$. However, with instantaneous probability I_N, a higher quality product is discovered, the incumbent Northern quality leader goes out of business and the investor suffers a total capital loss. In addition, with instantaneous probability I_F, the firm is successful in transferring its production to the South and the investor reaps the additional capital gain $[v_F - v_N]/v_N$. Since the quality level in an industry jumps up only at the end of the R&D race when innovation occurs, the free-entry condition (13) implies that v_N is constant during an R&D race and there is no capital gain from just staying in business.

The equilibrium condition (14) implies that the capital gain associated with successful adaptive R&D is exactly offset by the cost of hiring Southern workers to engage in adaptive R&D. It follows from the no-arbitrage condition that the stock market value of a Northern quality leader is

$$v_N = \frac{\pi_N}{r + I_N}. \tag{15}$$

The stock-market valuation of a Northern quality leader equals the flow of its global monopoly profits π_N discounted by the market interest rate r plus the probability of default, which is captured by the Poisson arrival rate of further innovation I_N.

Similar considerations apply to calculating the stock-market valuation of a multinational firm that produces in the South v_F. The no-arbitrage condition in this case can be written as

$$\frac{\pi_F}{v_F} + I_N\left[\frac{0 - v_F}{v_F}\right] + \bar{I}_S\left[\frac{0 - v_F}{v_F}\right] = r.$$

By buying a stock of a multinational firm that produces in the South, an investor receives the dividend π_F/v_F. However, this investor faces two types of risk: First, with instantaneous probability I_N a higher quality product is discovered by a Northern challenger, the multinational firm is driven out of business by the new Northern quality leader, and the investor suffers a total capital loss. Second, with an exogenous instantaneous probability $\bar{I}_S$ a Southern firm copies the foreign affiliate's product, perfect competition prevails in the market, economic profits are driven down to zero and the investor suffers a total capital loss. The equilibrium conditions (13) and (14) together imply that the market value of a foreign affiliate v_F is constant during an R&D race (the time interval between to consecutive innovations) because the quality level does not change, and therefore there is no capital gain associated with a foreign affiliate staying in business. Consequently, the no-arbitrage condition for a multinational firm that produces in the South simplifies to

$$v_F = \frac{\pi_F}{r + I_N + \bar{I}_S}. \tag{16}$$

The stock-market valuation of the firm equals the flow of its global monopoly profits $\pi_F(t)$ discounted by the market interest rate r plus the probability of default, which is captured by the Poisson arrival rates of further innovation by Northern firms and imitation by Southern firms ($I_N + \bar{I}_S$).

3.6. Industry composition and quality dynamics

At each instant in time, there are three categories of industries in the global economy. There is a set (measure) of industries n_N where production is done in the North by Northern quality leaders; a set of industries n_F where production is done in the South by foreign affiliates of multinational firms; and a set of industries n_S where production is done in the South by Southern firms. As illustrated in Fig. 1, each industry can switch randomly across these three categories with transition probabilities that depend on the Poisson arrival rates associated with innovation, adaptation and imitation.

The measure of all industries equals unity by construction, $1 = n_N + n_F + n_S$, and therefore the measure of industries in each category must be constant in any steady-state equilibrium. This implies that the flow of industries into the Northern quality leaders category must be equal to the flow out of this category, that is, $n_N I_F = n_F I_N + n_S I_N = (1 - n_N) I_N$. Similarly, the flow of industries into the n_S-category must equal the flow of industries out of the n_S-category, that is, $n_F \bar{I}_S = n_S I_N$. Together with the requirement that the set of all industries has a unit measure, these flow equations imply that

$$n_N = \frac{I_N}{I_N + I_F}, \quad n_F = \frac{I_N}{\left(I_N + \bar{I}_S\right)} \frac{I_F}{(I_N + I_F)}, \quad n_S = \frac{\bar{I}_S}{\left(I_N + \bar{I}_S\right)} \frac{I_F}{(I_N + I_F)}. \tag{17}$$

According to Eq. (17), an increase in the rate of innovation I_N increases the set of industries with Northern quality leaders and decreases the set of industries with imitated products. Similarly, an increase in the rate of adaptation I_F increases the set of industries with production by foreign affiliates and the set of industries with production by Southern firms, but decreases the set of industries with production by Northern quality leaders. Finally, an increase in the rate of imitation by Southern firms $\bar{I}_S$ increases the set of industries with imitated products and reduces the set of industries where foreign affiliates produce in the South.

By definition, the average quality of products at time t is given by

$$Q(t) \equiv \int_0^1 q(\theta, t) dt = \int_0^1 \lambda^{j(\theta,t)} d\theta, \tag{18}$$

where $\lambda = \delta^{\sigma - 1} > 1$ is a parameter that is positively related to the innovation size δ and can be interpreted as an alternative measure of product quality. The average quality can be decomposed in three parts, $Q(t) = Q_N(t) + Q_F(t) + Q_S(t)$, where $Q_N(t) \equiv \int_{n_N} q(\theta, t) d\theta$ is the a measure of product quality for all products manufactured by Northern quality leaders, $Q_F(t) \equiv \int_{n_F} q(\theta, t) d\theta$ is a measure of product quality for products manufactured by foreign affiliates and $Q_S(t) \equiv \int_{n_S} q(\theta, t) d\theta$ is a measure of product quality for products manufactured by Southern firms.

In order to solve the model we need to calculate the allocation of labor across various industry categories and activities, and therefore we need to determine how the components of average quality evolve

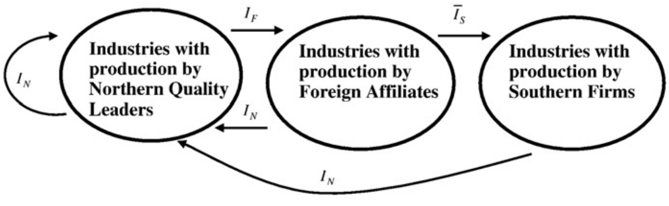

Fig. 1. Industry composition.

over time. Appendix A derives the following steady-state expressions for the three shares of the average quality:

$$\frac{Q_N(t)}{Q(t)} = \frac{\lambda I_N}{\lambda I_N + I_F}, \quad \frac{Q_F(t)}{Q(t)} = \frac{\lambda I_N}{\left(\lambda I_N + \bar{I}_S\right)} \frac{I_F}{(\lambda I_N + I_F)}$$
$$\frac{Q_S(t)}{Q(t)} = \frac{\bar{I}_S}{\left(\lambda I_N + \bar{I}_S\right)} \frac{I_F}{(\lambda I_N + I_F)}. \tag{19}$$

Eq. (19) states that $Q_N(t)$, $Q_F(t)$ and $Q_S(t)$ grow at the same rate over time as the average product quality $Q(t)$. Notice also the similarities between the corresponding expressions in Eqs. (17) and (19). The only difference is that the right-hand-side of each expression in Eq. (17) depends on I_N, whereas the right-hand-side of expressions in Eq. (19) depends on λI_N. The reason for this difference is that manufacturing only shifts from South to North when innovation occurs and the quality level of each product increases by a multiple of λ. In contrast, when adaptation or imitation occurs, the quality of each product remains the same.

