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Trade-Related Intellectual Property Rights: Industry Variation and Technology Diffusion

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Trade-related intellectual property rights: industry variation and technology diffusion

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Abstract. This paper assesses how a strengthening of intellectual property rights (IPRs) affects international technology diffusion by altering the volume of high-tech exports into developing countries. A simple North-South general equilibrium model in which industries differ in their imitation rates is developed. Stronger IPRs encourage Northern firms in a wider range of industries to start exporting. Exports in industries with the highest risk of imitation rise, while exports in other industries may fall. More technology diffuses to the South because new high-tech products are introduced in the Southern market. This works against the reduction in technology diffusion caused by limited imitation. JEL classification: F10, O34

Les droits de propriété intellectuelle reliés au commerce : variation selon l'industrie et diffusion de la technologie. Ce mémoire évalue comment le renforcement d'un régime de droits de propriété intellectuelle (DPI) affecte la diffusion internationale de la technologie en modifiant le volume d'exportations de biens de haute technologie vers les pays en développement. On développe un modèle d'équilibre général Nord-Sud dans lequel les industries ont des taux d'imitation différents. Des régimes plus robustes de DPI encouragent des firmes du Nord dans un plus vaste éventail d'industries à commencer à exporter. Les exportations dans des industries où le taux d'imitation est le plus élevé s'accroissent, alors que les exportations dans d'autres secteurs peuvent décliner. Davantage de technologie se diffuse vers le Sud parce que les biens de haute technologie sont introduits dans le marché du Sud. Voilà qui joue contre la réduction de la diffusion de technologie causée par une imitation limitée.

1. Introduction

The WTO-inspired strengthening of intellectual property rights (IPRs) in developing countries remains highly controversial even more than 15 years after

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the 1994 agreement on Trade-Related Aspects of Intellectual Property Rights (TRIPs). It is easy to see why. From the perspective of developed countries, stronger IPRs limit the risk of imitation associated with exporting and thereby promote high-tech exports. This increases developing countries' access to high-tech products and new technologies. Among developing countries, however, there is a concern that stronger IPRs increase the monopoly power of foreign firms and may reduce their access to new technologies as high-tech exports fall and technology diffusion from the developed world slows. This dispute is complicated by the fact that stronger IPRs are likely to affect industries differently, since there is ample evidence of cross-industry variation in imitation rates and the effectiveness of patents.[1] As a result, it is difficult to assess how a strengthening of IPRs affects international technology diffusion by altering the volume of high-tech exports into developing countries.

This paper assesses the impact of stronger IPRs on high-tech exports and diffusion. I develop a simple general equilibrium model of an innovative North and an imitative South in which a continuum of industries exists, each populated by a set of firms producing a unique product. Innovation in the North creates new products, and if these Northern products are exported to the South, they face some risk of imitation. Importantly, I assume industries differ in their imitation rates, because the ability to imitate a product typically depends on the nature of its technology. Each Northern firm weighs the benefits of selling to the larger international market against the risk of imitation and loss of monopoly profits. This decision process divides the continuum of industries into those that export and those that do not. By ranking industries according to their imitation rates, I find a critical industry such that Northern producers in the industries above this decide not to export to the South, because imitation is too easy. Export occurs only in the industries below the critical industry. The products of these industries follow a 'life cycle' – the technology of their production diffuses over time to the South through imitation. Once imitated, these products are produced in the South and traded for the products produced in the North.

In this context, a strengthening of IPRs in the South creates four potentially offsetting effects that vary across industries. First, stronger IPRs limit imitation and hence reduce the share of Southern products within each already trading industry. Northern producers in the already trading industries gain more power over the markets for their products, much as was feared by some in developing countries. However, this *market power* effect promotes Northern exports. Second, stronger IPRs make exporting less risky and expand the range of industries now engaged in trade with the South. This *market expansion* effect promotes Northern exports, but as the range of newly exporting industries expands, a given Southern income is now spent on a wider spectrum of products. The Southern budget share spent on the products in each already trading industry falls. This third effect – the *market dilution* effect – arises because industries differ in their imitation rates,

1 See, for example, Mansfield, Schwartz, and Wagner (1981), Levin et al. (1987), and Cohen, Nelson, and Walsh (2000).

and it lowers Northern exports. Lastly, a change in the relative wage – which occurs as a result of the three effects combined – creates a *terms of trade* effect on Northern exports, which can be either positive or negative. If the relative Northern wage falls in equilibrium, the terms of trade effect promotes Northern exports.

The theory predicts that when industries differ sufficiently in their imitation rates, the Southern wage and the *overall* volume of Northern exports rise with stronger IPRs. However, there are important differences across industries. Northern exports in industries with the highest risk of imitation rise, while exports in industries with the lowest risk of imitation may fall.[2] The theory also shows that international technology diffusion does not necessarily fall with stronger IPRs. More technology diffuses to the South because new high-tech products are introduced in the Southern market when IPRs are strengthened. This works against the reduction in technology diffusion caused by limited imitation. Hence, the theoretical findings suggest that South's access to Northern high-tech products and advanced technologies may rise with a strengthening of IPRs.

There is substantial theoretical literature on this subject. Researchers have increased our understanding of the relationship between IPRs and production, technology transfer, innovation, trade, and growth.[3] The question analyzed in this paper is similar to the one addressed in Maskus and Penubarti (1997), but the framework used for the analysis is quite different.[4] First, I develop a general equilibrium model.[5] Second, instead of examining one particular industry, a range of industries is analyzed. This is critical, since it allows for the possibility that an

2 In already trading industries (with the lowest risk of imitation), Northern exports are affected by the market power, market dilution, and terms of trade effects. When industries differ sufficiently in their imitation rates, the terms of trade effect is positive, but the combined impact of the market power and market dilution effects (i.e., the quantity response) is negative. As such, Northern exports in already trading industries may fall. In newly exporting industries (with the highest risk of imitation), Northern exports are affected by the market expansion effect. Since this effect is positive, stronger IPRs promote exports in newly exporting industries. When industries differ sufficiently in their imitation rates, the expansion in the range of exporting industries is so large that it creates a dominating positive impact on the overall volume of Northern exports.

3 See, for example, Chin and Grossman (1990), Deardorff (1992), Helpman (1993), Taylor (1993, 1994), Lai (1998), Zigic (2000), Glass and Saggi (2002), and Grossman and Lai (2004). The link between IPRs and trade is examined empirically in Ferrantino (1993), Maskus and Penubarti (1995), Fink and Braga (1999), Smith (1999), Rafiquzzaman (2002), Co (2004), Naghavi (2007), and Ivus (2010).

4 Maskus and Penubarti (1997) develop a partial equilibrium model in which a dominant exporting firm competes with an imitative fringe industry. It is predicted that strengthening IPRs has two effects on trade. On the one hand, stronger IPRs reduce the availability of local infringements to consumers and hence increase the demand for foreign innovative products. This market expansion effect promotes exports to the local market. On the other hand, stronger IPRs decrease the elasticity of demand for innovative products and enhance the pricing power of the exporting firm. This market power effect hampers exports. Since these two effects are offsetting, no definitive priors are made about the impact of stronger IPRs on exports.

5 In this setting, the individual effects of IPRs on exports are interlinked through their impact on wages. For example, the market power effect increases the relative Northern wage and Northern income. Accordingly, the relative profitability of exporting falls. This constrains the market expansion effect.

expansion in exports in one industry comes at the expense of exports in another industry. This feedback across industries is not present in Maskus and Penubarti (1997). In particular, as the range of exporting industries expands, the Southern budget share spent on the products of each already trading industry falls. When the extent to which industries differ in their imitation risk is sufficiently high, the resultant market dilution effect is strong enough that the overall quantity response of Northern exports in already trading industries is negative. Finally, when industries differ in their imitation rates, a change in the composition of Northern exports is expected in response to a strengthening of IPRs.

While the theory model developed in this paper is novel in that export decisions of Northern firms are endogenously determined, a similar decision is presented in Lai (1998), where foreign direct investment decisions are endogenous. In Lai (1998), Northern firms decide whether or not to shift their production to the South and face imitation risk. Stronger IPRs encourage Northern firms to move more quickly to the South, which is analogous to the market expansion effect obtained here. The key difference is that industries are symmetric in Lai (1998) and heterogeneous here. In this paper, stronger IPRs affect export decisions in a subset of industries only and create different responses among the newly exporting industries and already trading industries. This differential response is, of course, key to the analysis. The overall imitation rate is endogenously determined in this model, and in this respect, the model is similar to that of Glass and Saggi (2002) but differs from those of Helpman (1993) and Lai (1998), where imitation is exogenous. In contrast to Glass and Saggi (2002), however, imitation is costless here; it is determined by the range of exporting industries. While the determination of innovation is undoubtedly important for understanding the link between IPRs and trade, in this paper I do not consider how stronger IPRs impact the incentive to innovate.[6] This allows me to isolate the effects of IPRs on trade and technology diffusion by examining how the response of Northern producers differs across industries.

