

Trade-Related Intellectual Property Rights: Theory and Empirics

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Abstract

The WTO inspired strengthening of intellectual property rights (IPRs) in developing countries remains highly controversial even 15 years after the 1994 TRIPs agreement. This paper employs both theory and empirics to assess how a strengthening of IPRs affects international technology diffusion by altering the volume of high-tech exports into developing countries. In the context of a North-South general equilibrium model, stronger IPRs encourage Northern firms to introduce new high-tech products in the South. High-tech exports to the South rise, while low-tech exports may fall. International technology diffusion does not necessarily fall. These theoretical predictions are examined empirically. On average, developing countries that strengthened their IPRs under the TRIPs agreement saw an increase of approximately \$50 billion (1994 US dollars) in their high-tech imports. This amount is equivalent to a 13% increase in their annual value of high-tech imports.

Keywords: Trade; International law; Intellectual property rights

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I. Introduction

The WTO inspired strengthening of IPRs in developing countries remains highly controversial even 15 years after the 1994 agreement on Trade-Related Aspects of Intellectual Property Rights (TRIPs). It is easy to see why. Developed countries argue that 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. Developing countries are, however, afraid 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 disparity 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 employs both theory and empirics to assess 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.

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

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 traded industry. Northern producers in the traded industries gain more power over the markets for their products, much as was feared by some in developing countries. I show, however, that 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 traded 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 traded industry falls. This third effect – the *market dilution* effect – arises because industries differ in their imitation rates, and it lowers Northern exports. Lastly, a change in the relative wage – which occurs as a result of the three effects combined together – 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 provided industries differ sufficiently in their imitation rates, then both the Southern wage and the *overall* volume of Northern exports rise with stronger IPRs. There are however important differences across industries. Northern exports in high-tech industries (with the highest risk of imitation) rise, while exports in low-tech industries (with the lowest risk of imitation) may fall. As such, the composition of exports changes so that the average technology intensity of Northern exports rises. This is the key result I investigate empirically. To do so, I examine how the strengthening of IPRs in developing countries under the TRIPs agreement affected developed

countries' exports (into developing countries) over the 1994-2000 period. Using the ranking of industries by patent effectiveness documented in Cohen et al. (2000), I classify export industries into two groups: IPR-sensitive industries (professional and scientific equipment, medicinal and pharmaceutical products, chemicals, and non-electrical machinery) and IPR-insensitive industries (non-ferrous metals, textiles, food, and printing and publishing). Patents are the most effective in protecting the firm's competitive advantage in IPR-sensitive industries. I then conduct a difference-in-difference estimation on exports distinguished by both country and export classification.

The empirical results strongly support the theory's prediction of a differential impact across industries. Strengthening IPRs under the TRIPs agreement increased developed countries' exports in high-tech IPR-sensitive industries the most. On average, developing countries that strengthened their IPRs under the TRIPs agreement saw an increase of approximately \$50 billion (1994 US dollars) in their high-tech imports. This amount is equivalent to a 13% increase in their annual value of high-tech imports. While I have no empirical measure of technology diffusion, the theory 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. And 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 empirical finding of such a large increase in exports suggests that this may have indeed been the case from the 1994 TRIPs agreement.

There is a large theory literature on this subject. Researchers have increased our understanding of the relationship between IPRs and production, technology transfer, innovation, trade, and growth.² There are, however, very few contributions that employ

²See for example Chin and Grossman (1990), Deardorff (1992), Helpman (1993), Taylor (1993), Taylor (1994), Lai (1998), Glass and Saggi (2002), and Grossman and Lai (2004).

theory to help guide empirical work.³ The main paper in this area is that of Maskus and Penubarti (1997) who develop a partial equilibrium model in which a dominant exporting firm competes with an imitative fringe industry.⁴

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. 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 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 traded industries expands, the Southern budget share spent on the products of each existing traded industry falls. When industries are heterogeneous in their imitation risk, the resultant market dilution effect is strong enough that the expansion in the range of traded industries reduces Northern exports overall. Finally, when industries are allowed to differ in their imitation rates, a change in the composition of Northern exports is expected in response to a strengthening of IPRs. This differential growth prediction is the one I investigate empirically.

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 to shift their production to the South and face imitation risk or not. Stronger IPRs encourage Northern firms to move more quickly to the South, which is

³The link between IPRs and trade is examined empirically in Ferrantino (1993), Maskus and Penubarti (1995), Fink and Braga (1999), Smith (1999), Rafiquzzaman (2002), and Co (2004).

⁴Maskus and Penubarti (1997) predict that strengthening IPRs has two effects on trade. On 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.

⁵In 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.

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 marginal and inframarginal 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 Glass and Saggi (2002) but differs from Helpman (1993) and Lai (1998), where imitation is exogenous. Unlike in Glass and Saggi (2002), however, imitation is costless here; it is determined by the range of traded industries. While the determination of innovation is undoubtedly important for understanding the link between IPRs and trade, 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 II, I describe the basic North-South model of IPRs and trade. In section III, the trading equilibrium is established. The effects of stronger IPRs on the equilibrium range of traded industries and relative wage are analyzed in section IV. The predictions about the impact of stronger IPRs on Northern exports and technology diffusion are derived in section V, and evaluated in section VI using data on developed countries' exports over the 1994-2000 period. Section VII concludes.

II. The Model

Assume the world is comprised of two regions, North and South. The North is the region where newly invented products are produced, because of its comparative advantage in R&D; the South is the region where imitation occurs. A continuum of industries with different technology intensity indexed by $z \in [0, 1]$ exists. Each industry, z , has ongoing innovation and hence the number of products available for consumption, $N(z, t)$

⁶The 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).

grows over time. The industries differ in the rate at which the South can potentially imitate products developed in the North. Depending on the rate 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 traded goods 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.

As a result if z is a traded goods 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-traded goods industry, then its products are produced in the North, i.e. $N(z, t) = n(z, t)$. In what follows, I focus on steady-state equilibria and to save on notation, I ignore the dependance of variables on time.

A. Tastes

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

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

where $c_i(z)$ denotes the consumption of product i in industry z . $\theta = (\sigma - 1)/\sigma$, with $\sigma > 1$ being 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:

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

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

Maximizing (1) subject to (2), I obtain the North's demand for its domestically produced products $c(z)$ and for its imported Southern products $c_m(z)$:

$$c(z) = \left[\frac{E}{P(z)} \right] \left[\frac{p(z)}{P(z)} \right]^{-\sigma} \quad \text{and} \quad c_m(z) = \left[\frac{E}{P(z)} \right] \left[\frac{p^*(z)}{P(z)} \right]^{-\sigma}, \quad (3)$$

where $P(z) \equiv [\sum_{i=0}^{N(z)} p_i^{1-\sigma}]^{1/(1-\sigma)}$ is the overall price index, and $p(z)$ and $p^*(z)$ 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 $[0, 1]$. The products of non-traded industries are, however, 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 traded industries only. The South's demand for its domestically produced products $c^*(z)$ and for its imported Northern products $c_m^*(z)$ takes the following form:

$$c^*(z) = \left[\frac{b^* E^*}{P(z)} \right] \left[\frac{p^*(z)}{P(z)} \right]^{-\sigma} \quad \text{and} \quad c_m^*(z) = \left[\frac{b^* E^*}{P(z)} \right] \left[\frac{p(z)}{P(z)} \right]^{-\sigma}, \quad (4)$$

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

B. 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 goods produced in the North and p equals to a fixed mark-up above marginal

costs of w ; hence $p = \sigma w / (\sigma - 1)$ for any innovative Northern good. 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 labor respectively. One unit of labor produces one unit of output in both regions and no labor is required for innovation or imitation. Aggregate income (which equals expenditure E) consists of labor income and profits. In the North, $E = wL + \pi = wL + (p - w)L = \sigma wL / (\sigma - 1)$, where the last equality follows because monopoly price $p = \sigma w / (\sigma - 1)$. In the South, profits are zero and $E^* = w^*L^*$.

Within each industry, z , new products are innovated at a constant rate g , and they are imitated at an industry-specific rate $m(z)$ if exported. I assume industries differ in the ease of imitation, which depends on their technology intensity, and rank industries in terms of their imitation rates with low-tech $z = 0$ industry having the lowest imitation rate and high-tech $z = 1$ industry having the highest imitation rate. It proves useful to adopt a constant elasticity specification where the imitation rate across industries is:

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

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 . If $\alpha < 1$, the imitation function is concave: with an increase in z , the imitation rate is increasing at a decreasing rate. If $\alpha > 1$, the imitation function is convex: with an increase in z , the imitation rate is increasing at an increasing rate.

