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The Growth Effects of National Patent Policies*

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Abstract

We construct a two-country (innovative North and imitating South) model of product-cycle trade, fully endogenous Schumpeterian growth, and national patent policies. A move towards harmonization based on stronger Southern intellectual property rights (IPR) protection accelerates the long-run global rates of innovation and growth, reduces the North–South wage gap, and has an ambiguous effect on the rate of international technology transfer. Patent harmonization constitutes a suboptimal global-growth policy. However, if the global economy is governed by a common patent policy regime, then stronger global IPR protection: (a) increases the rates of global innovation and growth; (b) accelerates the rate of international technology transfer; and (c) has no impact on the North–South wage gap.

1. Introduction

The intense academic and policy debate, which emerged after the signing of the General Agreement on Trade-related Aspects of Intellectual Property Rights (TRIPs agreement) in the Uruguay Round (1986–94), serves as the primary motivation for the present paper. This agreement calls for all World Trade Organization (WTO) members to adopt a set of minimum standards on intellectual property rights (IPR) that are closer to the ones prevailing in advanced countries. The TRIPs agreement has been opposed by advocates of poor countries who point out that stronger global IPR protection could reduce the rate of technology transfer from advanced to poor countries, and that longer patents could generate income transfers from poor to rich countries.[1] Proponents of the TRIPs agreement argue that stronger IPR protection would stimulate global growth by offering more incentives to innovating firms and by accelerating the rate of international technology transfer through reductions in transaction costs associated with differences in laws and regulations across countries.

The controversy surrounding the TRIPs agreement raises a number of novel research questions: What are the effects of national patent policies on global growth, international technology transfer, and global income distribution? Is unilateral harmonization of patent rights, which requires adoption of Northern standards by Southern countries, beneficial to economic growth? Is harmonization of patent policies between developed and developing countries the optimal global growth policy? Does patent-duration harmonization imply harmonization of patent enforcement policies across countries?

Several earlier models of North–South trade and Schumpeterian (R&D-based) growth have analyzed the dynamic effects of stronger IPR protection (e.g. Segerstrom

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et al., 1990; Helpman, 1993; Lai, 1998; McCalman, 2001; Yang and Maskus, 2001; Glass and Saggi, 2002).[2] However, these models exhibit the counterfactual property of scale effects and therefore abstract from analytical difficulties arising from the presence of market expansion based on population growth. In addition, several recently-developed models of North–South trade and scale-invariant Schumpeterian growth have been employed in the analysis of IPR protection (Sener, 2006; Dinopoulos and Segerstrom, 2007; Dinopoulos et al., 2008). In these models, Southern firms that manage to copy Northern products protect their intellectual property through secrecy or receive a perfectly enforceable global patent of infinite duration. Consequently these models cannot be used to analyze the growth effects of IPR policies that differ across countries in patent duration and the degree of patent enforcement.

The present paper constructs a simple dynamic, general-equilibrium model of scale-invariant, fully endogenous, Schumpeterian (R&D-based) growth and trade to analyze the effects of national patent policies. The modeling of national patent policies follows the lead of Grossman and Lai (2004) and postulates that each region offers a patent of fixed duration which is enforced with an exogenous probability that the invention will not be copied and used by anyone else other than the patent holder. The patent excludes others from using, importing, or selling the claimed invention, i.e. we assume that the Northern government does not allow parallel importing. The present paper complements the analysis of Grossman and Lai (2004) by focusing on the effects of national patent policies and the impact of patent harmonization on long-run growth (including the nature of growth-maximizing patent policies), on the rate of international technology transfer, and on the global wage–income distribution.

As in Dinopoulos et al. (2008), our model combines the deterministic R&D sector in Romer's (1990) model with the preference structure of the quality-ladders growth model developed by Grossman and Helpman (1991, ch. 4). The resulting model generates fully endogenous long-run global growth that depends on Northern and Southern patent lengths, patent-enforcement policies, various labor-productivity parameters, the relative market size of each country, the rate of population growth, and the size of innovations. The presence of fully endogenous scale-invariant growth differentiates our model from earlier endogenous growth models.