3.7. The Northern labor market

We assume that there is perfect labor mobility across activities in both regions. Full employment of labor prevails at each instant in time and wages adjust to equalize labor demand and supply. Northern labor is employed in two activities: manufacturing of final consumption goods and innovative R&D. A Northern quality leader employs $d(\theta,t)L(t) = q(\theta,t) y_N L(t) \,/\, Q(t)$ workers in manufacturing production, using Eqs. (3) and (6). Since the measure of Northern quality leaders is n_N, the demand for manufacturing labor is given by $\int_{n_N} d(\theta, t) L(t) d\theta = y_N \frac{L(t)}{Q(t)} \int_{n_N} q(\theta, t) d\theta = y_N L(t) \frac{Q_N(t)}{Q(t)} = y_N L(t) \frac{\lambda I_N}{(\lambda I_N + I_F)}$. All industries are targeted by Northern firms engaged in innovative R&D and the aggregate demand for Northern researchers is given by $\int_0^1 \gamma I_N q(\theta,t) d\theta = \gamma I_N \int_0^1 q(\theta,t) d\theta = \gamma I_N Q(t)$, where Eq. (11) has been used to derive the demand for labor devoted to a particular industry $\ell_N = \gamma I_N q(\theta,t)$.

The Northern economy-wide demand for labor equals its supply $L_N(t)$ and there is full employment when $L_N(t) = y_N[\lambda I_N/(\lambda I_N + I_F)]L(t) + \gamma I_N Q(t)$. Dividing both sides of the full-employment condition by $L_N(t)$ and using the expression

$$\frac{L(t)}{Q(t)} = \frac{\bar{L}_N + \bar{L}_S}{x_N \bar{L}_N} \tag{20}$$

where $x_N \equiv Q(t)/L_N(t)$, we obtain the per-capita Northern full-employment condition

$$1 = y_N \frac{\lambda I_N}{(\lambda I_N + I_F)} \frac{(\bar{L}_N + \bar{L}_S)}{\bar{L}_N} + \gamma I_N x_N. \tag{21}$$

The two terms on the RHS of the Northern full-employment condition (21) correspond to the shares of Northern workers employed in manufacturing production and in innovative R&D, respectively. The share of Northern workers employed in manufacturing production increases in the per-capita global demand for Northern products y_N and in the relative (per capita) size of the global market $(\bar{L}_S + \bar{L}_N)/\bar{L}_N$. The share of Northern researchers increases in the average quality per Northern worker $x_N \equiv Q(t)/L_N(t)$.

Eq. (21) implies that in the steady-state equilibrium the average quality per Northern worker $x_N \equiv Q(t)/L_N(t)$ must be constant over time. Hence, as product quality improves over time and $Q(t)$ rises, innovating becomes more difficult. In addition, as the Northern labor force $L_N(t)$ grows, there are more resources that can be channeled to innovative R&D. Thus x_N constitutes a natural measure of "relative R&D difficulty": R&D difficulty relative to the size of the Northern economy. Consequently, in Eq. (21) the share of Northern researchers increases in x_N because an increase in the average quality per Northern worker increases average R&D difficulty and raises the demand for R&D workers required to maintain a constant steady-state rate of innovation.

3.8. The Southern labor market

Similar considerations apply to the analysis of the Southern labor market. At each instant in time, there is perfect labor mobility across activities in the South. Southern workers can be employed in manufacturing by foreign affiliates of multinational firms, they can be hired by these foreign affiliates to engage in adaptive R&D, or they can be hired by Southern firms to manufacture imitated products.

Each of n_F foreign affiliates employs $d(\theta,t)L(t)=q(\theta,t)y_F L(t)/Q(t)$ workers, using Eqs. (3) and (7) The manufacturing labor employed by all foreign affiliates is given by

$$\int_{n_F} q(\theta,t)y_F\frac{L(t)}{Q(t)}d\theta = \frac{Q_F(t)}{Q(t)}y_F L(t) = \frac{\lambda I_N}{\left(\lambda I_N+\bar{I}_S\right)}\frac{I_F}{(\lambda I_N+I_F)}y_F L(t).$$

The manufacturing employment of labor by all Southern firms producing imitated products is

$$\int_{n_S} d(\theta,t)L(t)d\theta = y_S L(t)\frac{Q_S(t)}{Q(t)} = y_S L(t)\frac{\bar{I}_S}{\left(\lambda I_N+\bar{I}_S\right)}\frac{I_F}{(\lambda I_N+I_F)},$$

and the employment of Southern workers who are engaged in adaptive R&D and are hired by n_N foreign affiliates is

$$\int_{n_N} I_F\alpha q(\theta,t)d\theta = \alpha I_F Q_N(t) = \alpha I_F[\lambda I_N/(\lambda I_N+I_F)]Q(t).$$

Putting the above calculations together yields the Southern full-employment condition

$$L_S(t) = \frac{\lambda I_N}{\left(\lambda I_N+\bar{I}_S\right)}\frac{I_F}{(\lambda I_N+I_F)}y_F L(t) + \frac{\bar{I}_S}{\left(\lambda I_N+\bar{I}_S\right)}\frac{I_F}{(\lambda I_N+I_F)}y_S L(t) + \alpha I_F\frac{\lambda I_N}{(\lambda I_N+I_F)}Q(t).$$

The Southern full-employment condition can be simplified by noting that $y_S=[\sigma/(\sigma-1)]^{\sigma}y_F$, using Eqs. (7), (8) and the monopoly-pricing expressions. Dividing the full-employment condition by $L_S(t)$and using Eq. (20) generates the per-capita Southern full-employment condition:

$$1 = \frac{I_F}{(\lambda I_N+I_F)}\left\{\frac{\left(\bar{L}_N+\bar{L}_S\right)}{\bar{L}_S}y_F\Phi\left(\bar{I}_S\right)+\alpha\lambda I_N x_N\frac{\bar{L}_N}{\bar{L}_S}\right\}, \tag{22}$$

where

$$\Phi\left(\bar{I}_S\right) \equiv \frac{\lambda I_N}{\left(\lambda I_N+\bar{I}_S\right)} + \left(\frac{\sigma}{(\sigma-1)}\right)^{\sigma}\frac{\bar{I}_S}{\left(\lambda I_N+\bar{I}_S\right)} \tag{23}$$

is an increasing function of the rate of imitation $\bar{I}_S$.

The two terms on the RHS of the Southern full-employment condition (22) correspond to the shares of Southern workers employed in manufacturing production and in adaptive R&D, respectively. The share of Southern manufacturing workers increases in the per-capita demand for the products of foreign affiliates y_F, the relative market size of the North that Southern firms export their products to $\bar{L}_N/\bar{L}_S$, and the rate of Southern imitation $\bar{I}_S$ (faster Southern imitation means that more products in the South are produced under perfect competition at a lower price and higher quantity, which raises the demand for Southern labor). The share of Southern workers employed in adaptive R&D increases in the rate of innovation I_N (which increases the set of industries with Northern quality leaders), and in the relative R&D difficulty viewed from the South's perspective $Q(t)/L_S(t)=x_N\bar{L}_N/\bar{L}_S$ (because an increase in average product quality raises adaptive R&D difficulty and increases the number of Southern R&D workers needed to maintain a constant rate of adaptation). This completes the description of the model.

4. The steady-state equilibrium

In this section, we solve the model for a steady-state (or balanced-growth) equilibrium where the rates of innovation I_N and adaptation I_F are constant over time, as well as the nominal wage rates w_N and w_S. In any steady-state equilibrium, the shares of Northern manufacturing and innovative-R&D labor must be constant over time. It immediately follows from Eq. (21) that y_N and x_N must be constant over time. Likewise, the shares of Southern labor devoted to foreign affiliate production, Southern firm production and adaptive R&D must be constant over time in any steady-state equilibrium. It immediately follows from Eq. (22) that y_F must be constant over time as well.