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

rate is defined as:

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

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 traded industries only, is proportional to the number of newly invented products traded. Therefore, the number of Southern products within each traded 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 traded industry, defined as $\eta(z) \equiv n^*(z)/n(z)$, changes over time and is governed by the following differential equation: $\dot{\eta}(z) = m(z) - g\eta^2(z) - [g - m(z)]\eta(z)$.⁷ Setting $\dot{\eta}(z)$ to zero solves for the steady state relative number of Southern products in each industry z :

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

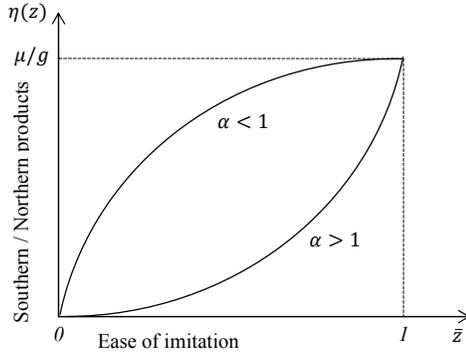


Figure 1: **Number of products**

⁷Differentiate $\eta(z) \equiv n^*(z)/n(z)$ 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: $\dot{\eta} = m - [g - m + g\eta]\eta$, which simplifies to $\dot{\eta} = m - g\eta^2 - [g - m]\eta$.

If 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.

C. 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:⁸

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

which follows from (5). In absolute terms, the impact of stronger IPRs on imitation rate varies across industries. It is the weakest in the low-tech traded industries with the lowest imitation and the strongest in the high-tech traded industries with the highest imitation.

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

D. Exporting and Imitation: The Equalized Profits Schedule

A Northern producer in each industry decides whether to export to the South or not. 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

⁸Cohen et al. (2000) find that prevention of imitation is the main reason for patenting. Levin et al. (1987) and Mansfield et al. (1981) provide evidence that patenting increases the costs and time necessary to imitate.

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 facing lower wage costs. As such, with probability $m(z)dt$ the future profits are zero. With probability $1 - m(z)dt$ the Northern producer earns future profits, which are discounted at the rate of rdt . As a result, the expected present discounted value of the stream of profits from exporting is given by:

$$V^X(z, t) = \Pi^X(z, t)dt + [1 - rdt][1 - m(z)dt]V^X(z, t + dt). \quad (9)$$

If the Northern producer decides not to export, there is no risk of imitation and the expected present discounted value of his stream of profits is given by:

$$V^{NX}(z, t) = \Pi^{NX}(z, t)dt + [1 - rdt]V^{NX}(z, t + dt), \quad (10)$$

where $\Pi^{NX}(z, t)dt$ is a stream of profits from selling in the North.

The Northern producer in industry z will export at time t if (9) is greater than (10). Rearranging (9) and (10), 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:⁹

⁹First, rearrange (9) and (10) to get:

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

Next, letting dt approach zero, the expressions above can be rewritten as:

$$\dot{V}^X(z, t) = [r + m(z)]V^X(z, t) - \Pi^X(z, t) \quad \text{and} \quad \dot{V}^{NX}(z, t) = rV^{NX}(z, t) - \Pi^{NX}(z, t).$$

$$\frac{\Pi^X(z)}{r + m(z)} > \frac{\Pi^{NX}(z)}{r}. \quad (11)$$

The output of a Northern producer who exports is sold to consumers in the North and in the South. The output of a Northern producer who does not export is 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:

$$\Pi^X(z) = \frac{w}{\sigma - 1} [c(z) + c_m^*(z)] \quad \text{and} \quad \Pi^{NX}(z) = \frac{w}{\sigma - 1} c(z). \quad (12)$$

Profits are proportional to revenues, which are in turn proportional to consumer expenditures. Substituting (12) into (11) and using the demand functions (3) and (4), I find that exporting is the best strategy for a Northern producer in industry z if:

$$\frac{E + b^* E^*}{r + m(z)} > \frac{E}{r}, \quad (13)$$

which simplifies to:

$$\frac{b^* E^*}{E} > \frac{m(z)}{r}, \quad \text{where} \quad E = \left(\frac{\sigma}{\sigma - 1} \right) wL \quad \text{and} \quad E^* = w^* L^*. \quad (14)$$

The left hand side of (14) is independent of (z) . The right hand side ranges from zero to μ/r and is increasing in z .¹⁰ Assume that the North-South income gap is large enough and imitation risk is severe enough 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 (14) holds with equality. The products of industry $z \leq \bar{z}(\omega)$ are exported (and eventually traded),

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:

$$V^X(z) = \frac{\Pi^X(z)}{r + m(z)} \quad \text{and} \quad V^{NX}(z) = \frac{\Pi^{NX}(z)}{r}.$$

The Northern producer in industry z exports if $V^X(z) > V^{NX}(z)$. Inequality (11) follows.

¹⁰This follows from $\mu(0) = 0$, $\mu(1) = \mu$, and $m'(z) > 0$.

and the products of industry $z > \bar{z}(\omega)$ are not exported (and remain non-traded).¹¹

The critical industry defines the range of traded industries $[0, \bar{z}(\omega)]$. Over this range, Southern budget shares, b^* , sum to one, thus $b^* = 1/\bar{z}(\omega)$. Setting (14) to equality and using (5), I obtain one relationship between relative wages and the critical industry \bar{z} :

$$E(\bar{z}, \omega) \equiv \omega - \frac{r}{\mu \bar{z}^{\alpha+1}} \left(\frac{\sigma - 1}{\sigma} \right) \frac{L^*}{L} = 0. \quad (15)$$

I refer to (15) 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 and not exporting are equalized. The *EP* schedule 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. \bar{z} rises. As the range of traded industries expands, the attractiveness of exporting at the margin falls for two reasons. First, the rate 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. As a result, the elasticity of the *EP* schedule is $-(\alpha + 1)$. It is also apparent from (15) that $\omega \rightarrow \infty$ as $\bar{z} \rightarrow 0$ along the schedule. At $\bar{z} = 1$, the relative Northern wage is at its minimum value given by:

$$\omega_{min} \equiv \frac{r}{\mu} \left(\frac{\sigma - 1}{\sigma} \right) \frac{L^*}{L}. \quad (16)$$

In order for Northern producers to be priced out of the market by Southern produces once imitation occurs, I assume the parameters are such that $\omega_{min} > 1$ throughout.¹²

¹¹If $b^*E^*/E < \mu/r$ 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).

¹²Northern wages always exceed Southern if the South is relatively abundant in labor (high L^*/L), the imitation rate is low (low μ means lower Southern output and lower demand for Southern labor), the discount rate is high (high r means lower risk of imitation, greater Northern exports, and greater demand for Northern labor), and the profit margins Northern producers earn are small (i.e. σ is high,

E. 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:

$$L^* = \int_0^{\bar{z}} n^*(z)y^*(z)dz. \quad (17)$$

Southern output is consumed in both the South and in the North, i.e. $y^*(z) = c^*(z) + c_m(z)$. Substituting (3) and (4) into (17) and simplifying, I obtain:¹³

$$L^* = \int_0^{\bar{z}} n^*(z)p^{*-\sigma} \frac{p^*L^*/\bar{z} + pL}{n^*(z)p^{*1-\sigma} + n(z)p^{1-\sigma}} dz. \quad (18)$$

Rewriting (18) 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:

$$F(\bar{z}, \omega) \equiv \int_0^{\bar{z}} \frac{1/\bar{z} + \rho L/L^*}{\rho^{1-\sigma}g/[\mu z^\alpha] + 1} dz - 1 = 0, \quad \text{where} \quad \rho \equiv \frac{p}{p^*} = \frac{\sigma}{\sigma - 1}\omega. \quad (19)$$

The *FE* schedule associates with each \bar{z} a value of ω such that labor is fully employed in both regions. As the range of traded industries expands, the relative Northern wage falls for three reasons. First, the relative demand for the Southern labor 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 is pronounced when the elasticity of substitution, σ , is small so that Northern and Southern labor are poor substitutes.¹⁴ The heterogeneity of industries in their imitation rates further contributes to an increase in the relative demand for which means greater Northern output and greater demand for Northern labor.

¹³Use $b^* = 1/\bar{z}$, $E = pL$, $E^* = p^*L^*$, 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.

¹⁴If industries do not differ in their imitation rates ($\alpha = 0$), the elasticity of the *FE* schedule is $-1/\sigma$.

Southern labor. The higher α is, the higher is the share of Southern products within each newly traded industry. Consequently, ω falls more as \bar{z} rises. In addition, since the relative number of Southern products is the highest within the marginal industry (recall Figure 1), an expansion in the range of traded 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 . As a result, the FE schedule is negatively sloped. This result is recorded as Lemma 1 and proven in the Appendix.