The paper proceeds as follows. In section 2, I describe the basic North-South model of IPRs and trade. In section 3, the trading equilibrium is established. The effects of stronger IPRs on the equilibrium range of exporting industries and relative wage are analyzed in section 4. The predictions about the impact of stronger IPRs on Northern exports and technology diffusion are derived in section 5. Section 6 concludes.

2. The model

Assume the world comprises two regions, the North and the South. The North is the region where newly invented products are produced, because of its com-

6 The linkages between IPRs and the incentive to innovate are studied in Chin and Grossman (1990), Diwan and Rodrik (1991), Deardorff (1992), Helpman (1993), Taylor (1994), Lai (1998), Glass and Saggi (2002), and Grossman and Lai (2004).

parative advantage in R&D; the South is the region where imitation occurs. A continuum of industries indexed by $z \in [0, 1]$ exists. Each industry, z, has ongoing innovation and hence the number of products available for consumption, $N(z, t)$ grows over time. The industries differ in the rate at which the South can potentially imitate products developed in the North. Depending on the risk of imitation the industry confronts, Northern producers in each industry decide whether to export to the South or not. As a result of this decision, trade may occur in only a fraction of industries.

The products in the trading industries follow a 'life cycle', as described by Vernon (1966) and neatly formalized by Krugman (1979). Initially, new products are produced only in the North. If these Northern products are exported to the South, the technology of production diffuses over time to the South through imitation. Once imitation occurs, the Southern industries have a cost advantage because of a lower wage in the South. The Northern products are priced out of the market and are no longer produced in the North: production migrates toward the South. The South exchanges imitated products for newly invented ones by engaging in trade with the North.[7]

As a result, if z is a trading industry, then its products are produced and consumed in both the North and the South and $N(z, t) = n(z, t) + n^*(z, t)$, where (*) denotes the South. If z is a non-trading industry, then its products are produced in the North; that is, $N(z, t) = n(z, t)$. In what follows, I focus on steady-state equilibria and, to save on notation, I ignore the dependance of variables on time.

2.1. Tastes

The instantaneous utility function of the representative agent in the North is given by

$$U = \int_0^1 b(z) \ln[c(z)]\, dz, \quad c(z) = \left[\int_{i=0}^{N(z)} c_i(z)^\theta \right]^{1/\theta}, \tag{1}$$

where $c_i(z)$ denotes the consumption of product i in industry z. $\theta = (\sigma - 1)/\sigma$, where $\sigma > 1$ is the constant elasticity of substitution in consumption. $b(z)$ is the budget share spent on products of industry z, and $\int_0^1 b(z)\, dz = 1$. I assume that the budget share is the same across all z and thus, $b(z) = 1$.

The budget constraint faced by the representative agent in the North is the following:

$$E = \int_0^1 \left[\int_{i=0}^{N(z)} p_i(z) c_i(z) \right] dz, \tag{2}$$

7 It is important to distinguish imitation from copying. Unlike copied products, which are patent-infringing, imitated products are non-infringing close substitutes authorized for trade.

where $p_i(z)$ denotes the price of product i in industry z and E denotes total expenditures that are equal to total income.

Maximizing (1) subject to (2), I obtain the North's demand for its domestically produced products $c_i(z)$ and for its imported Southern products $c_{i_m}(z)$:

$$c_i(z) = \left[\frac{E}{P(z)}\right]\left[\frac{p_i(z)}{P(z)}\right]^{-\sigma} \quad \text{and} \quad c_{i_m}(z) = \left[\frac{E}{P(z)}\right]\left[\frac{p_i^*(z)}{P(z)}\right]^{-\sigma}, \tag{3}$$

where $P(z) \equiv [\sum_{i=0}^{N(z)} p_i^{1-\sigma}]^{1/(1-\sigma)}$ is the overall price index, and $p_i(z)$ and $p_i^*(z)$ are the prices of output produced in the North and the South, respectively.

The products of any industry are available for consumption in the North. Therefore, (1) and (2) are defined over the entire industry range [0, 1]. However, the products of industries that do not export are not available in the South. As such, the utility function and the budget constraint of the representative agent in the South are defined over the range of exporting industries only. The South's demand for its domestically produced products $c_i^*(z)$ and for its imported Northern products $c_{i_m}^*(z)$ takes the following form:

$$c_i^*(z) = \left[\frac{b^*E^*}{P(z)}\right]\left[\frac{p_i^*(z)}{P(z)}\right]^{-\sigma} \quad \text{and} \quad c_{i_m}^*(z) = \left[\frac{b^*E^*}{P(z)}\right]\left[\frac{p_i(z)}{P(z)}\right]^{-\sigma}, \tag{4}$$

where b^* sums to one over the range of exporting industries. For example, if the range of exporting industries was $[0, \bar{z}]$, then $b^* = 1/\bar{z}$.

2.2. Technologies and endowments

A Northern producer charges a monopoly price as long as his product has not been imitated. Given the preferences specified in (1), the standard monopoly-pricing rule applies to products produced in the North and p equals a fixed mark-up above marginal costs of w; hence, $p = \sigma w/(\sigma - 1)$ for any innovative Northern product. Once a Northern product is imitated, it is in the public domain and thus, Southern produced products are competitively priced at Southern marginal costs of w^*; hence $p^* = w^*$.

Assume the North and the South are endowed with L and L^* units of labour, respectively. One unit of labour produces one unit of output in both regions and no labour is required for innovation or imitation.[8] Aggregate income (which equals expenditure E) consists of labour income and profits. In the North, $E = wL + \pi = wL + (p - w)L = \sigma wL/(\sigma - 1)$, where the last equality follows because the monopoly price $p = \sigma w/(\sigma - 1)$. In the South, profits are zero and $E^* = w^*L^*$.

8 Costless innovation and imitation is a simplification that allows me to isolate the effects of IPRs on trade and technology diffusion by examining how the response of Northern producers differs across industries. Helpman (1993), for example, makes this assumption to focus on welfare considerations.

Within each industry, z, new products are introduced at a constant rate g, and they are imitated at an industry-specific rate $m(z)$ if exported.[9] I assume industries differ in the risk of imitation, and rank industries in terms of their imitation rates, with $z = 0$ industry having the lowest imitation rate and $z = 1$ industry having the highest imitation rate. It proves useful to adopt a constant elasticity specification, where the imitation rate across industries is

$$m(z) \equiv \mu z^{\alpha}, \quad \text{where} \quad \mu > 0, \quad \alpha > 0, \quad \text{and} \quad m'(z) > 0. \tag{5}$$

The imitation rate rises from its minimum of zero at $z = 0$ to its maximum of μ at $z = 1$. The elasticity of imitation with respect to the industry ranking is constant and equals α. The parameter α measures the extent to which industries differ in the probability that their products will be imitated at the next instance, provided they have not been imitated until this instance. If $\alpha < 1$, the imitation function is concave: with an increase in z, the imitation rate increases at a decreasing rate. If $\alpha > 1$, the imitation function is convex: with an increase in z, the imitation rate increases at an increasing rate.

Whether or not the products of a given industry are eventually imitated depends on whether this industry's products are exported or not exported. If the industry's products are exported, the fraction of its products being imitated per unit time equals $m(z)$. If the industry's products are not exported, it faces no imitation.[10] Let $[0, \bar{z}]$ be the range of exporting industries. Then the overall imitation rate is defined as

$$M(\bar{z}) \equiv \int_0^{\bar{z}} m(z)\, dz = \frac{\mu \bar{z}^{\alpha+1}}{\alpha + 1}, \tag{6}$$

where the last equality follows from (5).

Following Krugman (1979), assume innovation is proportional to the number of products already in existence in both the North and the South. Then the total number of products within each industry, given by $N(z) = n(z) + n^*(z)$, evolves according to $\dot{N}(z) = gN(z)$. Imitation, which occurs in exporting industries only, is proportional to the number of newly invented products traded. Hence, the number of Southern products within trading industry evolves according to $\dot{n}^*(z) = m(z)n(z)$, where $m(z)$ is given in (5). The relative number of Southern products within each trading industry, defined as $\eta(z) \equiv n^*(z)/n(z)$, changes over time and is governed by the following differential

9 I assume that the duration between the date of exporting and the date of imitation, T, is a random variable that has an exponential distribution with cumulative density $P(T \leq t) = 1 - e^{-m(z)t}$, where $m(z)$ is the hazard rate of being imitated or Poisson event rate. The imitation rate $m(z)$ gives the probability that a product of an industry z will be imitated at the next instant conditional on survival until this instant. The notion of 'hazard rate' is discussed in Helpman (1993) and Lai (1998).

10 This assumption can be relaxed by allowing imitation to occur without exports. In this case, the extent to which IPRs reduce imitation under exporting *relative to* imitation under no exporting is critically important. Assuming that stronger IPRs are more or equally effective in preventing imitation under exporting, the findings of the paper remain similar.