Referring back to Eqs. (4) and (19), we can derive the following steady-state expression for the quality-adjusted price index

$$P(t) = \left[p_N^{1-\sigma}\frac{\lambda I_N}{(\lambda I_N+I_F)} + p_F^{1-\sigma}\frac{\lambda I_N}{\left(\lambda I_N+\bar{I}_S\right)}\frac{I_F}{(\lambda I_N+I_F)} + p_S^{1-\sigma}\frac{\bar{I}_S}{\left(\lambda I_N+\bar{I}_S\right)}\frac{I_F}{(\lambda I_N+I_F)}\right]^{\frac{1}{1-\sigma}} Q(t)^{\frac{1}{1-\sigma}}. \tag{24}$$

All terms in square brackets are constant over time. Consequently this expression for $P(t)$ together with Eq. (6) implies that per-capita consumption expenditure c must be constant over time and from Eq. (5) we obtain $r(t)=\rho$. In any steady-state equilibrium, it is optimal for each consumer to choose a constant expenditure path over time. Although nominal consumer expenditure is constant over time, real consumer expenditure $c/P(t)$ grows over time as the quality-adjusted price index declines due to growth in average product quality $Q(t)$.

The property that $x_N\equiv Q(t)/L_N(t)$ is constant over time has important implications for the rate of innovation I_N. Referring back to the definition of average quality $Q(t)\equiv\int_0^1 q(\theta,t)d\theta=\int_0^1\lambda^{j(\theta,t)}d\theta$, we can calculate how $Q(t)$ evolves over time. When a new product is discovered the index jumps up from $j(\theta,t)$ to $j(\theta,t)+1$ and this event occurs with instantaneous probability I_N. Thus the time derivative of average quality is

$$\dot{Q}(t) = \int_0^1\left(\lambda^{j(\theta,t)+1}-\lambda^{j(\theta,t)}\right)I_N d\theta = (\lambda-1)I_N Q(t). \tag{25}$$

The growth rate of average quality $\dot{Q}/Q$ is proportional to the rate of innovation I_N and depends positively on the innovation size parameter λ. Next, combining the definition of x_N and Eq. (25), we obtain that the growth rate of relative R&D difficulty is $\dot{x}_N/x_N=\dot{Q}/Q-\dot{L}_N/L_N=(\lambda-1)I_N-g_L=0$, from which it follows that

$$I_N = \frac{g_L}{\lambda-1}. \tag{26}$$

As in Segerstrom (1998), the steady-state rate of innovation I_N is completely determined by the world population growth rate g_L (or more generally, the world human capital growth rate[16]) and the innovation-size parameter λ.

The economic intuition behind Eq. (26) is as follows. Along any steady-state equilibrium path, there is a constant innovation rate I_N and rising product quality in every industry. But as product quality rises, products become more complex and it gets harder for researchers to find further improvements. Thus, to maintain a constant innovation rate over time, firms need to continually increase their R&D employment, compensating for the fact that R&D workers are becoming less productive by increasing the number of R&D workers. This can only be achieved at an economy-wide level if there is positive population growth. The higher is the population growth

[16] Using a closely-related model of R&D-driven growth, Arnold (1998) shows that the property that public policy choices do not affect the steady-state economic growth rate is preserved when the assumption of exogenous population growth is replaced by endogenous human capital accumulation.

rate g_L, the higher is the innovation rate I_N that can be sustained over time. In addition, the higher is innovation size λ, the faster is the rate at which innovations increase the R&D difficulty, and therefore the lower is the innovation rate I_N that can be sustained over time.

The equation that governs the evolution of relative R&D difficulty $\dot{x}_N/x_N = (\lambda-1)I_N - g_L$ has important implications for the transition of the rate of innovation from one steady-state equilibrium to the next. Any steady-state increase in the value of the relative R&D difficulty x_N must be associated with a temporary (transitional) increase in I_N above its steady-state value given by Eq. (26). In other words, an increase in the steady-state value of x_N is possible only if $\dot{x}_N/x_N > 0$, and therefore only if $I_N(t) > g_L/(\lambda-1)$ during the transition. Consequently any parameter change that increases (decreases) the steady-state value of the relative R&D difficulty x_N generates a temporary acceleration (deceleration) in the global rate of technological change.

The next step in the analysis is to solve for the steady-state equilibrium value of the North–South wage gap measured by the Northern relative wage $\omega \equiv w_N/w_S$. Unlike in Helpman (1993), where technology transfer to the South within multinational firms is costless and results in factor price equalization $\omega = 1$, the presence of multinational firms in our model does not suffice to eliminate the North–South wage gap. Because adaptive R&D is costly in our model, Northern workers earn higher wages than Southern workers. It turns out that the incentives to conduct innovative and adaptive R&D completely determine the steady-state value of the North–South wage gap $\omega \equiv w_N/w_S$.

Substituting Eqs. (9) and (20) into Eq. (15) and the resulting expression into Eq. (13) yields the *steady-state innovative R&D condition*:

$$\frac{y_N(\bar{L}_N+\bar{L}_S)}{x_N\bar{L}_N(\sigma-1)(\rho+I_N)} = \gamma. \tag{27}$$

The LHS of Eq. (27) is related to the benefit (expected-discounted profits) from innovating and the RHS is related to the cost of innovation. The benefit from innovating increases when y_N increases (the average consumer buys more), when $\bar{L}_N$ or $\bar{L}_S$ increases (there are more consumers to sell to), when $x_N\bar{L}_N$ decreases (firms in other industries sell lower-quality products), when ρ decreases (future profits are discounted less), and when I_N decreases (each Northern quality leader is threatened less by further innovation). The cost of innovating increases when γ increases (it takes more R&D workers to generate any given innovation rate).

Similar substitutions using Eqs. (10), (13), (14), (16) and (20) yield the *steady-state adaptive R&D condition*:

$$\frac{y_F(\bar{L}_N+\bar{L}_S)}{x_N\bar{L}_N(\sigma-1)(\rho+I_N+\bar{I}_S)} - \gamma\omega = \alpha. \tag{28}$$

The LHS of Eq. (28) is related to the benefit a Northern firm obtains from transferring its manufacturing operations to the low-wage South and the RHS is related to the cost of doing so. The benefit from transferring production to the South increases when y_F increases (the average consumer buys more of Southern-manufactured products), when $\bar{L}_N$ or $\bar{L}_S$ increases (there are more consumers to sell to), when $x_N\bar{L}_N$ decreases (firms in other industries sell lower-quality products), when ρ decreases (future profits are discounted less), when γ decreases (the firm earns lower profits prior to transferring production to the South), when I_N decreases (the firm is less threatened by further innovation), and when $\bar{I}_S$ decreases (the firm is less threatened by further imitation). The cost of transferring production to the South increases when α increases (it takes more workers to generate any given production-transfer rate.)