Lemma 1 *The FE schedule is negatively sloped, with $\omega \rightarrow \infty$ as $\bar{z} \rightarrow 0$.*

Proof: see Appendix.

III. 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.

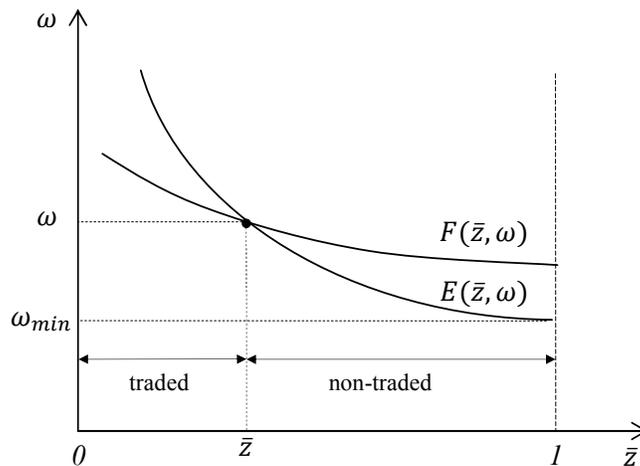


Figure 2: **The trading equilibrium**

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

Proof: see Appendix.

The condition $\sigma \geq 2$ ensures that the *FE* schedule is flatter than the *EP* schedule at any point (\bar{z}, ω) . 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.

The elasticity of substitution in consumption, σ , affects the slope of the *FE* schedule only. The higher σ is, the less consumer behavior changes with a change in the range of traded industries. Northern and Southern labor are better substitutes and so a smaller relative wage adjustment is required for any change in \bar{z} . Thus, the *FE* schedule is flatter. For any given σ , however, consumers respond to a change in the range of traded 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, the relative wage 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.¹⁵

High innovation rate, g , implies high relative demand for Northern labor. 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 ω and \bar{z} are deter-

¹⁵If industries do not differ in their imitation rates, i.e. $\alpha = 0$, 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 the risk of imitation rises much 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} 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 labor rises more and ω falls more for a given increase in \bar{z} . The *FE* schedule is steep.

mined by the innovation rate, the discount rate, and relative market size.¹⁶ Propositions 2 and 3 summarize the results.

Proposition 2 \bar{z} and ω respond to a change in g and r as follows:

- (i) ω rises and \bar{z} falls as g increases;
- (ii) ω falls and \bar{z} rises as r increases.

Proof: see 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 labor. With a constant \bar{z} , the relative Northern wage rises. Higher ω , in turn, implies 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 traded industries expands, the relative demand for Southern labor rises and ω falls along the FE schedule.

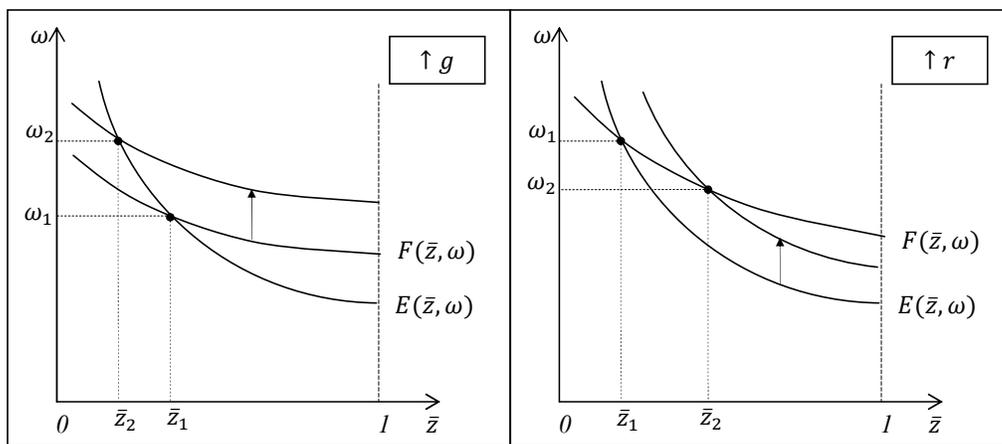


Figure 3: The impact of g and r

¹⁶It is also determined by the imitation rate, which is discussed in the next section.

Proposition 3 \bar{z} always falls as L/L^* increases. Further, there exists a unique critical value $\alpha^* > 0$ such that the following is true:

- (i) if $\alpha < \alpha^*$, ω rises as L/L^* increases;
- (ii) if $\alpha > \alpha^*$, ω falls as L/L^* increases;
- (iii) if $\alpha = \alpha^*$, ω is unaffected by a change in L/L^* .¹⁷

Proof: see 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.¹⁸ The reduction in \bar{z} is strong when industries do not differ much in their imitation rates, i.e. α is low.¹⁹ Second, the relative supply of Northern labor rises. The *FE* schedule implies that for a constant \bar{z} , ω falls.²⁰ The reduction in ω is strong when σ is low or α is high.²¹

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.²² The direction of a change in ω depends on the

¹⁷ α^* can be greater or less than one, depending on the values of σ , r , μ , g , and L/L^* .

¹⁸The elasticity of \bar{z} with respect to L/L^* (the horizontal shift of the *EP* schedule) is:

$$\frac{d\bar{z}}{dL/L^*} \frac{L/L^*}{\bar{z}} = -\frac{1}{\alpha + 1}.$$

¹⁹If $\alpha \rightarrow \infty$, \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. As a result, \bar{z} remains unchanged.

²⁰The elasticity of ω with respect to L/L^* (the vertical shift of the *FE* schedule) is:

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

$$\frac{d\omega}{dL/L^*} \frac{L/L^*}{\omega} = -\frac{1}{\sigma} \text{ if } \alpha = 0.$$

²¹If $\sigma \rightarrow \infty$, ω does not change with L/L^* . Northern and Southern labor are good substitutes and so the relative wage is unaffected by a change in the relative labor supply. 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 and so a smaller ω adjustment is required for a given change in L/L^* .

²²If $\sigma = 1$, the vertical shift of the schedules is identical and the equilibrium \bar{z} is unaffected (see (A17))

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 traded industries contracts greatly and so the indirect effect dominates. The relative demand for Northern labor increase enough that ω rises. If α is high, ω falls. In this case, the range of traded industries does not contract much and so the direct effect dominates. ω falls with an increase in L/L^* .

IV. 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. However, stronger IPRs also affect the export incentives of Northern producers. The range of traded 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 \bar{z} . The relative Northern wage changes as follows: ω rises if $\alpha < \alpha^*$; ω falls if $\alpha > \alpha^*$; and ω is unaffected if $\alpha = \alpha^*$.*

Proof: see Appendix.

in 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.²³ An increase in \bar{z} is strong when industries do not differ much in their imitation rates, i.e. α is low.²⁴ Second, the relative number of Southern products within each traded industry falls. This increases the relative demand for Northern labor. The *FE* schedule implies that for a constant \bar{z} , ω rises.²⁵ The increase in ω is strong when σ or α is low.²⁶

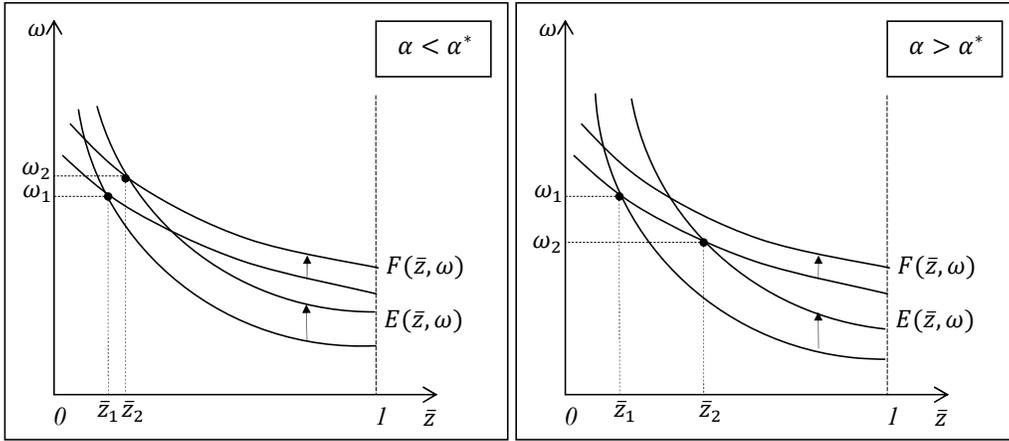


Figure 4: **The impact of strengthening IPRs**

²³The elasticity of \bar{z} with respect to μ (the horizontal shift of the *EP* schedule) is:

$$\frac{d\bar{z}}{d\mu} \frac{\mu}{\bar{z}} = -\frac{1}{\alpha + 1}.$$

²⁴If $\alpha \rightarrow \infty$, the risk of imitation rises enough with z that the range of traded industries does not expand with stronger IPRs.