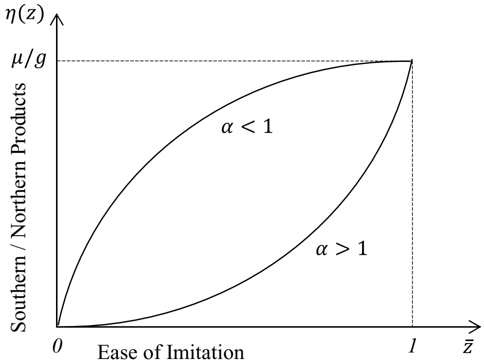

FIGURE 1 Number of products

equation: $\dot{\eta}(z) = m(z) - g\eta^2(z) - [g - m(z)]\eta(z)$.[11] Setting $\dot{\eta}(z)$ to zero solves for the steady-state relative number of Southern products in each industry z:

$$\eta(z) = \frac{m(z)}{g} = \frac{\mu z^\alpha}{g}. \tag{7}$$

If products of all industries are traded, then the steady-state relative number of Southern products is as shown in figure 1. Naturally, the South's share rises with z. It starts at zero when $z = 0$ and reaches its maximum of μ/g when $z = 1$ (because $z = 1$ industry has the highest imitation rate given by μ). If $\alpha > 1$, the relative number of Southern products rises precipitously with the industry ranking; if $\alpha < 1$, it rises only slowly.[12]

2.3. *Strengthening IPRs*

I assume that stronger IPRs limit the South's capacity to imitate: $d\mu/dIPR < 0$. As a result, the rate at which the products of each industry are imitated falls:[13]

$$\frac{dm(z)}{dIPR} = z^\alpha \frac{d\mu}{dIPR} < 0, \tag{8}$$

which follows from (5). In absolute terms, the impact of strengthening IPRs on the imitation rate varies across industries. It is the weakest in trading industries

11 Differentiate $\eta(z) \equiv n^*(z)/n(z)$ to obtain $\dot{\eta}(z) = \dot{n}^*/n - (\dot{n}/n)(n^*/n) = \dot{n}^*/n - (\dot{n}/n)\eta$. It follows from $N = n + n^*$ that $\dot{n} = \dot{N} - \dot{n}^*$. Using $\dot{N} = gN = g(n + n^*)$ and $\dot{n}^* = mn$, I obtain $\dot{n} = g(n + n^*) - mn = [g - m + g\eta]n$. I now substitute $\dot{n} = [g - m + g\eta]n$ and $\dot{n}^* = mn$ into $\dot{\eta}(z) = \dot{n}^*/n - (\dot{n}/n)\eta$ to obtain: $\dot{n} = m - [g - m + g\eta]\eta$, which simplifies to $\dot{\eta} = m - g\eta^2 - [g - m]\eta$.

12 The model can be extended to allow the innovation rate to vary across industries. Assuming $g(z) = gz^\beta$, the relative number of Southern products is given by $\eta(z) = \mu z^{\alpha-\beta}/g$. If $\alpha > \beta$, so that the South's share rises with z, the findings of the paper are much the same.

13 Cohen, Nelson, and Walsh (2000) find that prevention of imitation is the main reason for patenting. Levin et al. (1987) and Mansfield, Schwartz, and Wagner (1981) provide evidence that patenting increases the costs and time necessary to imitate.

with the lowest imitation and the strongest in trading industries with the highest imitation.

By limiting imitation, stronger IPRs reduce technology diffusion to the South. The share of Southern-produced products within each trading industry falls: $d\eta(z)/dIPR < 0$, which follows from (7) and (8).

2.4. Exporting and imitation: the equalized profits schedule

A Northern producer in each industry decides whether or not to export to the South. This decision involves comparing the expected present discounted value of the stream of profits from each activity. Let $V^X(z, t)$ represent the expected present discounted value of the stream of profits for a Northern producer who exports. Let $V^{NX}(z, t)$ represent the stream of profits for a Northern producer who does not export. At every point in time, the Northern producer in each industry chooses the maximum of these two options given by $V(z, t) \equiv \max[V^X(z, t), V^{NX}(z, t)]$.

Suppose the Northern producer decides to export. Then, in a small time interval of length dt, the Northern producer earns a stream of profits from selling in the North and the South, $\Pi^X(z, t)\,dt$. The probability of imitation in a time interval dt equals $m(z)\,dt$. Once imitation occurs, the Northern producer is priced out of the market by Southern producers enjoying lower wage costs. As such, with probability $m(z)\,dt$, future profits are zero. With probability $1 - m(z)\,dt$, the Northern producer earns future profits, which are discounted at the rate of $r\,dt$. As a result, the expected present discounted value of the stream of profits from exporting is $V^X(z, t) = \Pi^X(z, t)\,dt + [1 - r\,dt][1 - m(z)\,dt]V^X(z, t + dt)$. If the Northern producer decides not to export, there is no risk of imitation and the expected present discounted value of the stream of profits is $V^{NX}(z, t) = \Pi^{NX}(z, t)\,dt + [1 - r\,dt]V^{NX}(z, t + dt)$, where $\Pi^{NX}(z, t)\,dt$ is the flow of profits from selling in the North. The Northern producer in industry z will export at time t if $V^X(z, t) > V^{NX}(z, t)$. Rearranging this inequality, letting dt approach zero and simplifying, shows that exporting will occur in industry z when profits from selling in the North and the South, adjusted for the imitation rate, exceed profits from selling solely in the North:[14]

$$\frac{\Pi^X(z)}{r + m(z)} > \frac{\Pi^{NX}(z)}{r}. \tag{9}$$

14 First, rearrange $V^X(z, t)$ and $V^{NX}(z, t)$ to get

$$[V^X(z, t + dt) - V^X(z, t)]/dt = [r + [1 - r\,dt]m(z)]V^X(z, t + dt) - \Pi^X(z, t);$$
$$[V^{NX}(z, t + dt) - V^{NX}(z, t)]/dt = rV^{NX}(z, t + dt) - \Pi^{NX}(z, t).$$

Next, letting dt approach zero, the expressions above can be rewritten as $\dot{V}^X(z, t) = [r + m(z)]V^X(z, t) - \Pi^X(z, t)$ and $\dot{V}^{NX}(z, t + dt) = rV^{NX}(z, t) - \Pi^{NX}(z, t)$. In steady state profits are constant. Set $\dot{V}^X(z, t)$ and $\dot{V}^{NX}(z, t)$ to zero and drop index t to obtain $V^X(z) = \Pi^X(z)/[r + m(z)]$ and $V^{NX}(z) = \Pi^{NX}(z)/r$. The Northern producer in industry z exports if $V^X(z) > V^{NX}(z)$. Inequality (9) follows.

The products of Northern producers who export are sold to consumers in both the North and in the South. The products of Northern producers who do not export are consumed entirely in the North. Using the pricing rules and recalling that Northern marginal costs are equal to w, I obtain the profits a Northern producer earns from each activity:

$$\Pi^X(z) = \frac{w}{\sigma - 1}\left[c(z) + c_m^*(z)\right] \quad \text{and} \quad \Pi^{NX}(z) = \frac{w}{\sigma - 1}c(z). \tag{10}$$

Profits are proportional to revenues, which are in turn proportional to consumer expenditures. Substituting (10) into (9) and using (3) and (4), I find that exporting is the best strategy for a Northern producer in industry z if $[E + b^* E^*]/[r + m(z)] > E/r$, which simplifies to:

$$\frac{b^* E^*}{E} > \frac{m(z)}{r}, \quad \text{where} \quad E = \left(\frac{\sigma}{\sigma - 1}\right) wL \quad \text{and} \quad E^* = w^* L^*. \tag{11}$$

The left-hand side of (11) is independent of (z). The right-hand side ranges from zero to μ/r and is increasing in z.[15] Assume that the North-South income gap is large enough and the imitation risk is severe enough such that $b^* E^*/E < \mu/r$. Then, for a given relative Northern wage, defined by $\omega \equiv w/w^*$, there exists the critical industry $\bar{z}(\omega)$ such that (11) holds with equality. The products of industry $z \leq \bar{z}(\omega)$ are exported (and eventually traded), and the products of industry $z > \bar{z}(\omega)$ are not exported (and remain non-traded).[16]

The critical industry defines the range of exporting industries $[0, \bar{z}(\omega)]$. Over this range, Southern budget shares, b^*, sum to one; thus $b^* = 1/\bar{z}(\omega)$. Setting (11) to equality and using (5), I obtain one relationship between relative wages and the critical industry $\bar{z}$:

$$E(\bar{z}, \omega) \equiv \omega - \frac{r}{\mu \bar{z}^{\alpha+1}}\left(\frac{\sigma - 1}{\sigma}\right)\frac{L^*}{L} = 0. \tag{12}$$