Combining the monopoly pricing conditions $p_N = [\sigma/(\sigma-1)]w_N$ and $p_F = [\sigma/(\sigma-1)]w_S$ with Eqs. (6) and (7) yields $y_F = \omega^\sigma y_N$. Solving Eq. (27) for y_N and then substituting into Eq. (28) using $y_F = \omega^\sigma y_N$ yields the *steady-state wage equation*:

$$\frac{(\rho+I_N)}{(\rho+I_N+\bar{I}_S)}\omega^\sigma - \omega = \frac{\alpha}{\gamma}. \tag{29}$$

This equation uniquely determines the steady-state equilibrium value of the Northern relative wage $\omega \equiv w_N/w_S > 1$.[17]

Eq. (29) reveals how the North–South wage gap depends on innovative and adaptive R&D incentives. The long-run North–South wage gap increases if α increases (it is costlier to transfer production operations to the South because adaptive R&D workers are less productive), if γ decreases (it is cheaper to develop better products in the North because innovative R&D workers are more productive), or if the rate of copying $\bar{I}_S$ increases (there is weaker Southern IPR protection). In other words, factors that encourage more production by Northern quality leaders put upward pressure in the long-run North–South wage gap. A permanent increase in the rate of innovation I_N reduces the North–South wage gap because it increases the profitability of a foreign affiliate producing in the South relative to a Northern quality leader [which is proportional to $(\rho+I_N)/(\rho+I_N+\bar{I}_S)$]. This in turn encourages the transfer of more production to the South and reduces permanently the Northern relative wage.

Eqs. (26) and (29) determine the steady-state values of two endogenous variables, the innovation rate I_N and the Northern relative wage ω. We continue the analysis by solving for the steady-state values of the FDI intensity I_F and the relative R&D difficulty x_N. Solving the innovative R&D condition (27) for y_N and substituting into the Northern per-capita full employment condition (21) yields the *Northern steady-state condition*

$$1 = \gamma x_N\left\{(\sigma-1)(\rho+I_N)\frac{\lambda I_N}{(\lambda I_N+I_F)} + I_N\right\}, \tag{30}$$

which defines an upward-sloping curve in (x_N, I_F) space with a positive x_N intercept.

The intuition behind the positive slope of the Northern steady-state condition is as follows. An increase in relative R&D difficulty x_N increases the demand for innovative-R&D labor (more researchers are needed to maintain the steady-state innovation rate I_N) and the demand for Northern labor employed in manufacturing production (stronger consumer demand for final products is required to justify the stronger R&D effort triggered by higher relative R&D difficulty). In contrast, an increase in the FDI intensity I_F decreases Northern manufacturing employment by shifting production to the South. Consequently, to satisfy both Northern profit-maximization and full employment conditions, any increase in relative R&D difficulty x_N must be matched by an increase in the FDI intensity I_F.

Solving the adaptive-R&D condition (28) for y_F and substituting into the Southern full-employment condition (22) yields the *Southern steady-state condition*

$$1 = x_N\frac{\bar{L}_N}{\bar{L}_S}\frac{I_F}{(\lambda I_N+I_F)}\{(\sigma-1)(\alpha+\gamma\omega)(\rho+I_N+\bar{I}_S)\Phi(\bar{I}_S) + \alpha\lambda I_N\}, \tag{31}$$

where $\Phi(\bar{I}_S)$ is defined by (23). The Southern steady-state condition defines a downward-sloping curve in (x_N,I_F) space with no intercepts.

The intuition behind the negative slope of the Southern steady-state condition is as follows: an increase in the relative R&D difficulty x_N increases the demand for adaptive-R&D labor (more Southern researchers are needed to maintain the steady-state FDI intensity I_F) and the demand for Southern production labor (stronger consumer demand is needed to justify greater R&D effort). In contrast, a decrease in I_F reduces the demand for Southern manufacturing workers since less production shifts to the South. Consequently, to satisfy the

[17] Formally, let $f(\omega) \equiv [(\rho+I_N)/(\rho+I_N+\bar{I}_S)]\omega^\sigma - \omega$ where I_N is given by Eq. (26). Then it is straightforward to establish the following properties: $f(1)<0$; $\lim_{\omega\to\infty} f(\omega) = +\infty$; and for all $\omega>1$, $d^2f(\omega)/d^2\omega>0$. These properties imply that the LHS of the wage equation is an increasing function of the relative wage ω in the positive quadrant and that the wage Eq. (29) determines uniquely the steady-state Northern relative wage $\omega>1$ as a function of the model's parameters.

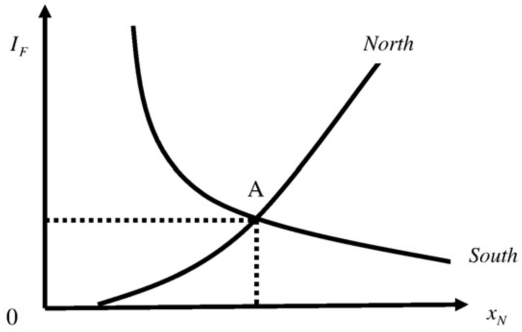

Fig. 2. The steady-state equilibrium.

Southern full-employment condition, any increase in the relative R&D difficulty x_N must be matched by a decrease in the FDI intensity I_F.

The graphs of Northern and Southern steady-state equilibrium conditions are illustrated in Fig. 2 and are labeled “North” and “South”. Their intersection at point A determines the unique steady-state values for FDI intensity I_F and relative R&D difficulty x_N. Although the wage Eq. (29) determines the unique steady-state Northern relative wage, we need to impose a restriction on the parameters of the model to guarantee that $\omega<\delta$. Since the LHS of Eq. (29) is an increasing function of the relative wage in the positive quadrant, requiring the LHS of the wage equation evaluated at $\omega=\delta>1$ to be strictly greater than the RHS yields the following condition

$$\alpha<\gamma\left\{\delta^{\sigma}\frac{(\rho+I_N)}{\left(\rho+I_N+\bar{I}_S\right)}-\delta\right\}, \tag{32}$$

where the steady-state rate of innovation is $I_N=g_L/(\lambda-1)$. Condition (32) is satisfied for sufficiently low values of parameter α, that is, if the productivity of researchers engaged in adaptive R&D is not too low. We have established.

Theorem 1. *If adaptive R&D workers are sufficiently productive so that Eq. (32) holds, then the model has unique steady-state equilibrium with strictly positive rates of innovation I_N, adaptation I_F and a Northern relative wage ω that satisfies $\delta>\omega>1$.*

5. Steady-state equilibrium properties

Theorem 1 establishes the existence and uniqueness of steady-state equilibrium in a model of a growing global economy with multinational firms and international technology transfer. In doing so, it paves the way for the analysis of the model's comparative steady-state properties. This section studies the equilibrium effects of strengthening Southern IPR protection. Since the results are the same, we also report on the implications of the South adopting friendlier FDI policies that reduce the costs of international technology transfer within multinational firms.

The signing of the Trade-Related Intellectual Property Rights (TRIPs) agreement by members of the WTO, which in effect calls for the adoption of longer patent lengths and stricter enforcement of patent policies by developing countries, has created a policy debate regarding its effects on the global economy and in particular developing countries. We address this policy debate by analyzing the dynamic effects of a reduction in the exogenous rate of imitation $\bar{I}_S$. As stated before, we interpret this parameter change as capturing the effects of stronger IPR protection.[18]

We also consider the effects of a permanent reduction in parameter α which is proportional to the unit-labor requirement for adaptive R&D. We think of a decrease in α as capturing more FDI friendly policies, making it less costly for multinational firms to transfer their manufacturing operations to the low-wage South. For instance, Hill (2005) reports that in the period 1991–2001 about 95% of the 1395 changes in FDI laws and regulations created a more favorable environment for multinational firms. In addition, many countries have encouraged more FDI by engaging in a number of bilateral investment treaties designed to protect and promote investment between countries. As of 2002, there were 2099 such bilateral investment treaties in the world involving more than 160 countries.