²⁵The elasticity of ω with respect to μ (the vertical shift of the *FE* schedule) is:

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

$$\frac{d\omega}{d\mu} \frac{\mu}{\omega} = -\frac{1}{\sigma} \text{ if } \alpha = 0.$$

²⁶If $\sigma \rightarrow \infty$, Northern and Southern labor are good substitutes and ω is unaffected by a strengthening of IPRs. If α is high, the share of Southern products within each industry is small. Strengthening IPRs does not increase the relative demand for Northern labor much and so ω does not rise much.

Strengthening IPRs has two effects on \bar{z} . The direct effect is positive: \bar{z} rises, for a constant ω (the horizontal shift of the *EP* schedule). The indirect effect is, however, negative: stronger IPRs increase ω (the vertical shift of the *FE* schedule) and \bar{z} falls in response (along the *EP* schedule). The overall impact of stronger IPRs on the equilibrium \bar{z} is positive. \bar{z} always rises because the substitutability between the products limits the strength of the indirect effect such that the direct effect dominates.²⁷

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 traded 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 traded 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 traded industries expands only slightly. As a result, the negative impact of an increase in \bar{z} on ω is weak and ω rises.

V. 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:

$$\frac{dM(\bar{z})/M(\bar{z})}{dIPR/IPR} = \left[1 + (\alpha + 1) \frac{d\bar{z}/\bar{z}}{d\mu/\mu} \right] \frac{d\mu/\mu}{dIPR/IPR}. \quad (20)$$

Stronger IPRs limit the South's capacity to imitate, i.e. $d\mu/dIPR < 0$. This reduces the overall imitation rate, which means less technology diffuses to the South. However,

²⁷Strengthening IPRs reduces $\eta(z)$. In response, ω rises (the vertical shift of the *FE* schedule). The highest elasticity of ω with respect to $\eta(z)$ (when $\alpha = 0$) equals to $1/(1 - \sigma)$.

stronger IPRs also lower the imitation risk of exporting and so increase the range of traded industries, i.e. $d\bar{z}/d\mu < 0$. As Northern firms in a wider range of industries start exporting and new high-tech products are introduced in the South, 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 traded industries is sufficiently strong, which requires a high α . This result is established in Proposition 5.

Proposition 5 *Strengthening IPRs affects the overall imitation rate as follows: $M(\bar{z})$ rises if $\alpha > \alpha^*$; $M(\bar{z})$ falls if $\alpha < \alpha^*$; and $M(\bar{z})$ is unaffected if $\alpha = \alpha^*$.*

Proof: see Appendix.

The volume of Northern exports is defined by:

$$X \equiv \int_0^{\bar{z}} n(z)c_m^*(z)dz = \frac{L^*}{\bar{z}} \int_0^{\bar{z}} \frac{n(z)p^*p^{-\sigma}}{n(z)p^{1-\sigma} + n^*(z)p^{*1-\sigma}} dz,$$

where the second equality follows (4) and the definitions of b^* , E^* , and $P(z)$.²⁸

As a function of the relative Northern wage, ω , and the relative number of Southern products, $\eta(z)$, the volume of Northern exports is given by:

$$X = \frac{L^*}{\bar{z}} \int_0^{\bar{z}} \frac{\rho^{-\sigma}/\eta(z)}{\rho^{1-\sigma}/\eta(z) + 1} dz, \quad \text{where} \quad \rho = \frac{\sigma}{\sigma - 1}\omega. \quad (21)$$

The function (21) 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 traded 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

²⁸Recall that $b^* = 1/\bar{z}$, $E^* = p^*L^*$, and $P^{1-\sigma}(z) = n(z)p^{1-\sigma} + n^*(z)p^{*1-\sigma}$.

are endogenously determined by the interaction of the *EP* and *FE* schedules). Totally differentiating the Northern export function yields:

$$\frac{dX}{dIPR} = X_\eta \frac{d\eta(z)}{dIPR} + X_{\bar{z}} \frac{d\bar{z}}{dIPR} + X_\omega \frac{d\omega}{dIPR}. \quad (22)$$

Lemma 2 *Northern exports are decreasing in $\eta(z)$, ω , \bar{z} : $X_\eta < 0$, $X_{\bar{z}} < 0$, $X_\omega < 0$.*

Proof: see Appendix.

Stronger South's IPRs limit imitation. As a result, Northern exports are affected through three different channels. First, stronger IPRs reduce the relative number of Southern products within each traded industry. Northern producers in the traded 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 (22). Since $X_\eta < 0$ and $d\eta(z)/dIPR < 0$, the market power effect promotes Northern exports directly.

Second, stronger IPRs increase the range of traded industries. Higher \bar{z} creates a positive *market expansion effect*. As new industries start exporting, Northern exports rise. However, higher \bar{z} also creates a negative *market dilution effect*. As the range of traded industries expands, the Southern budget share spent on the products of each existing traded industry falls. This reduces Northern exports. Lemma 2 establishes that the overall impact of an increase in \bar{z} is negative, i.e. $X_{\bar{z}} < 0$, which means the market dilution effect dominates. This result arises because industries differ in their imitation rates. High-tech products of the new firms that start exporting are the easiest to imitate. Once imitation occurs, the relative number of Northern products within each of the newly traded industries is the smallest. As such, these new industries don't add much to Northern exports. However, they take away the share of the Southern market from the existing traded industries, which have the highest relative number of Northern products. As a result, a wider range of traded industries hampers Northern exports directly.²⁹

²⁹If industries do not differ in their imitation rates, i.e. $\alpha = 0$, the market expansion and the market

Last, the three effects together affect ω and hence via (19) p/p^* . This creates a *terms of trade effect*, represented by the third term in (22). Lemma 2 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 effect can be positive or negative.

The overall impact of strengthening South's IPRs on the volume of Northern exports, aggregated over the range of traded industries, is ambiguous. It depends on the extent to which the range of traded industries expands, determined by α . If stronger IPRs stimulate exporting in a wide range of industries (i.e. α is low), Northern exports rise. In contrast, if the range of traded industries expands only slightly, Northern exports fall. In this case, the relative Northern wage necessarily rises.

Most importantly, stronger IPRs affect Northern exports differently across industries. In high-tech marginal industries — which are not traded prior to a strengthening of IPRs because the risk of imitation is 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). In low-tech inframarginal industries, Northern exports rise the least, and may fall. The risk of imitation in these industries is low to begin with and so stronger IPRs do not affect the export decisions of the Northern firms. The positive market expansion effect is absent in inframarginal industries. Instead, the negative market dilution effect is present. Northern exports fall in inframarginal industries as the Southern market is diluted away from these industries towards newly traded ones.

Stronger IPRs change the composition of Northern exports, which shifts away from low-tech and towards high-tech industries. Hence, the average technology intensity of Northern exports rises. This impact is critically important as it suggests that the South's access to Northern technological advancement may rise.

dilution effects offset each other and so an expansion in \bar{z} does not effect Northern exports: $X_\eta = 0$.

VI. Empirical Evidence

To investigate key predictions of the theory, I examine how the impact of stronger IPRs on Northern exports differs across industries empirically. I look at two groups of industries: IPR-sensitive and IPR-insensitive industries. Industries are classified in Table 1. The classification is based on Cohen et al.'s (2000) ranking of industries by the effectiveness of patents in protecting a given industry's "competitive advantage". Patent protection is more effective in IPR-sensitive than in IPR-insensitive industries. The classification I adopt is expected to reflect the distinction across industries made in the theory. IPR-sensitive industries are high-tech industries which rely on intellectual property protection much because the risk of imitation is high. IPR-insensitive industries, on the other hand, are lower-tech industries which rely on on intellectual property protection less because the risk of imitation is lower.

Table 1: **Industry classification**

IPR-sensitive industries	IPR-insensitive industries
Professional and scientific equipment	Non-ferrous metals
Medicinal and pharmaceutical products	Textiles
Other chemicals	Food
Industrial chemicals	Printing and publishing
Non-electrical machinery	

I examine how strengthening of IPRs in developing countries under the TRIPs agreement affected developed countries exports over the 1994-2000 period. The export data are organized by 3-digit ISIC codes (Rev.2) for the years 1994 and 2000. The value of exports into each developing country is aggregated over the 24 OECD members. The developing countries are countries classified by the World Bank as lower-middle or low income economies.³⁰ The strength of IPRs in each country is measured by the Ginarte and Park (1997) patent rights index, which is available for each 5-year time period from 1960 to 2000.