I refer to (12) as the *Equalized Profits* (*EP*) schedule. It associates with each value of ω an industry $\bar{z}$ such that the expected present value of the stream of profits earned by exporting and facing imitation is equal to the expected present value of the stream of profits when not exporting. It is negatively sloped because a lower ω means the South is relatively richer, and this implies a reduced demand for new products in the North relative to that in the South. Exporting is relatively more profitable and new industries decide to face the imitation risk of exporting. The critical industry $\bar{z}$ rises. As the range of exporting industries expands, the attractiveness of exporting at the margin falls for two reasons. First, the rate

15 This follows from $\mu(0) = 0$, $\mu(1) = \mu$, and $m'(z) > 0$.

16 If $b^* E^*/E < \mu/r$ does not hold, then Northern producers in all industries export. In this case, the effects of strengthening IPRs are similar to those recognized in Krugman (1979) and Helpman (1993).

of imitation rises at the elasticity rate of α. Second, the Southern budget share spent on the products of each individual industry falls at the elasticity rate of 1 (recall $b^* = 1/\bar{z}(\omega)$), making the share of the Southern pie earned by a new exporter smaller. Hence, the elasticity of the *EP* schedule is $-(\alpha + 1)$. It is also apparent from (12) that $\omega \to \infty$ as $\bar{z} \to 0$ along the schedule. At $\bar{z} = 1$, the relative Northern wage is at its minimum value:

$$\omega_{min} \equiv \frac{r}{\mu}\left(\frac{\sigma - 1}{\sigma}\right)\frac{L^*}{L}. \tag{13}$$

In order for Northern producers to be priced out of the market by Southern producers once imitation occurs, I assume the parameters are such that $\omega_{min} > 1$ throughout.[17]

2.5. Market clearing: the full employment schedule

To generate a second relationship between ω and $\bar{z}$, I combine full employment in the South with world market clearing. Let $y^*(z)$ denote output per product in the South; then, the full employment condition in the South is $L^* = \int_0^{\bar{z}} n^*(z)y^*(z)\,dz$. Southern output is consumed in both the South and in the North; that is $y^*(z) = c^*(z) + c_m(z)$. Using (3) and (4), I obtain[18]

$$L^* = \int_0^{\bar{z}} n^*(z)p^{*-\sigma}\,\frac{p^*L^*/\bar{z} + pL}{n^*(z)p^{*1-\sigma} + n(z)p^{1-\sigma}}\,dz. \tag{14}$$

Rewriting (14) in terms of the relative Northern wage, ω, and the relative number of Southern products, $\eta(z) = \mu z^\alpha/g$, yields the *Full Employment* (*FE*) schedule:

$$F(\bar{z}, \omega) \equiv \int_0^{\bar{z}} \frac{1/\bar{z} + \rho L/L^*}{\rho^{1-\sigma}g/[\mu z^\alpha] + 1}\,dz - 1 = 0, \quad \text{where} \quad \rho \equiv \frac{p}{p^*} = \frac{\sigma}{\sigma - 1}\omega. \tag{15}$$

The *FE* schedule associates with each $\bar{z}$ a value of ω such that labour is fully employed in both regions. As the range of exporting industries expands, the relative Northern wage falls for three reasons. First, the relative demand for the Southern labour rises because newly traded Southern produced products add to consumption in both regions while newly traded Northern produced products add to consumption in the South only. Thus, ω falls. The reduction in ω

17 Northern wages always exceed Southern if the South is relatively abundant in labour (high L^*/L), the imitation rate is low (low μ means lower Southern output and lower demand for Southern labour), the discount rate is high (high r means lower risk of imitation, greater Northern exports, and greater demand for Northern labour), and the profit margins Northern producers earn are small (i.e., σ is high, which means greater Northern output and greater demand for Northern labour).

18 Use $b^* = 1/\bar{z}$, $E = pL$, $E^* = p^*L^*$, and $P^{1-\sigma}(z) = \sum_{i=0}^{N(z)} p_i^{1-\sigma} = n(z)p^{1-\sigma} + n^*(z)p^{*1-\sigma}$, which follows from the symmetry of prices.

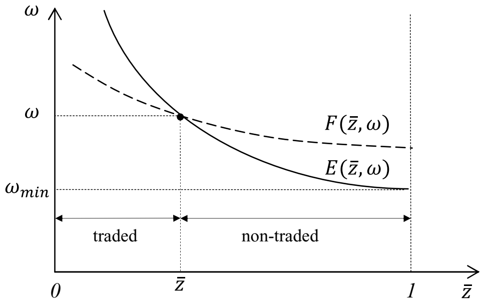

FIGURE 2 The trading equilibrium

is pronounced when the elasticity of substitution, σ, is small, so that Northern and Southern labour are poor substitutes.[19] The heterogeneity of industries in their imitation rates further contributes to an increase in the relative demand for Southern labour. When α is high, the share of Southern products rises precipitously within an increase in z. Hence, ω falls more as $\bar{z}$ rises. In addition, since the relative number of Southern products is the highest within the critical industry (recall figure 1), an expansion in the range of exporting industries leads to a shift of Southern expenditure away from industries the North dominates and towards the industries the South dominates. This further reduces ω. It is proven in the appendix that the *FE* schedule is negatively sloped, with $\omega \to \infty$ as $\bar{z} \to 0$.

3. Trading equilibrium

The *EP* and *FE* schedules together solve for the critical industry $\bar{z}$ and the relative Northern wage ω. Under certain conditions, set forth in proposition 1 below, the trading equilibrium is established at an interior point $(\bar{z}; \omega)$ where the two schedules intersect, as shown in figure 2 .

PROPOSITION 1. *If the elasticity of substitution is $\sigma \geq 2$ and the innovation rate,g, is sufficiently high, then there exists a unique interior equilibrium with $0 < \bar{z} \leq 1$, where the products of industries in the range $(0, \bar{z}]$ are traded and the products of industries in the range $(\bar{z}, 1]$ are non-traded.*

Proof. See the appendix.

The condition $\sigma \geq 2$ ensures that the *FE* schedule is flatter than the *EP* schedule at any point $(\bar{z}, \omega)$. Sufficiently high g guarantees that the *FE* schedule lies above the *EP* schedule at $\bar{z} = 1$. The two conditions together ensure that the two schedules intersect, and the point of intersection is unique and interior.

19 If industries do not differ in their imitation rates, the elasticity of the *FE* schedule is $-1/\sigma$.

The elasticity of substitution, σ, affects the slope of the *FE* schedule only. The higher σ is, the less consumer behaviour changes with a change in the range of exporting industries. Northern and Southern labour are better substitutes, and so a smaller relative wage adjustment is required for any change in $\bar{z}$. The *FE* schedule is flatter. For any given σ, however, consumers respond to a change in the range of exporting industries by adjusting the budget share spent on the products of each individual industry at the elasticity rate of 1. Since industries differ in their imitation rates, ω adjusts in response. In order to offset this adjustment in ω created by the dilution of consumption, $\sigma \geq 2$ is required for the *FE* schedule to be flatter than the *EP* schedule.[20]

High innovation rate, g, implies high relative demand for Northern labour. The equilibrium relative Northern wage rises (see proposition 2). For a sufficiently high g, the equilibrium relative Northern wage is above its minimum value, ω_{min}.

Before I proceed with examining the effects of strengthening IPRs on the trading equilibrium, I describe the features of the equilibrium. The equilibrium is determined by the innovation rate, the discount rate, and relative market size.[21] Propositions 2 and 3 summarize the results.

PROPOSITION 2. *The critical industry $\bar{z}$ and the relative Northern wage ω respond to a change in the innovation rate g and the discount rate r as follows:*

i) $\bar{z}$ falls (i.e., the range of exporting industries contracts) and ω rises as g increases;
ii) $\bar{z}$ rises (i.e., the range of exporting industries expands) and ω falls as r increases.

Proof. See the appendix.

As is shown in figure 3, an increase in the innovation rate shifts the *FE* schedule upward: higher g increases the relative demand for Northern labour. With a constant $\bar{z}$, the relative Northern wage rises. Higher ω, in turn, implies that the North is relatively richer and so exporting is relatively less profitable. As such, $\bar{z}$ falls along the *EP* schedule. An increase in the discount rate shifts the *EP* schedule upward: higher r reduces the present value of losses that Northern producers incur in the event of imitation. Consequently, exporting is less risky and $\bar{z}$ rises, all else being equal. As the range of exporting industries expands, the relative demand for Southern labour rises and ω falls along the *FE* schedule.

20 If industries do not differ in their imitation rates, the *FE* schedule is flatter than the *EP* schedule for any $\sigma > 1$. The elasticity of imitation, α, affects the slopes of both schedules. First, high α implies that the risk of imitation rises greatly with industry ranking. As such, a stronger reduction in ω (which increases the profitability of exporting) is required for a given increase in $\bar{z}$ in order to keep profits constant. The *EP* schedule is steep. Second, high α implies the relative number of Southern products rises precipitously with z. The relative demand for the Southern labour rises more and ω falls more for a given increase in $\bar{z}$. The *FE* schedule is steep.