Our study differs from other North–South studies of growth and trade in the way the Southern IPR protection is modeled. In previous studies, the effects of stronger IPR protection are captured by a reduction in the productivity of Southern workers engaged in imitative R&D (e.g. Helpman, 1993; Lai, 1998; Dinopoulos et al., 2008). In contrast, the present paper captures the impact of stronger Southern IPR protection via an increase in the duration and/or enforcement of imitative patents offered to Southern firms that manage to copy Northern products via costly imitative R&D. This novel modeling approach to IPR protection is motivated by the existence of the so-called *utility models*, which are patents of short duration that cover claims to adaptive inventions. Utility models have been used effectively by Japan, Brazil, China, and the Philippines among other countries to accelerate the rate of technology adoption.[3]

The analysis produces a number of novel results. A move towards harmonization, which results in stronger Southern protection of patent rights, increases the rates of innovation and growth, reduces the North–South wage gap, and has an ambiguous effect on the rate of international technology transfer. This result represents an optimistic assessment of the TRIPs agreement and is consistent with the evidence in Park and Wagh (2002, Table 3), according to which most countries have been strengthening IPR protection over time. Under harmonization (i.e. a global patent regime with a common enforcement policy and equal-duration patents), stronger IPR protection:

(a) accelerates global Schumpeterian growth; (b) increases the rate of international technology transfer; and (c) has no effects on the global wage–income inequality. We also analyze the nature of growth-maximizing patent-policy regimes. We establish that maximum-growth patent enforcement requires stronger Northern IPR protection compared to Southern IPR protection. Consequently, harmonization of patent policies is neither a necessary nor a sufficient condition for maximum global growth.

The rest of the paper is organized as follows. The next section describes the building blocks of the model. Section 3 derives the steady-state equilibrium. Section 4 analyzes the long-run growth effects of patent harmonization policies and the nature of maximum-growth patent regimes. Section 5 offers some concluding remarks. The Appendix contains the algebraic derivations of the main results and proofs of Propositions 3 and 4. A working paper (Dinopoulos and Kottaridi, 2007) offers a more detailed exposition of the model and further results.

2. The Model

Consumers

The model consists of two regions, innovating North and imitating South. Each country is populated by a fixed measure of identical dynastic families with infinitely-lived members. We use star superscripts to denote functions and variables associated with the South, upper bars to denote world functions and variables, and the absence of superscripts to denote Northern functions and variables. Therefore, let L_0 (L_0^*) be the measure of families residing in North (South); normalize the initial size of each household to unity; and assume that each household's size grows exponentially over time at the rate $g_L > 0$. As a result, Northern population at time t is $L(t) = L_0 e^{g_L t}$, Southern population is $L^*(t) = L_0^* e^{g_L t}$, and world population is $\bar{L}(t) = (L_0 + L_0^*)e^{g_L t} = \bar{L}_0 e^{g_L t}$. Each household member supplies one unit of labor to the market, and therefore the aggregate supply of labor in each region equals its population level.

There is a continuum of industries indexed by $\theta \in [0, 1]$ producing final consumption goods. Higher values of the integer index j denote higher-quality products, and parameter $\lambda > 1$ denotes the size of each innovation. More specifically, the quality level of a product that has experienced j innovations equals λ^j. At time $t = 0$, the quality of all products is $\lambda^0 = 1$ and no firm knows how to manufacture higher-quality products. To learn how to produce higher-quality products, Northern firms engage in innovative R&D investments. When the state-of-the-art quality product in an industry is λ^j, a successful innovator becomes the only producer of a λ^{j+1} quality product.