³⁰The classification is according to 1995 GNP per capita.

The theory predicts that stronger IPRs promote Northern exports the most in IPR-sensitive industries and may lower exports in IPR-insensitive industries, which can be formulated as $\beta^s - \beta^i > 0$, where β^s and β^i denote the response of Northern exports to a strengthening of IPRs in IPR-sensitive (s) and IPR-insensitive (i) industries respectively. To evaluate this prediction, I specify the following statistical model:

$$\Delta X_{jt}^{s/i} = (\beta^s - \beta^i)\Delta IPR_{jt} + \varphi_t^{s/i} + u_{jt}^{s/i}, \quad (23)$$

where $\Delta X_{jt}^{s/i} \equiv \Delta X_{jt}^s - \Delta X_{jt}^i$, $\varphi_t^{s/i} \equiv \varphi_t^s - \varphi_t^i$, and $u_{jt}^{s/i} \equiv u_{jt}^s - u_{jt}^i$. All variables are in natural logarithms. The equation is obtained by differencing the export data across industry groups for each developing country. $\Delta X_{jt}^{s/i}$ is the log difference in the aggregate value of Northern exports into developing country j in IPR-sensitive relative to IPR-insensitive industries over the period t . It approximates the differential growth rate of exports across the two industry groups. ΔIPR_{jt} is the log difference in the strength of IPRs in country j over period t . $\varphi_t^{s/i}$ denotes industry-specific variables such as imitation rate and technology intensity. $u_{jt}^{s/i}$ is the stochastic error term.

Variables specific to a country, such as population, income, or capacity to imitate, are absent from (23). They do not differ across industries and so are removed by differencing the data across industry groups. This approach ensures that country-specific factors are not confounded with strengthening of IPRs, which is of critical importance since strengthening of IPRs in a country is likely to be related to other domestic policy changes which affect trade as well.

Estimation of (23) is challenging for two significant reasons. First, the decision to strengthen IPRs in a country could very well be influenced by the country's trading relations with the developed world. For example, a developing country that has a low inflow of foreign innovative products may have extra incentives to strengthen its intellectual property laws in order to attract more products. In this case, trade causes the stringency of IPRs, but not the reverse. Second, it may be that the changes in IPRs are correlated

with unobserved determinants of export growth. For example, technological progress — which promotes growth of Northern exports differentially across high-tech and low-tech industries — is likely to go in tandem with strengthening IPRs in developing countries. In this case, the positive association between the variables could bias the causal inference of stronger IPRs on export growth.

The empirical strategy I implement attempts to overcome the potential problems mentioned above in order to recover the causal effect of stronger IPRs on Northern exports. I argue that the imposition of the 1994 TRIPs agreement provides a largely exogenous shock to the intellectual property protection offered in a subset of developing countries. TRIPs is an international agreement that sets down minimum standards of IPRs. Its ratification is a condition for WTO membership. Faced with this requirement, some developing countries adopted TRIPs only reluctantly. I classify these countries into the treatment group, with all the other developing countries being in the control group. The binary country status variable is then used to instrument the changes in IPRs. This approach is outlined in detail in Ivus (2008), where colonial origin of a country — which is strongly correlated with the changes in the strength of IPRs during the 1960-2000 period — is used as a rule for the classification. For the post-TRIPs 1994-2000 period, developing countries without a British or French colonial origin are in the treatment group. They did not strengthen their IPRs prior to the 1990s, but did strengthen their IPRs by 30% more than former colonies in the 1990s, coinciding with TRIPs coming into force.³¹

Define $\Delta X_{jt}^{s/i}$ as the average annual log change in the aggregate value of Northern exports in IPR-sensitive industries relative to IPR-insensitive industries over the 1994 – 2000 period: $\Delta X_{jt}^{s/i} \equiv (\ln X_{j,2000}^{s/i} - \ln X_{j,1994}^{s/i}) / (2000 - 1994)$. Let $j = T$ for a treated country and $j = C$ for a control country. Assume that colonial origin does not directly determine the relative growth rate of exports in IPR-sensitive industries. It only affects

³¹The F statistic equals 13.26 in the regression $\Delta IPR_{jt} = a + bD + \varepsilon$, where D is the dummy that equals one if j is non-colony. Following Stock et al. (2002), I conclude that British or French colonial origin is a strong instrument.

$\Delta X_{jt}^{s/i}$ indirectly by affecting ΔIPR_{jt} . That is, $E[u_{jt}^{s/i}|j = T] = E[u_{jt}^{s/i}|j = C]$. Then the estimate of the impact of stronger IPRs on export growth in s relative to i industries is:

$$\widehat{\beta^s - \beta^i} = \frac{\overline{\Delta X}_t^{s/i,T} - \overline{\Delta X}_t^{s/i,C}}{\overline{\Delta IPR}_t^T - \overline{\Delta IPR}_t^C} \quad (24)$$

where $\overline{\Delta X}_t^{s/i,T}$ and $\overline{\Delta X}_t^{s/i,C}$ are the sample averages of $\Delta X_{jt}^{s/i}$ over the part of the sample where $j = T$ and $j = C$ respectively. Similarly, $\overline{\Delta IPR}_t^T$ and $\overline{\Delta IPR}_t^C$ are the sample averages of ΔIPR_{jt} . The denominator in (24) is positive, because the treated countries strengthened their IPRs the most. Therefore, the sign of $\widehat{\beta^s - \beta^i}$ depends on the sign of the numerator as follows:

$$\widehat{\beta^s - \beta^i} = \begin{cases} > 0 & \text{if } \overline{\Delta X}_t^{s/i,T} - \overline{\Delta X}_t^{s/i,C} > 0 \\ < 0 & \text{if } \overline{\Delta X}_t^{s/i,T} - \overline{\Delta X}_t^{s/i,C} < 0 \end{cases} \quad (25)$$

To estimate (25), a simple mean comparison analysis is employed: the average growth rate of exports in IPR-sensitive relative to IPR-insensitive industries for the treated countries is compared with that for the control countries. Table 2 shows the results.

Table 2: **Growth rates of exports**

	$\overline{\Delta X}_t^{s/i,T} - \overline{\Delta X}_t^{s/i,C}$	st.error
Aggregate of IPR-sensitive industries	.0455*	.024
Professional and scientific equipment	.0701**	.031
Medicinal and pharmaceutical products	.0601**	.029
Other chemicals	.0376	.023
Industrial chemicals	.0574**	.024
Non-electrical machinery	.0384	.032

Note: Export growth in IPR-sensitive industries relative to that in the aggregate of IPR-insensitive industries. The data is in log point changes.

***, **, and * denote 1%, 5%, and 10% significance level.

In the first row, the growth rate of exports in the aggregate of IPR-sensitive industries is evaluated relative to that in the aggregate of IPR-insensitive industries. The estimate of $\overline{\Delta X}_t^{s/i,T} - \overline{\Delta X}_t^{s/i,C}$ is positive and statistically significant. The null hypothesis that

the mean changes are equal across the two country groups is rejected at the 1% level of significance.³² The estimate equals .0455 log point changes, which is about 5.2% per year.³³ This result suggests that across the two country groups, the annual growth rate of exports in IPR-sensitive (relative to IPR-insensitive) industries was on average 5.2% higher for the treatment group. In the other rows, the growth rate of exports in each IPR-sensitive industry is evaluated relative to that in the aggregate of IPR-insensitive industries. The estimates are all positive, and statistically significant for professional and scientific equipment, medicinal and pharmaceutical products, and industrial chemicals.

To summarize, the analysis shows that $\overline{\Delta X}_t^{s/ns,T} - \overline{\Delta X}_t^{s/ns,C} > 0$ is positive, which implies $\widehat{\beta^s - \beta^i} > 0$. Across the two industry groups, a relative increase in developed countries' exports in high-tech IPR-sensitive industries was observed in response to strengthening of IPRs under the TRIPs agreement. As such, the empirical results strongly support the theory's prediction that Northern exports in high-tech industries rise, while Northern exports in low-tech industries may fall. These changes modify the composition of exports in a way that the average technology intensity of Northern exports rises.

The economic significance of the results is high. The estimates suggests that developing countries which strengthened their IPRs under the TRIPs agreement saw an increase of approximately \$50 billion (1994 US dollars) in their high-tech (relative to low-tech) imports.³⁴ This amount is equivalent to a 13% increase in their annual value of IPR-sensitive imports. While I have no empirical measure of technology diffusion, the theory predicts that new high-tech products are introduced in the Southern market when IPRs

³² $H_0 : DD = 0, H_1 : DD \neq 0; p - value = .06$. I use two-sample t test with unequal variances; under the two-sample t test with equal variances the results are the same.