21 It is also determined by the imitation rate, which is discussed in the next section.

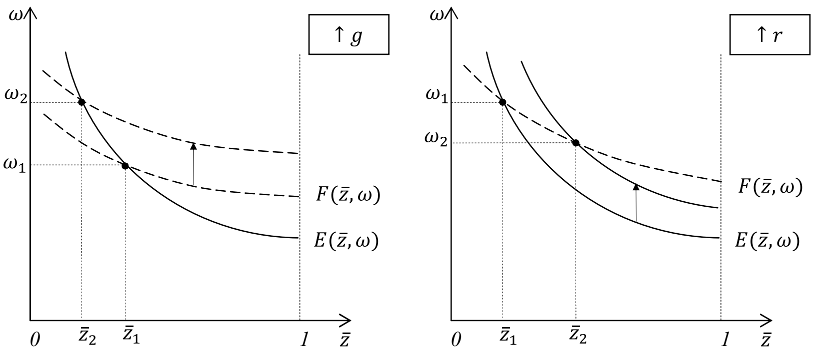

FIGURE 3 The impact of g and r

PROPOSITION 3. *The critical industry $\bar{z}$ always falls as the relative Northern market size L/L^* increases. Further, there exists a unique critical value of the elasticity of imitation with respect to the industry ranking, given by $\bar{\alpha}$, such that the following is true*

i) *if $\alpha < \bar{\alpha}$, the relative Northern wage ω rises as L/L^* increases;*
ii) *if $\alpha > \bar{\alpha}$, the relative Northern wage ω falls as L/L^* increases;*
iii) *if $\alpha = \bar{\alpha}$, the relative Northern wage ω is unaffected by a change in L/L^*.*[22]

Proof. See the appendix.

An increase in L/L^* shifts both schedules downward. First, the demand for new products in the North rises relative to that in the South. Thus, exporting is relatively less profitable. The *EP* schedule implies that for a constant ω, $\bar{z}$ falls. The reduction in $\bar{z}$ is strong when industries do not differ much in their imitation rates, that is, when α is low.[23] Second, the relative supply of Northern labour rises. The *FE* schedule implies that for a constant $\bar{z}$, ω falls. The reduction in ω is strong when σ is low or α is high.[24]

22 $\bar{\alpha}$ can be greater or less than one, depending on the values of σ, r, μ, g, and L/L^*.
23 The elasticity of $\bar{z}$ with respect to L/L^* (the horizontal shift of the *EP* schedule) equals $-[\alpha + 1]^{-1}$. If $\alpha \to \infty$, $\bar{z}$ does not change with L/L^*. Higher L/L^* pushes $\bar{z}$ down, but the imitation risk of exporting falls as well, pushing $\bar{z}$ up to its initial level.
24 The elasticity of ω with respect to L/L^* (the vertical shift of the *FE* schedule) is

$$\frac{d\omega}{dL/L^*}\frac{L/L^*}{\omega} = -\left[\frac{\sigma-1}{\alpha}\left(1-\frac{k}{h}\right)\frac{h+1}{k+1}+1\right]^{-1}, \quad \text{where} \quad k \equiv \frac{\rho^{1-\sigma}g}{\mu\bar{z}^{\alpha}} < h \equiv \bar{z}\rho\frac{L}{L^*}, \quad \alpha \neq 0.$$

If $\sigma \to \infty$, Northern and Southern labour are good substitutes and so ω does not change with L/L^*. If $\alpha = 0$, the elasticity of ω with respect to L/L^* equals $-1/\sigma$. If α is low, ω falls only slightly. In this case, the share of Northern products does not fall much with z. There is more room for a substitution between the Northern and Southern products, so a smaller adjustment of ω is required for a given change in L/L^*.

The overall impact of an increase in L/L^* on the equilibrium $\bar{z}$ is negative. $\bar{z}$ always falls because the *FE* schedule shifts downward less than the *EP* schedule, provided products are sufficiently good substitutes.[25] The direction of a change in ω depends on the relative strength of two effects. The direct effect is negative: higher L/L^* reduces ω, all else being equal (the vertical shift of the *FE* schedule). The indirect effect is, however, positive: higher L/L^* reduces $\bar{z}$ (the horizontal shift of the *EP* schedule) and ω rises in response (along the *FE* schedule). Proposition 3 states that ω rises with an increase in L/L^* if α is low. In this case, the range of exporting industries contracts greatly, and so the indirect effect dominates. The relative demand for Northern labour increases enough that ω rises. If α is high, ω falls. In this case, the range of exporting industries does not contact much and so the direct effect dominates.

4. Strengthening IPRs

With the established trading equilibrium in hand, the impact of stronger IPRs may be analyzed. Strengthening IPRs in developing countries is highly controversial because of the uncertainty over the effect stronger IPRs may have on developing countries' access to foreign technological advancement. Foreign technological advancement can be accessed through international technology diffusion and the inflows of high-tech products from trading partners. Stronger IPRs may be opposed on the grounds that they limit the South's imitation and so reduce technology diffusion from the North. Nonetheless, stronger IPRs also affect the export incentives of Northern producers. The range of exporting industries changes. The overall impact of strengthening IPRs on international technology diffusion and Northern exports crucially depends on how the trading equilibrium is affected. Proposition 4 establishes the result.

PROPOSITION 4. *Strengthening IPRs increases the critical industry $\bar{z}$ (i.e., the range of exporting industries expands). The relative wage ω falls if the imitation rate is sufficiently elastic with respect to the industry ranking, that is, if $\alpha > \bar{\alpha}$; ω rises if $\alpha < \bar{\alpha}$; and ω is unaffected if $\alpha = \bar{\alpha}$.*

Proof. See the appendix.

Strengthening IPRs shifts both schedules upward, as shown in figure 4 . First, the imitation risk of exporting falls. Exporting is relatively more profitable and the *EP* schedule implies that for a constant ω, $\bar{z}$ rises. An increase in $\bar{z}$ is strong when industries do not differ much in their imitation rates, that is, when α is low.[26]

25 If $\sigma = 1$, the vertical shift of the schedules is identical and $\bar{z}$ is unaffected.

26 The elasticity of $\bar{z}$ with respect to μ (the horizontal shift of the *EP* schedule) equals $-[\alpha + 1]^{-1}$. If $\alpha \to \infty$, the risk of imitation rises enough with z that the range of exporting industries does not expand with stronger IPRs.

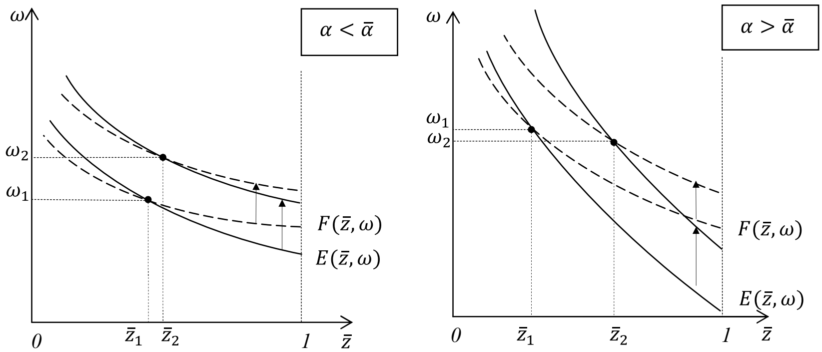

FIGURE 4 The impact of strengthening IPRs

Second, the relative number of Southern products within each already trading industry falls. This increases the relative demand for Northern labour. The *FE* schedule implies that, for a constant $\bar{z}$, ω rises. The increase in ω is strong when σ or α is low.[27]

Strengthening IPRs has two effects on $\bar{z}$. The direct effect is positive: $\bar{z}$ rises, for a constant ω. However, the indirect effect is negative: stronger IPRs increase ω and $\bar{z}$ falls in response. The overall impact of stronger IPRs on the equilibrium $\bar{z}$ is positive. The critical industry $\bar{z}$ always rises because the substitutability between the products limits the strength of the indirect effect such that the direct effect dominates.

The direction of a change in ω depends on the extent to which $\bar{z}$ rises, determined by α. The higher α is, the steeper is the *EP* schedule and the less $\bar{z}$ falls for a given increase in ω. The indirect effect is weak and so the range of exporting industries expands greatly. This pushes ω down along the *FE* schedule enough to more than offset an increase in ω caused by a reduction in the share of Southern products within each already trading industry. The lower α is, the flatter is the *EP* schedule and the more $\bar{z}$ falls for a given increase in ω. The indirect effect is strong and so the range of exporting industries expands only slightly. As a result, the negative impact of an increase in $\bar{z}$ on ω is weak and ω rises.