A decrease in $\bar{I}_S$ or α has no effect on the Northern steady-state condition (30), but implies that x_N increases for any given value of I_F in the Southern steady-state condition (31).[19] Thus the graph of the Southern steady-state condition shifts to the right in Fig. 2 (not shown) generating a higher steady-state FDI intensity I_F and a higher steady-state value of relative R&D difficulty x_N. The permanent increase in x_N is associated with a temporary increase in the innovation rate above its steady-state value $I_N=g_L/(\lambda-1)$. Finally, the wage-Eq. (29) implies that a decrease in $\bar{I}_S$ or α results in a permanent reduction in the North–South wage gap ω. We have derived the following theorem:

Theorem 2. *The adoption of stronger IPR protection ($\bar{I}_S\downarrow$) generates a permanent increase in the rate of technology transfer to the South within multinational firms ($I_F\uparrow$), a permanent decrease in the North–South wage-gap ($\omega\downarrow$) and a temporary increase in the Northern innovation rate ($I_N\uparrow$). The adoption of more FDI-friendly policies by the South ($\alpha\downarrow$) generates the same steady-state equilibrium effects.*

When faced with stronger IPR protection in the South (or lower costs of transferring their intellectual property to the South), multinational firms find it more profitable to increase the adaptive R&D spending of their foreign affiliates and transfer their manufacturing production to the low-wage South more quickly ($I_F\uparrow$). The more rapid technology transfer from North to South in turn increases the demand for Southern labor employed in adaptive R&D and decreases the demand for production labor in the North. These two effects cause a permanent decline in the Northern relative wage ω and make it more attractive for firms to engage in innovative R&D in the North. Firms respond by innovating more frequently, R&D difficulty rises at a faster than usual rate, and this increase causes the innovation rate to gradually slow down. The permanent increase in the relative R&D difficulty x_N is associated with a temporary increase in the rate of innovation I_N.

The effects of increased IPR protection summarized in Theorem 2 contrast with the results derived in the earlier literature. In particular, Glass and Saggi (2002), Sener (2006), and Glass and Wu (2007) study the same issue but find that stronger IPR protection reduces the rates of innovation and technology transfer. This paper presents the first model that is consistent with the empirical evidence in Branstetter et al. (2006) that multinational firms increase their R&D spending in developing countries that offer stronger IPR protection and increase their technology transfer to these reforming countries. The model is also consistent with the evidence in Jones (1995a) on the absence of scale effects in TFP growth and the evidence in Jones (1997) and Sala-i-Martin (2006) on the decline in global income inequality.

6. Steady-state welfare analysis

The previous section established that, in a global growing economy where multinational firms engage in technology transfer from

[18] This is not the only way to analyze the effects of stronger intellectual property rights. For example, Grossman and Lai (2004) and Dinopoulos and Kottaridi (2008) develop models with finite-length patents to study the dynamic effects of patent rights protection. However, unlike the present paper, these studies abstract from multinational-firm considerations.

[19] A reduction in $\bar{I}_S$ lowers the RHS of the Southern steady state condition (31) directly and through a reduction in $\Phi(\bar{I}_S)$ defined in Eq. (23).

developed to developing countries, strengthening IPR protection in developing countries increases the rates of innovation and growth, accelerates the rate of technology transfer and improves the global income distribution. But do these changes make people happier in developing countries? Do they lead to globalization with a human face? This section aims at providing insights concerning the welfare implications of policy changes. It is beyond the scope of the paper to assess whether or not discounted consumer utility increases at the time of policy change. To do so, we would need to take into account how consumer utility evolves along the entire transition path leading to the new steady-state equilibrium. Instead, we pursue the more modest objective of trying to determine the long-run welfare effects of policy changes. We ask the question: do these changes make consumers in developing countries better off eventually? To answer this question, it suffices to compare steady-state utility paths before and after policies change.

Eq. (2) implies that the steady-state utility of a Northern consumer at time t equals

$$u_N(t) = \left\{ \int_{n_N} q(\theta,t)^{\frac{1}{\sigma}} d_N(\theta,t)^{\frac{\sigma-1}{\sigma}} d\theta + \int_{n_F} q(\theta,t)^{\frac{1}{\sigma}} d_F(\theta,t)^{\frac{\sigma-1}{\sigma}} d\theta + \int_{n_S} q(\theta,t)^{\frac{1}{\sigma}} d_S(\theta,t)^{\frac{\sigma-1}{\sigma}} d\theta \right\}^{\frac{\sigma}{\sigma-1}},$$

where the integrals represent the utility derived from the consumption of goods produced by Northern-quality leaders, foreign affiliates and Southern firms, respectively. Substituting using Eq. (3) and the monopoly-pricing conditions yields the following expression for the utility of a Northern consumer:

$$u_N(t) = c_N / P(t), \tag{33}$$

where c_N is per-capita consumption expenditure and $P(t)$ is the quality-adjusted price index defined in Eq. (4). Similar considerations apply to the derivation of the utility of a typical Southern consumer:

$$u_S(t) = c_S / P(t). \tag{34}$$

In the present model Northern and Southern consumers face the same quality-adjusted price index but have different per-capita consumption expenditures.

Using Eq. (24), setting $w_S = 1$ and $w_N = \omega$, we obtain $P(t) = Q(t)^{1/(1-\sigma)} \Psi^{1/(1-\sigma)}$, where

$$\Psi \equiv \frac{(\sigma\omega)^{1-\sigma}}{(\sigma-1)^{1-\sigma}} \frac{\lambda I_N}{(\lambda I_N + I_F)} + \frac{(\sigma)^{1-\sigma}}{(\sigma-1)^{1-\sigma}} \frac{\lambda I_N}{(\lambda I_N + \bar{I}_S)} \frac{I_F}{(\lambda I_N + I_F)} + \frac{\bar{I}_S}{(\lambda I_N + \bar{I}_S)} \frac{I_F}{(\lambda I_N + I_F)} \tag{35}$$

is constant over time and captures the contributions of Northern quality leaders, foreign affiliates and Southern imitators to $P(t)$. The price index declines over time due to the increase in average product quality $Q(t)$. Using the definition of relative R&D difficulty $x_N \equiv Q(t)/L_N(t)$, the above expression for the price index can be written as

$$P(t) = \{x_N L_N(t) \Psi\}^{\frac{1}{1-\sigma}}. \tag{36}$$

Per-capita consumption expenditures are constant over time in any steady-state equilibrium, and therefore taking logs and differentiating with respect to time $u_N(t)$ and $u_S(t)$ yields

$$g \equiv \frac{\dot{u}_N}{u_N} = \frac{\dot{u}_S}{u_S} = \frac{1}{(\sigma-1)} \frac{\dot{Q}(t)}{Q(t)} = \frac{g_L}{(\sigma-1)}, \tag{37}$$

that is, there is a common steady-state rate of utility growth which is proportional to the constant rate of population growth g_L. The constant rate of utility growth means that, for long-run welfare comparisons, it is sufficient to compare the level of each consumer's steady-state utility at time $t = 0$ under different policies.