³³To convert the estimate from log point change into percent change the next formula should be used: $[\exp(\text{estimate} \times 6) - 1]/6 \times 100$.

³⁴The annual growth rate of exports in IPR-sensitive (relative to IPR-insensitive) industries was on average 5.2% higher in the treated countries, for which the average annual rate of increase in IPRs was 1.9% higher during the 1990s. This implies that for each 1% increase in the IPRs index the value of developed countries' exports in IPR-sensitive (relative to IPR-insensitive) industries increased by 2.7% per year during the TRIPs period, i.e. $\beta^s - \beta^i = 2.7$. This is about \$1 billion per year (1994 US dollars). The treated countries increased their IPRs by over 50% during the 1990s. As a result, they gained approximately \$50 billion (1994 US dollars) of high-tech IPR-sensitive (relative to low-tech IPR-insensitive) imports.

are strengthened. The empirical finding of such a large increase in Northern exports suggests that this may have indeed been the case from the 1994 TRIPs agreement.

VII. Conclusion

This paper employed both theory and empirics 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 high-tech industries rise, while Northern exports in low-tech industries may fall with stronger IPRs. Stronger IPRs change the composition of exports so that the average technology intensity of Northern exports rises. This is the key result I investigated empirically. The empirical results strongly supported the theory's prediction of differential impact across industries. Strengthening IPRs under the TRIPs agreement increased developed countries' exports in high-tech industries the most. On average, developing countries that strengthened their IPRs under the TRIPs agreement saw an increase of approximately \$50 billion (1994 US dollars) in their high-tech imports, which is equivalent to a 13% increase in their annual value of high-tech imports. While I had no empirical measure of technology diffusion, the theory showed 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. And 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 empirical finding of such a large increase in Northern exports suggests that this may have indeed been the case from the 1994 TRIPs agreement.

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Appendix

PROOF OF LEMMA 1:

The *FE* schedule is given by:

$$F(\bar{z}, \omega) \equiv \int_0^{\bar{z}} \frac{1/\bar{z} + \rho L/L^*}{k(z) + 1} dz - 1 = 0, \quad \text{where } \rho = \frac{\sigma}{\sigma - 1} \omega, \quad k(z) = \frac{\rho^{1-\sigma} g}{\mu z^\alpha}. \quad (\text{A1})$$

Rearranging yields:

$$F(\bar{z}, \omega) \equiv \int_0^{\bar{z}} \frac{dz}{k(z) + 1} - \frac{\bar{z}}{\bar{z}\rho L/L^* + 1} = 0. \quad (\text{A2})$$

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

Differentiating (A2) with respect to \bar{z} yields:

$$F_{\bar{z}} = \frac{1}{k(\bar{z}) + 1} - \frac{1}{[\bar{z}\rho L/L^* + 1]^2} > 0. \quad (\text{A3})$$

The derivative (A3) is positive because $k(\bar{z}) < \bar{z}\rho L/L^*$. This can be shown by applying the mean-value theorem to solve for the integral in (A2). Let the function under the integral be defined by $f(z) \equiv k(z) + 1$. Given that $f(z)$ is a continuous function on the

interval $[0, \bar{z}]$, there exists a number \tilde{z} such that $\int_0^{\tilde{z}} dz/f(z) = \bar{z}/f(\tilde{z})$, where $0 < \tilde{z} < \bar{z}$. Applying this theorem to (A2) yields:

$$F(\bar{z}, \omega) \equiv \frac{\bar{z}}{k(\tilde{z}) + 1} - \frac{\bar{z}}{\bar{z}\rho L/L^* + 1} = 0. \quad (\text{A4})$$

If $\bar{z} \neq 0$, it follows from (A4) that $k(\tilde{z}) = \bar{z}\rho L/L^*$. Since $\tilde{z} < \bar{z}$, it is true that:

$$k(\bar{z}) < \bar{z}\rho L/L^*. \quad (\text{A5})$$

Differentiating (A2) with respect to ω yields:

$$F_\omega = \frac{\sigma}{\sigma - 1} F_\rho = \frac{\sigma}{\rho} \int_0^{\bar{z}} \frac{k(z)}{[k(z) + 1]^2} dz + \left(\frac{\sigma}{\sigma - 1} \right) \frac{\bar{z}^2 L/L^*}{[\bar{z}\rho L/L^* + 1]^2} > 0. \quad (\text{A6})$$

Since $F_{\bar{z}} > 0$ and $F_\omega > 0$, it follows from $d\omega/d\bar{z} = -F_{\bar{z}}/F_\omega$ that $d\omega/d\bar{z} < 0$ and the *FE* schedule is negatively sloped.

From (A4), $k(\tilde{z}) = \bar{z}\rho L/L^*$ along the *FE* schedule, which simplifies to:

$$\rho = \left[\frac{gL^*}{\mu L} \left(\frac{\bar{z}}{\tilde{z}} \right)^\alpha \right]^{1/\sigma} \frac{1}{\bar{z}^{(\alpha+1)/\sigma}}, \quad (\text{A7})$$

where $\bar{z}/\tilde{z} > 1$ provided $\bar{z} \neq 0$. It follows from (A7) that $\omega \rightarrow \infty$ as $\bar{z} \rightarrow 0$.

PROOF OF PROPOSITION 1:

First, I show that the condition $\sigma \geq 2$ ensures that the *FE* schedule is flatter than the *EP* schedule at any point $(\bar{z}; \omega)$, i.e. $F_{\bar{z}}/F_\omega < E_{\bar{z}}/E_\omega$. The *EP* schedule is given by:

$$E(\bar{z}, \omega) \equiv \omega - \frac{r}{\mu \bar{z}^{\alpha+1}} \left(\frac{\sigma - 1}{\sigma} \right) \frac{L^*}{L} = 0, \quad (\text{A8})$$

which implies that $F_{\bar{z}}/F_\omega < E_{\bar{z}}/E_\omega$ simplifies to $F_{\bar{z}}/F_\omega < (\alpha + 1)\omega/\bar{z}$.

$F_{\bar{z}}$ and F_ω are given in (A3) and (A6) respectively. Recalling that $\eta(z) = \mu z^\alpha/g$, the

integral in (A6) can be rewritten as:

$$\int_0^{\bar{z}} \frac{k(z)}{[k(z) + 1]^2} dz = \frac{\bar{z}}{\alpha} \left[\frac{1}{k(\bar{z}) + 1} - \frac{1}{\bar{z}} \int_0^{\bar{z}} \frac{dz}{k(z) + 1} \right],$$

which using (A2) can be further rewritten as:

$$\int_0^{\bar{z}} \frac{k(z)}{[k(z) + 1]^2} dz = \frac{\bar{z}}{\alpha} \left[\frac{1}{k(\bar{z}) + 1} - \frac{1}{\bar{z}\rho L/L^* + 1} \right]. \quad (\text{A9})$$

Combining (A9) with (A6) and using (A3), I rewrite $F_{\bar{z}}/F_{\omega} < (\alpha + 1)\omega/\bar{z}$ as:

$$[\alpha(\sigma - 2) + \sigma - 1] \left[\frac{\bar{z}\rho L/L^* - k(\bar{z})}{k(\bar{z}) + 1} \right] + \alpha^2 \frac{\bar{z}\rho L/L^*}{\bar{z}\rho L/L^* + 1} > 0, \quad (\text{A10})$$

where the second term in the square brackets is positive since $k(\bar{z}) < \bar{z}\rho L/L^*$ (see (A5)).

Thus, the sufficient condition for (A10) to hold is $\sigma \geq 2$.

Second, I show that if g is sufficiently high, the FE schedule lies above the EP schedule at $\bar{z} = 1$. The vertical intercept of the EP schedule at $\bar{z} = 1$ is given by ω_{min} , which is independent of g :

$$\omega_{min} = \frac{r}{\mu} \left(\frac{\sigma - 1}{\sigma} \right) \frac{L^*}{L} \quad (\text{A11})$$

The vertical intercept of the FE schedule at $\bar{z} = 1$ is increasing in g (since $d\omega/dg = -F_g/F_{\omega}$, where $F_g < 0$ and $F_{\omega} > 0$). Since an increase in g increases the vertical intercept of the FE schedule only, it must be true that $F(\bar{z} = 1, \omega(g), g) > E(\bar{z} = 1, \omega)$ for a sufficiently high g , that is the FE schedule lies above the EP schedule at $\bar{z} = 1$.

Third, I show that the two conditions together ensure that a unique equilibrium exists.