27 The elasticity of ω with respect to μ (the vertical shift of the *FE* schedule) is

$$\frac{d\omega}{d\mu}\frac{\mu}{\omega} = -\left[\sigma - 1 + \alpha\frac{h}{h-k}\frac{k+1}{h+1}\right]^{-1}, \quad \text{where} \quad k \equiv \frac{\rho^{1-\sigma}g}{\mu\bar{z}^{\alpha}} < h \equiv \bar{z}\rho\frac{L}{L^*}, \quad \alpha \neq 0.$$

If $\sigma \to \infty$, Northern and Southern labour are good substitutes and ω is unaffected by a strengthening of IPRs. If $\alpha = 0$, the elasticity of ω with respect to μ equals $-1/\sigma$. If α is high, the share of Southern products within each industry is small. Strengthening IPRs does not increase the relative demand for Northern labour much and so ω does not rise much.

5. Impact of IPRs

Having discussed how a change in IPRs affects μ, $\bar{z}$, and ω, the impact of strengthening IPRs on international technology diffusion and Northern exports may be analyzed. The extent of technology diffusion to the South is given by the overall imitation rate, defined in (6). Totally differentiating (6) with respect to IPRs, I obtain:

$$\frac{dM(\bar{z})/M(\bar{z})}{dIPR/IPR} = \left[1 + (\alpha + 1)\frac{d\bar{z}/\bar{z}}{d\mu/\mu}\right]\frac{d\mu/\mu}{dIPR/IPR}. \tag{16}$$

The following proposition establishes the result.

PROPOSITION 5. *Strengthening IPRs affects the overall imitation rate, $M(\bar{z})$, as follows:$M(\bar{z})$ rises if the imitation rate is sufficiently elastic with respect to the industry ranking; that is, if $\alpha > \bar{\alpha}$; $M(\bar{z})$ falls if $\alpha < \bar{\alpha}$; and $M(\bar{z})$ is unaffected if $\alpha = \bar{\alpha}$.*

Proof. See the appendix.

Strengthening IPRs limits the South's capacity to imitate; that is, $d\mu/dIPR < 0$. This reduces the overall imitation rate, which means less technology diffuses to the South. However, strengthening IPRs also lowers the imitation risk of exporting and so increases the range of exporting industries; that is, $d\bar{z}/d\mu < 0$. As Northern firms in a wider range of industries start exporting, the scope for imitation rises. This increases the overall imitation rate and the diffusion of Northern advanced technologies. As a result, stronger South's IPRs do not necessarily lower technology diffusion. Technology diffusion rises provided an expansion in the range of exporting industries is sufficiently strong, which requires a high α.

It is instructive to see how the possibility of $M(\bar{z})$ rising with stronger IPRs depends on the initial level of South's capacity to imitate, μ. If μ is small, the range of exporting industries is wide to begin with, and it does not expand much with strengthening IPRs. The negative impact on technology diffusion is strong. The critical value of α, that is $\bar{\alpha}$, is high in this case, which means that the share of Southern products should increase sharply with the industry ranking in order for $M(\bar{z})$ to rise. If μ is close to zero, then $\bar{\alpha}$ is infinitely large and hence, technology diffusion necessarily falls with strengthening IPRs.[28]

The overall volume of Northern exports is defined by $X \equiv \int_0^{\bar{z}} n(z)c_m^*(z)\,dz$. As a function of the relative Northern wage, ω, and the relative number of Southern

28 I thank an anonymous referee for this comment.

products, $\eta(z)$, the volume of Northern exports can be rewritten as follows:[29]

$$X = \frac{L^*}{\bar{z}} \int_0^{\bar{z}} \frac{\rho^{-\sigma}/\eta(z)}{\rho^{1-\sigma}/\eta(z) + 1}\, dz, \quad \text{where} \quad \rho = \frac{\sigma}{\sigma - 1}\omega. \tag{17}$$

The function (17) defines Northern exports in the long run. ω and $\bar{z}$ are at their trading equilibrium values, and the relative number of Southern products within a trading industry z is at its steady state value given by $\eta(z) = \mu z^{\alpha}/g$. As a function of the variables impacted by IPRs, Northern exports can be represented by $X = X(\eta(z), \bar{z}, \omega)$. That is, it is a function of the relative number of Southern products (which is exogenously given), the critical industry and the relative Northern wage (which are endogenously determined by the interaction of the *EP* and *FE* schedules). Totally differentiating the Northern export function yields

$$\frac{dX}{dIPR} = X_{\eta}\frac{d\eta(z)}{dIPR} + X_{\bar{z}}\frac{d\bar{z}}{dIPR} + X_{\omega}\frac{d\omega}{dIPR}. \tag{18}$$

LEMMA. *Northern exports are decreasing in $\eta(z)$, ω, $\bar{z}$: $X_{\eta} < 0$, $X_{\bar{z}} < 0$, $X_{\omega} < 0$.*

Proof. See the appendix.

Stronger South's IPRs limit imitation. As a result, the overall volume of Northern exports is affected through three different channels. First, the relative number of Southern products within each trading industry falls. Northern producers in these industries gain more power over the markets for their products. The direct impact of this *market power effect* is represented by the first term in (18). Since $X_{\eta} < 0$ and $d\eta(z)/dIPR < 0$, the market power effect promotes Northern exports directly.

Second, the range of exporting industries expands. Higher $\bar{z}$ creates a positive *market expansion effect*. As new industries start exporting, the overall volume of Northern exports rises. However, higher $\bar{z}$ also creates a negative *market dilution effect*. As the range of exporting industries expands, the Southern budget share spent on the products of each already trading industry falls. This reduces the overall volume of Northern exports. The lemma establishes that the overall impact of an increase in $\bar{z}$ is negative, that is, $X_{\bar{z}} < 0$, which means the market dilution effect dominates. This result arises because industries differ in their imitation rates. Products of the new firms that start exporting are the easiest to imitate. Once imitation occurs, the relative number of Northern products within each newly exporting industry is the smallest. As such, these new industries don't add much to X. However, they take away the share of the Southern market from the already trading industries, which have the highest relative number of

29 The result follows from (4) and $b^* = 1/\bar{z}$, $E^* = p^*L^*$, and $P^{1-\sigma}(z) = n(z)p^{1-\sigma} + n^*(z)p^{*1-\sigma}$.

Northern products. As a result, a wider range of exporting industries hampers X directly.[30]

Last, the three effects together affect ω and hence via (15) p/p^*. This creates a *terms of trade effect*, represented by the third term in (18). The lemma states that $X_\omega < 0$. A higher relative Northern wage drives down Southern incomes relative to those in the North. Lower overall buying power of Southern consumers reduces Northern exports. Depending on the sign of $d\omega/dIPR$, the terms of trade can have a positive or negative effect on Northern exports.

The overall impact of strengthening South's IPRs on the volume of Northern exports, aggregated over the range of exporting industries, is ambiguous. The quantity response of exports, given by the first two terms in (18), is always positive. This is because the positive market power and market expansion effects dominate the negative market dilution effect. The price response of exports, given by the third term in (18), is uncertain. It depends on the extent to which industries differ in their imitation rates, α. If α is high, the relative Northern wage falls, which promotes Northern exports. Both the price and the quantity response of exports are positive in this case; hence, the overall volume of Northern exports rises with stronger IPRs. If α is low, the relative Northern wage rises, which hampers Northern exports. For a sufficiently low α, the negative price response is strong enough that the overall volume of Northern exports falls with stronger IPRs.

Most important, stronger IPRs affect Northern exports differently across industries. In newly exporting industries – which were not exporting prior to a strengthening of IPRs because the risk of imitation was too high – Northern exports rise the most. Stronger IPRs reduce imitation and thus encourage Northern firms in these industries to start exporting (the market expansion effect). The composition of Northern exports shifts towards newly exporting industries, where the rate of imitation is the highest.

The differential impact on developed countries' industry exports is tested empirically in Ivus (2010). The results indicate that, in response to a strengthening of patent rights in developing countries, exports in high-tech industries rise relatively more than exports in low-tech industries. Since high-tech industries (such as medicinal and pharmaceutical products, professional and scientific equipment, chemicals, and non-electrical machinery) rank the highest in the importance of patents in preventing product imitation (Cohen, Nelson, and Walsh 2000), these results suggest that newly exporting industries are more high-tech and have a higher risk of imitation.

Despite the negative impact of an expansion in the range of exporting industries on Northern exports in already trading industries, the market expansion effect allows the South to benefit from stronger IPRs. Northern exports shift

30 If industries do not differ in their imitation rates, that is, $\alpha = 0$, the market expansion and the market dilution effects offset each other, so an expansion in $\bar{z}$ does not effect Northern exports: $X_{\bar{z}} = 0$.

away from low-tech industries where imitation rates are low and toward the high-tech industries where imitation rates are high. As a result, more technology can diffuse to the South through imitation of high-tech industries. Technology diffusion can rise even though the overall imitation ability of the South falls with the strengthening of IPRs.[31]

In already trading industries, Northern exports rise the least and may even fall. The risk of imitation in these industries is low to begin with and, as a result, stronger IPRs do not affect the export decisions of the Northern firms. The positive market expansion effect is absent here, while the negative market dilution effect is present. Northern exports fall in already trading industries as the Southern market is diluted away from these industries toward newly exporting ones. When α is high, the resultant market dilution effect is strong enough that it dominates the market power effect. Thus, the overall quantity response of Northern exports in already trading industries is negative. This works against the positive price response and as a result, Northern exports in already trading industries may fall.