Assuming that innovative R&D done in the North is financed by Northern savings and adaptive R&D done in the South is financed by Southern savings, the following expressions for per-capita consumption expenditures are derived in Appendix A:

$$c_N = \omega + (\rho - g_L)\omega\gamma x_N \left[\frac{\lambda I_N}{(\lambda I_N + I_F)} + \frac{\lambda I_N}{(\lambda I_N + \bar{I}_S)} \frac{I_F}{(\lambda I_N + I_F)} \right], \tag{38}$$

$$c_S = 1 + (\rho - g_L)\alpha \frac{\lambda I_N}{(\lambda I_N + \bar{I}_S)} \frac{1}{[(\sigma-1)(\alpha+\gamma\omega)(\rho + I_N + \bar{I}_S)\Phi(\bar{I}_S) + \alpha\lambda I_N]}. \tag{39}$$

The first term on the RHS of these two equations is the wage-income component of per-capita consumption expenditure, and the second component corresponds to the value of steady-state asset-generated income based on innovative and adaptive R&D investment. Policy changes shift the steady-state utility paths of Northern and Southern consumers by changing the levels of per-capita consumption expenditures c_N and c_S, and the quality-adjusted price index $P(t)$.

We are now in a position to analyze the long-run welfare effects of stronger IPR protection ($\bar{I}_S \downarrow$). Most of the long-run effects benefit Southern consumers. Recall that, according to Theorem 2, the adoption of stronger IPR protection by the South increases the rate of technology transfer to the South within multinational firms ($I_F \uparrow$), decreases permanently the North–South wage gap ($\omega \downarrow$), and increases temporarily the rate of innovation ($I_N \uparrow$). Because $\Phi(\bar{I}_S)$ declines as $\bar{I}_S$ is reduced, Eq. (39) implies that per-capita expenditure of a typical Southern consumer increases ($c_S \uparrow$) as a result of stronger IPR protection. Two channels through which stronger IPR protection benefits Southern consumers are by increasing their asset-generated income (because stronger IPR protection results in the establishment of more foreign affiliates) and by raising their relative wage (because stronger IPR protection results in the transfer of more production to the South). A third channel through which stronger IPR protection benefits Southern consumers is by temporarily increasing the rate of innovation, because an increase in x_N lowers $P(t)$ holding Ψ fixed. Southern consumers benefit from being able to buy higher-quality products earlier in time since stronger IPR protection stimulates technological change. Two remaining channels through which Southern consumers benefit are captured by the property that Ψ increases as the relative wage declines ($\omega \downarrow$) and as the intensity of FDI increases ($I_F \uparrow$) holding $\bar{I}_S$ fixed. Southern consumers benefit from being able to buy products at lower prices when the relative wage of Northern workers falls and also when there is a shift in the composition of production from higher-priced Northern firms to lower-priced foreign affiliates located in the low-wage South.

The only channel through which stronger IPR protection hurts Southern consumers is that Ψ decreases when $\bar{I}_S$ decreases holding ω and I_F fixed:

$$\frac{\partial \Psi}{\partial \bar{I}_S} = \frac{\lambda I_N I_F}{(\lambda I_N + \bar{I}_S)^2 (\lambda I_N + I_F)} \left\{ 1 - \left(\frac{\sigma}{\sigma-1} \right)^{1-\sigma} \right\} > 0.$$

Stronger IPR protection contributes towards shifting the composition of production from lower-priced Southern firms to higher-priced foreign affiliates. When IPR protection becomes stronger, less manufacturing production is transferred within the South from multinational firms with higher prices to Southern firms with lower prices. We have established.

Theorem 3. *Stronger IPR protection in the South contributes to benefiting Southern consumers in the long run by increasing temporarily the rate of innovation, by increasing permanently the rate of technology transfer within multinational firms, and by increasing permanently the relative wage of Southern workers. The only channel through which stronger IPR protection in the South hurts Southern consumers in the long run is that less manufacturing production is transferred within the South from higher-priced foreign affiliates to lower-priced Southern firms.*

Although the overall long-run welfare effect of stronger IPR protection on Southern consumers is theoretically ambiguous, most of the channels through which stronger IPR protection affects Southern consumers are beneficial in nature. Our analysis supports a rather positive assessment concerning the long-run welfare effects of stronger IPR protection in developing countries.

7. Concluding remarks

In this paper, we have developed a model of North–South product-cycle trade where multinational firms play a central role. Higher-quality products are discovered in the high-wage North through stochastic and sequential R&D races, and the winners of these innovative R&D races then engage in adaptive R&D in order to transfer their manufacturing operations to the low-wage South. Once firms have succeeded in transferring their manufacturing operations to the South, they face a risk that their technology will be copied by Southern firms and their profits will vanish. The model generates semi-endogenous growth because we assume that innovating becomes more difficult as products improve in quality and become more complex. Therefore, the model is not subject to the Jones (1995a) critique of early endogenous growth models.

The main focus of the paper is on analyzing the steady-state equilibrium effects of stronger intellectual property rights (IPR) protection. We find that stronger IPR protection in the South increases permanently the rate of international technology transfer within multinational firms and generates a temporary increase in the Northern innovation rate. In addition, stronger IPR protection reduces permanently the North–South wage gap. The steady-state equilibrium effects of stronger IPR protection are consistent with the empirical findings of Branstetter et al. (2006) on technology transfer within multinational firms and the evidence in Jones (1997) and Sala-i-Martin (2006) on the decline in global income inequality. Encouraged by these results, we also analyze the long-run welfare effects of stronger IPR protection. We find that stronger IPR protection in the South contributes to benefiting Southern consumers in the long run by increasing temporarily the rate of innovation, by increasing permanently the rate of technology transfer within multinational firms, and by increasing permanently the relative wage of Southern workers. The only channel through which stronger IPR protection in the South hurts Southern consumers is that less manufacturing production is transferred within the South from higher-priced foreign affiliates to lower-priced Southern firms. Overall, this paper supports a rather positive assessment concerning the long-run effects of stronger IPR protection in developing countries, in contrast to several previous theoretical studies. For example, Glass and Saggi (2002), Sener (2006), and Glass and Wu (2007) all find that stronger IPR protection in the South leads to a lower rate of international technology transfer within multinational firms.

The analysis could be extended in several dimensions. For instance, the effects of commercial policies and trade costs could be incorporated into the present model, and the assumption that only the North can innovate could be relaxed. In addition, finite patents and patent enforcement policies could be modeled following the lead of Grossman and Lai (2004). These important issues represent interesting directions for further research.

Acknowledgments

Financial support from the Wallander Foundation is gratefully acknowledged by Paul Segerstrom.

Appendix A

Derivation of equations in Eq. (19)

The time derivative of Q_N is given by

$$\dot{Q}_N(t) = \int_{n_N}\left[\lambda^{j(\theta,t)+1} - \lambda^{j(\theta,t)}\right] I_N d\theta + \int_{n_F+n_S}\lambda^{j(\theta,t)+1} I_N d\theta - \int_{n_N}\lambda^{j(\theta,t)} I_F d\theta$$
$$= (\lambda-1)I_N Q_N(t) + \lambda I_N[Q_F(t)+Q_S(t)] - I_F Q_N(t).$$

The time derivative of Q_F is given by

$$\dot{Q}_F(t) = \int_{n_N}\left[\lambda^{j(\theta,t)} I_F d\theta - \int_{n_F}\lambda^{j(\theta,t)} I_N d\theta - \int_{n_F}\lambda^{j(\theta,t)}\bar{I}_S d\theta\right.$$
$$= I_F Q_N(t) - I_N Q_F(t) - \bar{I}_S Q_F(t).$$

Finally, the time derivative of Q_S is given by

$$\dot{Q}_S(t) = \int_{n_F}\lambda^{j(\theta,t)}\bar{I}_S d\theta - \int_{n_S}\lambda^{j(\theta,t)} I_N d\theta = \bar{I}_S Q_F(t) - I_N Q_S(t).$$