I first solve for ω as a function of \bar{z} from the EP schedule (A8) and obtain $\omega_E(\bar{z})$:

$$\omega_E(\bar{z}) = \frac{r}{\mu\bar{z}^{\alpha+1}} \left(\frac{\sigma - 1}{\sigma} \right) \frac{L^*}{L} \quad (\text{A12})$$

I then evaluate the FE schedule at $\omega_E(\bar{z})$ and examine how $F(\bar{z}, \omega_E(\bar{z}))$ changes with \bar{z} . Since the vertical intercept of the FE schedule is above $\omega_E(\bar{z})$ at $\bar{z} = 1$ and $F_\omega > 0$, it is true that $F(\bar{z}, \omega_E(\bar{z})) < 0$ at $\bar{z} = 1$. Also, $F(\bar{z}, \omega_E(\bar{z})) > 0$ at $\bar{z} \rightarrow 0$. To see this, use (A4) to get: $F(\bar{z}, \omega_E(\bar{z})) > 0$ if $\bar{z}\rho_E^\sigma(\bar{z})L/L^* - 1/\eta(\bar{z}) > 0$, where $\rho_E(\bar{z}) = \sigma\omega_E(\bar{z})/(\sigma - 1)$. Using (A12) and the definition of $\eta(z) = \mu z^\alpha/g$, I rewrite this inequality as:

$$\frac{1}{\bar{z}^{(\sigma-1)(\alpha+1)}} > \frac{g}{r^\sigma} \left(\frac{\mu L}{L^*} \right)^{\sigma-1} \left(\frac{\bar{z}}{\tilde{z}} \right)^\alpha, \quad (\text{A13})$$

where $\bar{z}/\tilde{z} > 1$. It follows that at $\bar{z} \rightarrow 0$ (A13) holds and so $F(\bar{z}, \omega_E(\bar{z})) > 0$. Further, $F(\bar{z}, \omega_E(\bar{z}))$ is monotonically decreasing in \bar{z} provided $\sigma \geq 2$. To see this, substitute (A3), (A6), (A9), and (A12) into:

$$\frac{dF(\bar{z}, \omega_E(\bar{z}))}{d\bar{z}} = F_{\bar{z}} + F_{\omega_E} \frac{d\omega_E}{d\bar{z}}.$$

Since $F(\bar{z}, \omega_E(\bar{z}))$ is above zero at $\bar{z} \rightarrow 0$, below zero at $\bar{z} = 1$, and is monotonically decreasing in \bar{z} , there exists a unique \bar{z} such that $F(\bar{z}, \omega_E(\bar{z})) = 0$. In other words, a unique interior equilibrium exists provided $\sigma \geq 2$ and g is sufficiently high.

PROOF OF PROPOSITION 2:

The FE and EP schedules are given by (A2) and (A8). Totally differentiating $E(\bar{z}, \omega) = 0$ and $F(\bar{z}, \omega; g) = 0$ with respect to g , I obtain:

$$\begin{pmatrix} E_{\bar{z}} & E_\omega \\ F_{\bar{z}} & F_\omega \end{pmatrix} \begin{pmatrix} d\bar{z}/dg \\ d\omega/dg \end{pmatrix} = \begin{pmatrix} 0 \\ -F_g \end{pmatrix}$$

It follows that $d\bar{z}/dg = F_g E_\omega / D$ and $d\omega/dg = -F_g E_{\bar{z}} / D$, where $D \equiv E_{\bar{z}} F_\omega - F_{\bar{z}} E_\omega > 0$ (since the FE schedule is flatter than the EP schedule at any point $(\bar{z}; \omega)$). From (A2) and (A8) I have $F_g < 0$, $E_\omega > 0$, and $E_{\bar{z}} > 0$. As a result, $d\bar{z}/dg < 0$ and $d\omega/dg > 0$.

Totally differentiating $E(\bar{z}, \omega; r) = 0$ and $F(\bar{z}, \omega) = 0$ with respect to r , I obtain:

$$\begin{pmatrix} E_{\bar{z}} & E_{\omega} \\ F_{\bar{z}} & F_{\omega} \end{pmatrix} \begin{pmatrix} d\bar{z}/dr \\ d\omega/dr \end{pmatrix} = \begin{pmatrix} -E_r \\ 0 \end{pmatrix}$$

It follows that $d\bar{z}/dr = -E_r F_{\omega}/D$ and $d\omega/dr = E_r F_{\bar{z}}/D$, where $D > 0$. From (A2) and (A8) I have $E_r < 0$, $F_{\omega} > 0$, and $F_{\bar{z}} > 0$. As a result, $d\bar{z}/dr > 0$ and $d\omega/dr < 0$.

PROOF OF PROPOSITION 3:

Totally differentiating $E(\bar{z}, \omega; L/L^*) = 0$ and $F(\bar{z}, \omega; L/L^*) = 0$ (given by (A2) and (A8)) with respect to L/L^* , I obtain:

$$\begin{pmatrix} E_{\bar{z}} & E_{\omega} \\ F_{\bar{z}} & F_{\omega} \end{pmatrix} \begin{pmatrix} d\bar{z}/d(L/L^*) \\ d\omega/d(L/L^*) \end{pmatrix} = \begin{pmatrix} -E_{L/L^*} \\ -F_{L/L^*} \end{pmatrix}$$

It follows that $d\bar{z}/d(L/L^*) = [F_{L/L^*} E_{\omega} - E_{L/L^*} F_{\omega}]/D$ and $d\omega/d(L/L^*) = [E_{L/L^*} F_{\bar{z}} - F_{L/L^*} E_{\bar{z}}]/D$, where $D > 0$. From (A2) and (A8), the partial derivatives are as follows:

$$E_{L/L^*} = \frac{\omega}{L/L^*} \quad \text{and} \quad F_{L/L^*} = \frac{\bar{z}^2 \rho}{[\bar{z} \rho L/L^* + 1]^2}; \quad (\text{A14})$$

$$E_{\omega} = 1 \quad \text{and} \quad F_{\omega} = \frac{\sigma}{\rho} \int_0^{\bar{z}} \frac{k(z)}{[k(z) + 1]^2} dz + \left(\frac{\sigma}{\sigma - 1} \right) \frac{\bar{z}^2 L/L^*}{[\bar{z} \rho L/L^* + 1]^2}; \quad (\text{A15})$$

$$E_{\bar{z}} = (\alpha + 1) \frac{\omega}{\bar{z}} \quad \text{and} \quad F_{\bar{z}} = \frac{1}{k(\bar{z}) + 1} - \frac{1}{[\bar{z} \rho L/L^* + 1]^2}. \quad (\text{A16})$$

$d\bar{z}/dL/L^* < 0$ if $F_{\omega} E_{L/L^*} > E_{\omega} F_{L/L^*}$, which using (A14) and (A15) is rewritten as:

$$(\sigma - 1) \frac{L^*}{L} \int_0^{\bar{z}} \frac{k(z)}{[k(z) + 1]^2} dz > 0, \quad (\text{A17})$$

which is always positive since $\sigma > 1$.

$d\omega/d(L/L^*) < 0$ if $F_{L/L^*}E_{\bar{z}} > E_{L/L^*}F_{\bar{z}}$, which using (A14) and (A16) is rewritten as:

$$\alpha > \left[1 - \frac{k(\bar{z})}{\bar{z}\rho L/L^*} \right] \frac{\bar{z}\rho L/L^* + 1}{k(\bar{z}) + 1} \quad (\text{A18})$$

From the *EP* schedule, given by (A8), I have $\bar{z} = [rL^*/(\mu L\rho)]^{1/(\alpha+1)}$. Substituting this result into (A18) and simplifying I obtain:

$$\alpha > \left[1 - g\rho^{1-\sigma}/r \right] \frac{A(\rho) + 1}{A(\rho) + g\rho^{1-\sigma}/r}, \quad \text{where } A(\rho) = \left[\frac{\mu}{r} \left(\frac{L^*}{\rho L} \right)^\alpha \right]^{\frac{1}{\alpha+1}}. \quad (\text{A19})$$

Define the following two functions:

$$H(\alpha) \equiv \alpha \quad \text{and} \quad R(\alpha) \equiv \left[1 - g\rho^{1-\sigma}/r \right] \frac{A(\rho) + 1}{A(\rho) + g\rho^{1-\sigma}/r}. \quad (\text{A20})$$

The function $R(\alpha)$ lies strictly above zero. This result is implied by $g\rho^{1-\sigma}/r < 1$, which is obtained from $k(\bar{z}) < \bar{z}\rho L/L^*$ (see (A5)), where $\bar{z} = [rL^*/(\mu L\rho)]^{1/(\alpha+1)}$. Since $R(\alpha) > 0$ for any α , it is true that $H(\alpha) < R(\alpha)$ at $\alpha \rightarrow 0$. As $\alpha \rightarrow \infty$, $H(\alpha)$ is infinitely large, while $R(\alpha)$ is a finite number (since $\mu/r < 1$ and $L^*/(\rho L) < 1$, $A(\rho) \rightarrow 1$ as $\alpha \rightarrow \infty$). As a result, $H(\alpha) > R(\alpha)$ at $\alpha \rightarrow \infty$. It follows that the functions $H(\alpha)$ and $R(\alpha)$ must intersect at some point α^* implicitly defined by $H(\alpha^*) = R(\alpha^*)$.