6. Conclusion

This paper employed theory to assess how stronger IPRs affect international technology diffusion by altering the volume of high-tech exports into developing countries. A simple general equilibrium model of an innovating North and an imitating South in which industries differ in their imitation rates was developed. The theory predicted that Northern exports in industries with the highest risk of imitation rise, while Northern exports in industries with the lowest risk of imitation may fall with stronger IPRs. International technology diffusion does not necessarily fall with stronger IPRs. More technology diffuses to the South because new high-tech products are introduced in the Southern market when IPRs are strengthened. This works against the reduction in technology diffusion caused by limited imitation. Hence, the theoretical findings suggest that South's access to Northern high-tech products and advanced technologies may rise with a strengthening of IPRs.

The paper showed that the cross-industry variation in imitation rates is important for evaluating the impact of IPRs. A strengthening of IPRs impacts industries differently. This differential industry response is critical for understanding how international trade and technology diffusion are affected by a change in IPRs.

31 It could be argued that the products of high-tech industries with sophisticated technologies are the hardest to imitate. In this case, strengthening IPRs would hurt the South by limiting its overall imitative ability and also shifting the composition of Northern exports away from high-tech industries and toward the low-tech industries. The empirical evidence, however, indicates that newly exporting industries are more high-tech and have higher a risk of imitation than already trading industries. In this case, strengthening IPRs could increase technology diffusion to the South. I thank an anonymous referee for this comment.

The paper identified four effects of stronger IPRs on exports. These effects can be classified into the variety response of exports (the market expansion effect), the price response of exports (the terms of trade effect), and the quantity response of exports (the market dilution and market power effects). Classified this way, the theoretical results can be tested empirically. In particular, the impact of stronger IPRs on the extensive and intensive margins of trade can be evaluated.

Appendix

Proof

The *FE* schedule is negatively sloped, with $\omega \to \infty$ as $\bar{z} \to 0$

The *FE* schedule is given by

$$F(\bar{z}, \omega) \equiv \int_0^{\bar{z}} \frac{dz}{k(z)+1} - \frac{\bar{z}}{\bar{z}\rho L/L^* + 1} = 0, \quad \text{where}$$

$$\rho = \frac{\sigma}{\sigma - 1}\omega, \quad k(z) = \frac{\rho^{1-\sigma} g}{\mu z^{\alpha}}. \tag{A1}$$

It is required to show that $d\omega/d\bar{z} < 0$. By the implicit function theorem, $d\omega/d\bar{z} = -F_{\bar{z}}/F_{\omega}$.

$$F_{\bar{z}} = \frac{1}{k(\bar{z})+1} - \frac{1}{[\bar{z}\rho L/L^* + 1]^2} > 0, \quad \text{since} \quad k(\bar{z}) < \bar{z}\rho L/L^*. \tag{A2}$$

I show that $k(\bar{z}) < \bar{z}\rho L/L^*$ by applying the mean-value theorem to solve for the integral in (A1). Let $f(z) \equiv k(z) + 1$. Given that $f(z)$ is a continuous function on the interval $[0, \bar{z}]$, there exists a number $\tilde{z}$ such that $\int_0^{\bar{z}} dz/f(z) = \bar{z}/f(\tilde{z})$, where $0 < \tilde{z} < \bar{z}$. Applying this theorem to (A1), I find that $k(\tilde{z}) = \bar{z}\rho L/L^*$ if $\bar{z} \neq 0$. Since $\tilde{z} < \bar{z}$, it is true that $k(\bar{z}) < \bar{z}\rho L/L^*$.

$$F_{\omega} = \frac{\sigma}{\rho}\int_0^{\bar{z}} \frac{k(z)}{[k(z)+1]^2}\,dz + \left(\frac{\sigma}{\sigma-1}\right)\frac{\bar{z}^2 L/L^*}{[\bar{z}\rho L/L^* + 1]^2} > 0. \tag{A3}$$

Thus, $d\omega/d\bar{z} < 0$ since $F_{\bar{z}} > 0$ and $F_{\omega} > 0$. Along the *FE* schedule, $k(\tilde{z}) = \bar{z}\rho L/L^*$ which simplifies to $\rho = [gL^*(\bar{z}/\tilde{z})^{\alpha}]^{1/\sigma}[\mu L\bar{z}^{\alpha+1}]^{-1/\sigma}$. It follows that $\omega \to \infty$ as $\bar{z} \to 0$ (since $\bar{z}/\tilde{z} > 1$).

Proof of proposition 1

The condition $\sigma \geq 2$ ensures that the *FE* schedule is flatter than the *EP* schedule at any point $(\bar{z}; \omega)$; that is, $F_{\bar{z}}/F_{\omega} < E_{\bar{z}}/E_{\omega}$. First, $E_{\bar{z}}/E_{\omega} = (\alpha+1)\omega/\bar{z}$ from the *EP* schedule is given by

$$E(\bar{z}, \omega) \equiv \omega - \frac{r}{\mu \bar{z}^{\alpha+1}} \left(\frac{\sigma - 1}{\sigma} \right) \frac{L^*}{L} = 0. \tag{A4}$$

Next, $F_{\bar{z}}$ and F_ω are given in (A2) and (A3). Using (A1), I rewrite the integral in (A3) as

$$\int_0^{\bar{z}} \frac{k(z)\,dz}{[k(z)+1]^2} = \frac{\bar{z}}{\alpha}\left[\frac{1}{k(\bar{z})+1} - \frac{1}{\bar{z}} \int_0^{\bar{z}} \frac{dz}{k(z)+1} \right] = \frac{\bar{z}}{\alpha}\left[\frac{1}{k(\bar{z})+1} - \frac{1}{\bar{z}\rho L/L^* + 1} \right]. \tag{A5}$$

Now substituting the result into (A3) and using (A2), I rewrite $F_{\bar{z}}/F_\omega < (\alpha + 1)\omega/\bar{z}$ as:

$$[\alpha(\sigma - 2) + \sigma - 1]\left[\frac{\bar{z}\rho L/L^* - k(\bar{z})}{k(\bar{z})+1} \right] + \alpha^2 \frac{\bar{z}\rho L/L^*}{\bar{z}\rho L/L^* + 1} > 0, \tag{A6}$$

where $k(\bar{z}) < \bar{z}\rho L/L^*$ and hence, $\sigma \geq 2$ is sufficient for (A6) to hold. If g is sufficiently high, the *FE* schedule lies above the *EP* schedule at $\bar{z} = 1$. This follows, since at $\bar{z} = 1$, the vertical intercept of the *EP* schedule is ω_{min}, which is independent of g, while the vertical intercept of the *FE* schedule increases with an increase in g (since $d\omega/dg = -F_g/F_\omega$, where $F_g < 0$ and $F_\omega > 0$).

The two conditions together ensure that a unique equilibrium exists. This proof is in a working version of the paper.

Proof of proposition 2

First, $d\bar{z}/dg = F_g E_\omega / D$ and $d\omega/dg = -F_g E_{\bar{z}}/D$, where $D \equiv E_{\bar{z}} F_\omega - F_{\bar{z}} E_\omega > 0$. From (A1) and (A4), $F_g < 0$, $E_\omega > 0$, and $E_{\bar{z}} > 0$. Hence, $d\bar{z}/dg < 0$ and $d\omega/dg > 0$. Next, $d\bar{z}/dr = -E_r F_\omega/D$ and $d\omega/dr = E_r F_{\bar{z}}/D$, where $E_r < 0$, $F_\omega > 0$, $F_{\bar{z}} > 0$. Therefore, $d\bar{z}/dr > 0$ and $d\omega/dr < 0$.