Let $Q_{FS}(t) \equiv Q_F(t) + Q_S(t)$ be the average product quality of all products manufactured in the South. Using the above derived expressions yields $\dot{Q}_{FS}(t) = \dot{Q}_F(t) + \dot{Q}_S(t) = I_F Q_N(t) - I_N Q_{FS}(t)$. The requirement that the industry composition be time invariant in any steady-state equilibrium implies that the growth rates of average quality and its components must be equal to each other and constant over time. Setting $\dot{Q}_N(t)/Q_N(t) = \dot{Q}_{FS}(t)/Q_{FS}(t)$ yields $Q_{FS}(t)/Q_N(t) = I_F/\lambda I_N$. Combining this equation with the identity $Q(t) \equiv Q_N(t) + Q_{FS}(t)$ generates the share of average quality accounted by the North $Q_N(t)/Q(t) = \lambda I_N/(\lambda I_N + I_F)$, which is the first equation in Eq. (19) and the corresponding expression for the share of average quality associated with firms producing in the South $Q_{FS}(t)/Q(t) = I_F/(\lambda I_N + I_F)$.

Setting $\dot{Q}_F(t)/Q_F(t) = \dot{Q}_S(t)/Q_S(t)$ and substituting the corresponding expressions for $\dot{Q}_F(t)$ and $\dot{Q}_S(t)$ yields $Q_{FS}(t)/Q_N(t) = [I_F Q_S(t)]/[\bar{I}_S Q_F(t)]$. Combining this expression with $Q_{FS}(t)/Q_N(t) = I_F/\lambda I_N$ generates the following equation $Q_S(t)/Q(t) = [Q_F(t)\bar{I}_S]/[Q(t)\lambda I_N]$. Combining this equation with the expression for the share of average quality of all firms located in the South $Q_{FS}(t)/Q(t) = [Q_F(t)/Q(t)] + [Q_S(t)/Q(t)] = I_F/(\lambda I_N + I_F)$, one can obtain the shares of average quality associated with foreign affiliates and Southern firms, which are the last two expressions in Eq. (19). Q.E.D.

Derivation of Eqs. (38) and (39)

Following Dinopoulos and Segerstrom (2007), we begin by deriving expressions for the steady-state market values of all Northern quality leaders and foreign affiliates. The market value of a typical Northern quality leader is $v_N(\omega,t) = \pi_N(\omega,t)/(\rho + I_N) = \omega\gamma q(\theta,t)$ and the market value of a typical foreign affiliate is $v_F(\omega,t) = \pi_F(\omega,t)/(\rho + I_N + \bar{I}_S) = (\alpha + \omega\gamma)q(\theta,t)$. During the lifetime of a typical firm, the flow of profits is constant over time because the relative wage is constant and the quality level does not change. Therefore the two zero-profit conditions hold not just at the time of innovation but during the entire lifetime of a Northern quality leader or foreign affiliate. In addition, these two zero-profit conditions can be combined to generate $v_F(\omega,t) - v_N(\omega,t) = \alpha q(\theta,t)$.

Let $V_N(t)$ and $V_S(t)$ denote the aggregate value of Northern and Southern financial assets respectively. Then the steady-state value of global assets is equal to the expected discounted profits of all multinational firms. We assume that Northern consumers finance innovative R&D, receive dividends equal to the flow of global profits earned by Northern quality leaders, and continue to receive the same flow of global profits from foreign affiliates. Southern consumers finance adaptive R&D and receive dividends equal to the difference between the foreign affiliate profits and the Northern quality-leader profits. This reasoning implies that the steady-state value of aggregate assets belonging to Northern consumers is equal to

$$V_N(t) = \int_{n_N + n_F} \omega\gamma q(\theta, t)d\theta = \omega\gamma[Q_N(t) + Q_F(t)] \tag{A1}$$
$$= \omega\gamma x_N L_N(t)\left[\frac{\lambda I_N}{(\lambda I_N + I_F)} + \frac{\lambda I_N}{(\lambda I_N + \bar{I}_S)}\frac{I_F}{(\lambda I_N + I_F)}\right],$$

where Eq. (19) and $Q(t) = x_N L_N(t)$ have been used. Similarly, the steady-state value of Southern assets is given by

$$V_S(t) = \int_{n_F} \alpha q(\theta, t)d\theta = \alpha Q_F(t) = \alpha x_N L_N(t)\frac{\lambda I_N}{(\lambda I_N + \bar{I}_S)}\frac{I_F}{(\lambda I_N + I_F)}. \tag{A2}$$

The next step is to solve for per-capita consumer expenditures. Let $A_N(t)$ denote the value of financial assets of the representative Northern consumer. The intertemporal budget constraint of a typical Northern consumer is given by $\dot{A}_N(t) = w_N + \rho A_N(t) - c_N - g_L A_N(t)$ and implies that in the long-run $A_N(t)$ must be constant over time. This means that steady-state Northern per-capita consumption expenditure is

$$c_N = w_N + (\rho - g_L)A_N. \tag{A3}$$

Similar reasoning implies that the per-capita Southern consumption expenditure is given by

$$c_S = w_S + (\rho - g_L)A_S. \tag{A4}$$

Substituting the definitions $A_N(t) = V_N(t)/L_N(t)$ and $A_S(t) = V_S(t)/L_S(t)$ into Eqs. (A3) and (A4), and using Eqs. (A1) and (A2), generates Eqs. (38) and (39). Q.E.D.

Appendix B

Long-run effects of Southern market expansion

This appendix analyzes the long-run impact of an increase in the South's size measured by its initial population level $\bar{L}_S$, as in Dinopoulos and Segerstrom (2007). This exercise is designed to provide insights on the effects of developing countries joining the world trading system: the entries of China and India into the world trading system and the collapse of communism have increased the labor force of developing countries by about 1460 million workers in a relatively short period of time (Venables, 2006). This structural change can be analyzed within the context of the present model by considering the effect of an increase in the initial size of the South.

An increase in $\bar{L}_S$ does not affect the Northern steady-state condition (30) but shifts the Southern steady-state condition (31) to the right in Fig. 2 (not shown). Consequently, an increase in $\bar{L}_S$ raises the adaptation rate I_F and the relative R&D difficulty x_N. Since $\bar{L}_S$ does not appear in the Northern relative wage Eq. (29), the long-run value of $\omega \equiv w_N/w_S$ is not affected by an increase in South's market size. The permanent increase in the relative R&D difficulty x_N implies a temporary increase in the innovation rate above its steady-state value $I_N = g_L/(\lambda - 1)$. We have established:

Theorem 4. *An increase in the size of the South ($\bar{L}_S\uparrow$) generates a permanent increase in the rate of technology transfer to the South within multinational firms ($I_F\uparrow$), no long-run change in the North–South wage gap ($\omega\leftrightarrow$) and a temporary increase in the Northern innovation rate ($I_N\uparrow$).*

Two of the above-derived effects of a market-size increase are quite intuitive: an expansion in the size of the South generates an excess supply of Southern labor which raises the amount of labor devoted to adaptive R&D. The increase in the size of the South also means that there are more consumers to buy products manufactured by Northern quality leaders. It becomes more profitable for Northern firms to innovate and firms respond by innovating more frequently. However, when firms innovate more frequently, R&D difficulty rises at faster than usual rate and the increase in R&D difficulty serves to gradually slow the economy's growth. The increase in profitability leads to a permanent increase in relative R&D difficulty ($x_N\uparrow$), a temporary increase in the Northern innovation rate I_N but no change in the permanent (or steady-state) innovation rate $I_N = g_L/(\lambda - 1)$.