At the point of intersection, $R(\alpha)$ is decreasing in α . To show this, I totally differentiate $R(\alpha)$ with respect to α to obtain:

$$\frac{dR(\alpha)}{d\alpha} = \frac{\partial R(\alpha)}{\partial A(\rho)} \left[\frac{\partial A(\rho)}{\partial \alpha} + \frac{\partial A(\rho)}{\partial \rho} \frac{d\rho}{d\alpha} \right], \quad \text{where} \quad (\text{A21})$$

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

Using (A16), I obtain the result that $d\rho/d\alpha = 0$ at $\alpha = \alpha^*$. Now (A21) simplifies to:

$$\frac{dR(\alpha)}{d\alpha} = \frac{\partial R(\alpha)}{\partial A(\rho)} \frac{\partial A(\rho)}{\partial \alpha}. \quad (\text{A22})$$

From (A20), $\partial R(\alpha)/\partial A(\rho) < 0$ because $g\rho^{1-\sigma}/r < 1$. Next, $\partial A(\rho)/\partial \alpha$ is given by:

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

which is positive because $r/\mu > 1$ and $\rho L/L^* > 1$. As a result, $dR(\alpha)/d\alpha < 0$ at $\alpha = \alpha^*$. Since $R(\alpha)$ is decreasing in α at the point of intersection and $H(\alpha)$ is always increasing in α at a constant rate, it must be that α^* is unique. For any $\alpha > \alpha^*$, $H(\alpha) > R(\alpha)$ and (A19) holds; thus, $d\omega/dL/L^* < 0$. For any $\alpha < \alpha^*$, $H(\alpha) < R(\alpha)$ and (A19) does not hold, thus $d\omega/dL/L^* > 0$. At $\alpha = \alpha^*$, (A19) holds with equality and so $d\omega/dL/L^* = 0$.

PROOF OF PROPOSITION 4:

The vertical shift in the *EP* schedule is $d\omega/d\mu = -E_\mu/E_\omega = -\omega/\mu < 0$ (see (A8)). Since $d\mu/dIPR < 0$, stronger IPRs shift the *EP* schedule upward. The vertical shift in the *FE* schedule is $d\omega/d\mu = -F_\mu/F_\omega$, where $F_\omega > 0$ from (A6). Differentiating (A2), where $\eta(z) = \mu z^\alpha/g$, with respect to μ yields:

$$F_\mu = \frac{1}{\mu} \int_0^{\bar{z}} \frac{k(z)}{[k(z) + 1]^2} dz > 0. \quad (\text{A23})$$

Thus, $d\omega/d\mu > 0$ and since $d\mu/dIPR < 0$, stronger IPRs shift the *FE* schedule upward.

Totally differentiating $E(\bar{z}, \omega; \mu) = 0$ and $F(\bar{z}, \omega; \mu) = 0$ with respect to μ , I obtain:

$$\begin{pmatrix} E_{\bar{z}} & E_\omega \\ F_{\bar{z}} & F_\omega \end{pmatrix} \begin{pmatrix} d\bar{z}/d\mu \\ d\omega/d\mu \end{pmatrix} = \begin{pmatrix} -E_\mu \\ -F_\mu \end{pmatrix}$$

It follows that $d\bar{z}/d\mu = [F_\mu E_\omega - E_\mu F_\omega]/D$, where $D > 0$, and E_μ and F_μ are given by:

$$E_\mu = \frac{\omega}{\mu}; \quad F_\mu = \frac{1}{\mu} \int_0^{\bar{z}} \frac{k(z)}{[k(z) + 1]^2} dz. \quad (\text{A24})$$

$d\bar{z}/d\mu < 0$ (i.e. stronger IPRs increase \bar{z}) if $F_\mu E_\omega < E_\mu F_\omega$, which using (A15) and (A24)

simplifies to:

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

which always holds provided $\sigma \geq 2$.

Next, $d\omega/d\mu = [E_\mu F_{\bar{z}} - F_\mu E_{\bar{z}}]/D$, where $D > 0$. $d\omega/d\mu > 0$ (i.e. stronger IPRs reduce ω) if $F_\mu E_{\bar{z}} < E_\mu F_{\bar{z}}$, which using (A16) and (A24) simplifies to:

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

which using (A9) can be further simplified to:

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

Note that this inequality is identical to (A18). It holds for any $\alpha > \alpha^*$. As a result, $d\omega/d\mu > 0$ if $\alpha > \alpha^*$; $d\omega/d\mu < 0$ if $\alpha < \alpha^*$; and $d\omega/d\mu = 0$ if $\alpha = \alpha^*$.

PROOF OF LEMMA 2:

The real value of Northern exports is given by:

$$X = \frac{L^*}{\bar{z} \rho} \int_0^{\bar{z}} \frac{k(z)}{k(z) + 1} dz, \quad \text{where } \rho = \frac{\sigma}{\sigma - 1} \omega, \quad k(z) = \frac{\rho^{1-\sigma}}{\eta(z)}. \quad (\text{A25})$$

Partially differentiating (A25) with respect to $\eta(z)$, ω , and \bar{z} yields:

$$\begin{aligned} X_\eta &= -\frac{L^*}{\bar{z} \rho} \int_0^{\bar{z}} \frac{k(z)/\eta(z)}{[k(z) + 1]^2} dz < 0; \\ X_\omega &= -\frac{\sigma}{\sigma - 1} \frac{L^*}{\bar{z} \rho^2} \int_0^{\bar{z}} \frac{[\sigma + k(z)]k(z)}{[k(z) + 1]^2} dz < 0; \\ X_{\bar{z}} &= \frac{L^*}{\bar{z} \rho} \left[\frac{k(\bar{z})}{k(\bar{z}) + 1} - \frac{1}{\bar{z}} \int_0^{\bar{z}} \frac{k(z)}{k(z) + 1} dz \right] < 0. \end{aligned} \quad (\text{A26})$$

To see that $X_{\bar{z}} < 0$, use (A2) to rewrite the integral in (A26) as follows:

$$\int_0^{\bar{z}} \frac{k(z)}{k(z)+1} dz = \bar{z} - \int_0^{\bar{z}} \frac{1}{k(z)+1} dz = \bar{z} - \frac{\bar{z}}{\bar{z}\rho L/L^* + 1} = \bar{z} \left[\frac{\bar{z}\rho L/L^*}{\bar{z}\rho L/L^* + 1} \right]. \quad (\text{A27})$$

Now substitute (A27) into (A26) and simplify to obtain:

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

which is negative since $k(\bar{z}) < \bar{z}\rho L/L^*$ (see (A5)).

PROOF OF PROPOSITION 5:

The total differential of the overall imitation rate with respect to IPRs is given by:

$$\frac{dM(\bar{z})/M(\bar{z})}{dIPR/IPR} = \left[1 + (\alpha + 1) \frac{d\bar{z}/\bar{z}}{d\mu/\mu} \right] \frac{d\mu/\mu}{dIPR/IPR}. \quad (\text{A28})$$

Since $d\mu/dIPR < 0$ and $d\bar{z}/d\mu < 0$, it follows from (A28) that $dM(\bar{z})/dIPR > 0$ if $-(d\bar{z}/\bar{z})/(d\mu/\mu) > 1/(\alpha + 1)$. From Proposition 3, if $\alpha = \alpha^*$ stronger IPRs do not affect ω . In this case, the elasticity of \bar{z} with respect to μ (the horizontal shift of the *EP* schedule) equals $1/(\alpha + 1)$. As a result, $dM(\bar{z})/dIPR = 0$. For any $\alpha > \alpha^*$ stronger IPRs reduce the equilibrium ω , and so \bar{z} expands by more than $1/(\alpha + 1)$. Accordingly, $dM(\bar{z})/dIPR > 0$. For any $\alpha < \alpha^*$ stronger IPRs increase the equilibrium ω , and so \bar{z} expands by less than $1/(\alpha + 1)$. Accordingly, $dM(\bar{z})/dIPR < 0$.