Proof of proposition 3

$d\bar{z}/d(L/L^*) = [F_{L/L^*} E_\omega - E_{L/L^*} F_\omega]/D$ and $d\omega/d(L/L^*) = [E_{L/L^*} F_{\bar{z}} - F_{L/L^*} E_{\bar{z}}]/D$, where $D > 0$, $F_{\bar{z}}$ and F_ω are given in (A2) and (A3) and the other partial derivatives are as follows:

$$E_\omega = 1; \quad E_{L/L^*} = \frac{\omega}{L/L^*}; \quad F_{L/L^*} = \frac{\bar{z}^2 \rho}{[\bar{z}\rho L/L^* + 1]^2}; \quad E_{\bar{z}} = (\alpha + 1)\frac{\omega}{\bar{z}}. \tag{A7}$$

$d\bar{z}/dL/L^* < 0$ if $F_\omega E_{L/L^*} > E_\omega F_{L/L^*}$, which holds, since $(\sigma - 1)L^*/L \int_0^{\bar{z}} k(z)/[k(z)+1]^2 dz > 0$. $d\omega/d(L/L^*) < 0$ if $F_{L/L^*} E_{\bar{z}} > E_{L/L^*} F_{\bar{z}}$, which can be rewritten as

$$\alpha > \left[1 - \frac{k(\bar{z})}{\bar{z}\rho L/L^*}\right]\frac{\bar{z}\rho L/L^* + 1}{k(\bar{z}) + 1}. \tag{A8}$$

From (A4), $\bar{z} = [rL^*/(\mu L\rho)]^{1/(\alpha+1)}$. Now (A8) simplifies to $H(\alpha) > R(\alpha)$, where $H(\alpha) \equiv \alpha$, and

$$R(\alpha) \equiv \left[1 - \frac{g\rho^{1-\sigma}}{r}\right]\frac{A(\rho)+1}{A(\rho) + g\rho^{1-\sigma}/r}, \quad \text{where} \quad A(\rho) = \left[\frac{\mu}{r}\left(\frac{L^*}{\rho L}\right)^{\alpha}\right]^{\frac{1}{\alpha+1}}. \tag{A9}$$

$R(\alpha) > 0$ for any α, since $g\rho^{1-\sigma}/r < 1$, which follows from $k(\bar{z}) < \bar{z}\rho L/L^*$. Hence, $H(\alpha) < R(\alpha)$ at $\alpha \to 0$. As $\alpha \to \infty$, $H(\alpha)$ is infinitely large, while $R(\alpha)$ is a finite number (since $\mu/r < 1$ and $L^*/(\rho L) < 1$, $A(\rho) \to 1$ as $\alpha \to \infty$). Thus, $H(\alpha) > R(\alpha)$ at $\alpha \to \infty$. It follows that $H(\alpha)$ and $R(\alpha)$ must intersect as some point $\bar{\alpha}$ implicitly defined by $H(\bar{\alpha}) = R(\bar{\alpha})$. At $\alpha = \bar{\alpha}$, $dR(\alpha)/d\alpha < 0$. To show this, I totally differentiate $R(\alpha)$ with respect to α to obtain

$$\frac{dR(\alpha)}{d\alpha} = \frac{\partial R(\alpha)}{\partial A(\rho)}\left[\frac{\partial A(\rho)}{\partial\alpha} + \frac{\partial A(\rho)}{\partial\rho}\frac{d\rho}{d\alpha}\right], \tag{A10}$$

where

$$\frac{d\rho}{d\alpha} = \frac{\sigma}{\sigma-1}\frac{-F_\alpha E_{\bar{z}} + E_\alpha F_{\bar{z}}}{D}, \quad F_\alpha = \ln(\bar{z})\int_0^{\bar{z}} \frac{k(z)}{[k(z)+1]^2}\,dz < 0,$$

$$E_\alpha = \omega\ln(\bar{z}) < 0.$$

From (A7), $d\rho/d\alpha = 0$ at $\alpha = \bar{\alpha}$. Next, $\partial R(\alpha)/\partial A(\rho) < 0$ because $g\rho^{1-\sigma}/r < 1$. Last,

$$\frac{\partial A(\rho)}{\partial\alpha} = \frac{1}{(\alpha+1)^2}\left[\frac{\ln(r/\mu)}{\alpha+1}\left(\frac{L^*}{\rho L}\right)^{\frac{\alpha}{\alpha+1}} + \alpha\left(\frac{\mu}{r}\right)^{\frac{1}{\alpha+1}}\ln\left(\frac{\rho L}{L^*}\right)\right] > 0,$$

$$\text{since} \quad \frac{r}{\mu} > 1; \quad \frac{\rho L}{L^*} > 1.$$

Since $dR(\alpha)/d\alpha < 0$ at $\alpha = \bar{\alpha}$ and $dH(\alpha)/d\alpha = 1$, it must be that $\bar{\alpha}$ is unique. For any $\alpha > \bar{\alpha}$, $H(\alpha) > R(\alpha)$ and (A9) holds; thus, $d\omega/dL/L^* < 0$. For any $\alpha < \bar{\alpha}$, $H(\alpha) < R(\alpha)$ and (A9) does not hold; thus, $d\omega/dL/L^* > 0$. At $\alpha = \bar{\alpha}$, (A9) holds with equality, so $d\omega/dL/L^* = 0$.

Proof of proposition 4

The vertical shift in the *EP* schedule is $d\omega/d\mu = -E_\mu/E_\omega = -\omega/\mu < 0$. Since $d\mu/dIPR < 0$, the *EP* schedule shifts upward. The vertical shift in the *FE* schedule is $d\omega/d\mu = -F_\mu/F_\omega < 0$, where $F_\omega > 0$ and $F_\mu = \int_0^{\bar{z}} k(z)/[k(z)+1]^2\, dz/\mu > 0$. Thus, the *FE* schedule shifts upward.

Next, $d\bar{z}/d\mu = [F_\mu E_\omega - E_\mu F_\omega]/D < 0$ if $F_\mu E_\omega < E_\mu F_\omega$, which simplifies to

$$\frac{\bar{z}^2 \rho L/L^*}{[\bar{z}\rho L/L^* + 1]^2} + (\sigma - 2)\int_0^{\bar{z}} \frac{k(z)}{[k(z)+1]^2}\, dz > 0, \quad \text{provided} \quad \sigma \geq 2.$$

Next, $d\omega/d\mu = [E_\mu F_{\bar{z}} - F_\mu E_{\bar{z}}]/D > 0$ if $F_\mu E_{\bar{z}} < E_\mu F_{\bar{z}}$, which simplifies to

$$\frac{(\alpha+1)}{\bar{z}}\int_0^{\bar{z}} \frac{k(z)}{[k(z)+1]^2}\, dz < \frac{1}{k(\bar{z})+1} - \frac{1}{(1+\bar{z}\rho L/L^*)^2}.$$

Using (A5), I simplify this inequality to obtain (A8), which holds for any $\alpha > \bar{\alpha}$. Thus, $d\omega/d\mu > 0$ if $\alpha > \bar{\alpha}$; $d\omega/d\mu < 0$ if $\alpha < \bar{\alpha}$; and $d\omega/d\mu = 0$ if $\alpha = \bar{\alpha}$.

Proof of lemma

Partially differentiating $X = L^*/[\bar{z}\rho]\int_0^{\bar{z}} k(z)/[k(z)+1]\, dz$ with respect to $\eta(z)$, ω, and $\bar{z}$ yields

$$X_\eta = -\frac{L^*}{\bar{z}\rho}\int_0^{\bar{z}} \frac{k(z)/\eta(z)}{[k(z)+1]^2}\, dz < 0;$$

$$X_\omega = -\frac{\sigma}{\sigma-1}\frac{L^*}{\bar{z}\rho^2}\int_0^{\bar{z}} \frac{[\sigma + k(z)]k(z)}{[k(z)+1]^2}\, dz < 0;$$

$$X_{\bar{z}} = \frac{L^*}{\bar{z}\rho}\left[\frac{k(\bar{z})}{k(\bar{z})+1} - \frac{1}{\bar{z}}\int_0^{\bar{z}} \frac{k(z)}{k(z)+1}\, dz\right] < 0. \tag{A11}$$

To see that $X_{\bar{z}} < 0$, use (A1) to rewrite the integral in (A11) as follows:

$$\int_0^{\bar{z}} \frac{k(z)}{k(z)+1}\, dz = \bar{z} - \int_0^{\bar{z}} \frac{1}{k(z)+1}\, dz = \bar{z} - \frac{\bar{z}}{\bar{z}\rho L/L^* + 1}.$$

Substituting the result into (A11) and simplifying, I obtain $X_{\bar{z}} < 0$, since $k(\bar{z}) < \bar{z}\rho L/L^*$.

Proof of proposition 5

$$\frac{dM(\bar{z})/M(\bar{z})}{dIPR/IPR} = \left[1 + (\alpha+1)\frac{d\bar{z}/\bar{z}}{d\mu/\mu}\right]\frac{d\mu/\mu}{dIPR/IPR} > 0 \quad \text{if} \quad -\frac{d\bar{z}/\bar{z}}{d\mu/\mu} > \frac{1}{\alpha+1}.$$

From proposition 3, if $\alpha = \bar{\alpha}$ stronger IPRs do not affect ω and $-(d\bar{z}/\bar{z})/(d\mu/\mu) = 1/(\alpha+1)$. Hence, $dM(\bar{z})/dIPR = 0$. If $\alpha > \bar{\alpha}$, ω falls and so $\bar{z}$

expands by more than $1/(\alpha + 1)$. Thus, $M(\bar{z})$ rises. If $\alpha < \bar{\alpha}$, ω rises and so $\bar{z}$ expands by less than $1/(\alpha + 1)$. Thus, $M(\bar{z})$ falls.

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