The absence of any steady-state effect of increasing $\bar{L}_S$ on the North–South wage gap is surprising. This result follows directly from the wage Eq. (29), but to understand it intuitively, it is helpful to rewrite the equations that were used to derive Eq. (29) as $\frac{\pi_N(\theta,t)/q(\theta,t)}{\rho + I_N} = \gamma\omega$, $\frac{\pi_F(\theta,t)/q(\theta,t)}{\rho + I_N + \bar{I}_S} = \alpha + \gamma\omega$, and $\frac{\pi_F(\theta,t)}{q(\theta,t)} = \omega^{\sigma - 1}\frac{\pi_N(\theta,t)}{q(\theta,t)}$. This represents a system of three equations in three unknowns $\left(\frac{\pi_N(\theta,t)}{q(\theta,t)}, \frac{\pi_F(\theta,t)}{q(\theta,t)}, \omega\right)$ which is independent of parameter $\bar{L}_S$. It is easy to verify that this system determines uniquely the steady-state value of ω which satisfies Eq. (29). From these equations, we can see that there are three reasons for why an increase in $\bar{L}_S$ has no long-run effect on the wage gap ω.

First, it is obvious from the first two equations that an increase in $\bar{L}_S$ has no effect on the quality-adjusted profits of firms $\left(\frac{\pi_N(\theta,t)}{q(\theta,t)}\right.$ and $\left.\frac{\pi_F(\theta,t)}{q(\theta,t)}\right)$. When the size of the South $\bar{L}_S$ increases, firms benefit from selling their products to more consumers but, in the long-run, this is fully offset by the increase in the average product quality of each firm's competitors ($\bar{L}_S\uparrow \Rightarrow x_N \equiv Q(t)/L_N(t)\uparrow \Rightarrow Q(t)\uparrow$). Second, an increase in $\bar{L}_S$ has no long-run effect on the expected duration of quality-adjusted profits. Firms earn quality-adjusted profits until they are driven out of business by further innovation (I_N), or until their products are copied by Southern firms ($\bar{I}_S$). An increase in $\bar{L}_S$ has no effect on the long-run innovation rate $I_N = g_L/(\lambda - 1)$ as we have shown earlier, and the imitation rate $\bar{I}_S$ is exogenously given. While an increase in $\bar{L}_S$ does contribute to increasing the long-run technology transfer rate within multinational firms I_F and the profits of multinational firms jump up when they transfer their production to their foreign affiliates, this capital gain from successful adaptive R&D is exactly offset by the costs of adaptive R&D, and has no effect on the expected discounted profits from innovating (see Eqs. (15) and (16)). Third, an increase in $\bar{L}_S$ has no long-run effect on the quality-adjusted costs of R&D success ($\gamma\omega$ for innovation and α for adaptation). Consequently, an increase in the size of the South $\bar{L}_S$ has no long-run effect on the North–South wage gap ω because it has no long-run effect on the quality-adjusted profits of firms, the expected duration of these profits or the quality-adjusted costs of obtaining these profits. Adjusting for product quality, the R&D incentives of firms are not affected by an increase in $\bar{L}_S$ and it is these R&D incentives that determine the long-run wage gap ω.

This result differs from the corresponding result obtained in our earlier paper, Dinopoulos and Segerstrom (2007, Theorem 2), where an increase in $\bar{L}_S$ was shown to permanently decrease the North–South wage gap ω. In contrast to the present paper, where all technology transfer takes the form of multinational firms transferring their own production to their foreign affiliates located in the South, in our earlier paper all technology transfer takes the form of Southern firms copying endogenously Northern products. In our earlier paper, an increase in the size of the South $\bar{L}_S$ leads to a permanent increase in the rate of copying ($\bar{I}_S$ using the present paper's notation), and as a result, Northern firms earn profits for a shorter expected period of time. The expected discounted profits from innovating drop and this means that the Northern relative wage ω must fall to make innovative R&D profitable again.

To summarize, the effect of an increase in the size of the South $\bar{L}_S$ on the North–South wage gap ω depends on the mode of technology transfer. When technology transfer takes place within multinational firms, an increase in $\bar{L}_S$ has no long-run effect on ω because it has no long-run effect on quality-adjusted incentives to innovate. In contrast, when technology transfer takes the form of Southern firms copying Northern products, an increase in $\bar{L}_S$ hurts Northern firms and reduces the incentives to innovate and the Northern relative wage ω.

Next, consider the steady-state welfare effects of a permanent increase in the size of the South. Starting with the welfare of a typical Southern consumer, recall that according to Theorem 4, this increase generates a temporary increase in the Northern innovation rate ($I_N\uparrow$), a permanent increase in the adaptation rate ($I_F\uparrow$), but has no effect on the steady-state relative wage ω. These changes have no effect on Southern per-capita consumption expenditure c_S but unambiguously increase Southern consumer utility $u_S(t)$ because the quality-adjusted price index $P(t)$ falls. Because $[\sigma\omega/(\sigma-1)]^{1-\sigma}<[\sigma/(\sigma-1)]^{1-\sigma}<1$, an increase in I_F raises Ψ by putting more weight on the last two terms of Eq. (35). It follows that an increase in $\bar{L}_S$ lowers $P(t)$ because both x_N and Ψ increase. Intuitively, Southern consumers unambiguously benefit in the long run from an increase in the size of the South because individual income is not affected and the quality-adjusted product prices fall. Southern consumers benefit from the temporary increase in the Northern innovation rate I_N because this leads to a permanent increase in the average quality of products that they buy. Southern consumers also benefit from the permanent increase in the adaptation rate I_F because the prices that they pay fall when more production gets transferred from the high-wage, high-price North to the low-wage, low-price South.

Finally, consider the steady-state effect on Northern utility $u_N(t)$ of a permanent increase in the size of the South ($\bar{L}_S\uparrow$). This increase causes the quality-adjusted price index $P(t)$ to fall (for the same reasons as above), but also affects Northern per-capita consumption expenditure c_N. The latter is increasing in x_N but decreasing in I_F for strictly positive values of $\bar{I}_S$. Thus the overall long-run effect of an increase in the size of the South on Northern consumer utility is theoretically ambiguous. Intuitively, Northern consumers benefit from the permanent increase in the adaptation rate I_F because the prices that they pay fall when more production gets transferred from the high-wage North to the low-wage South. But the permanent increase in the rate of technology transfer within multinational firms I_F also has negative implications for Northern consumers. It means that multinational firms earn their profit flows for a shorter expected time duration when $\bar{I}_S$ is strictly positive, since faster transfer of production to foreign affiliates by multinational firms means more exposure to the total capital loss that results from Southern imitation. However, if $\bar{I}_S=0$, then c_N is independent of I_F and $u_N(t)$ is unambiguously increasing in $\bar{L}_S$. Thus, by continuity, Northern consumers benefit in the long run from an increase in the size of the South if the Southern imitation rate $\bar{I}_S$ is sufficiently small. We have established.

Theorem 5. *A permanent increase in the market size of the South ($\bar{L}_S\uparrow$) makes Southern consumers better off in the long run and makes Northern consumers better off if the rate of imitation $\bar{I}_S$ is sufficiently small.*

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