Households in both the North and the South have identical preferences. Each dynastic family maximizes the discounted utility function:

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

where $\rho > g_L$ is the subjective discount rate of a representative family. The instantaneous utility of a typical household member is defined by

$$\ln u(t) = \int_0^1 \ln\left[\sum_j \lambda^j q(j, \theta, t)\right] d\theta. \tag{2}$$

Variable $q(j, \theta, t)$ is the per capita demand for a product in industry θ that has experienced j innovations at time t. Since the product-quality level λ^j increases in the number of innovations, equation (2) captures each consumer's preference for higher-quality products.

Following the standard practice of Schumpeterian growth models, we solve the consumer maximization problem—see, for instance, Dinopoulos et al. (2008) for more details—derive the consumer demand function:

$$q(\theta, t) = \frac{c(t)}{p(\theta, t)}, \tag{3}$$

and the standard differential equation

$$\frac{\dot{c}(t)}{c(t)} = r(t) - \rho. \tag{4}$$

Variable $p(\theta, t)$ is the price of the state-of-the-art quality product in industry θ, $c(t)$ is per capita consumer expenditure, and $r(t)$ is the market interest rate at time t. Equation (4) implies that, in a steady-state equilibrium with a constant per capita consumption expenditure, the market interest rate must be equal to the constant discount rate (i.e. $r(t) = \rho$).

Product Markets

Northern firms engage in innovative R&D and target industries that produce generic products (whose patents have expired or not enforced and whose production takes place under perfect competition). We assume that a successful Northern innovator in industry θ acquires a patent and becomes a global monopolist for a time period $T > 0$. This firm's patent is enforced with an exogenous instantaneous probability $1 \geq \varepsilon > 0$, as in Grossman and Lai (2004). For expositional simplicity, we suppose that one unit of labor manufactures one unit of output independently of the level of quality and the geographic location of production. Therefore, the marginal (average) manufacturing cost of Northern products is equal to the prevailing Northern wage w. We also postulate that the technology of all products one step below the state-of-the-art quality level in each industry's quality ladder is common knowledge in both the North and the South. This assumption implies that each firm that knows how to produce the state-of-the-art quality product in a particular industry faces competition from a competitive fringe located in the low-wage South. Firms in this fringe produce old products under perfect competition and charge a price equal to the Southern wage w^*.

We assume that firms compete in product markets by choosing prices. Because products are identical when adjusted for quality, competition in prices implies that the producer of a superior quality product maximizes profits by engaging in limit pricing and charging $p = \lambda w^*$. This price forces the firm that produces a good of quality one step below to charge a price equal to its unit cost and to earn zero profits. Consequently, by engaging in limit pricing a successful Northern innovator drives out of the market all potential producers of inferior quality products and earns a flow of expected monopoly profits:

$$\pi(t) = [p - w]\bar{q}\varepsilon = \left[1 - \frac{\omega}{\lambda}\right]\bar{c}\bar{L}(t)\,\varepsilon, \tag{5}$$

where $\omega = w/w^*$ denotes the relative Northern wage expressed in units of Southern labor; and $\bar{q} = \bar{c}\bar{L}(t)/p$ is the global quantity demanded, where $\bar{c} = [cL_0 + c^*L_0^*]/\bar{L}_0$ is the global per capita consumption expenditure. The flow of expected monopoly profits $\pi(t)$ provides incentives for innovative R&D and must be non-negative. A sufficient condition for this requirement is

$$\lambda > \omega = w/w^* > 1, \tag{6}$$

i.e. the relative Northern wage must be greater than unity but less than the size of each quality improvement $\lambda > 1$. Condition (6) suffices to allow Northern innovators to replace potential producers of lower quality products (as will be explained below).

The market value of a Northern patent is given by

$$V(t) = \int_t^{t+T} \pi(\tau) e^{-\rho(\tau-t)} d\tau = \int_0^T \pi(t+s) e^{-\rho s} ds, \tag{7}$$

where $\pi(t)$ is the flow of expected profits given by (5), $\rho = r(t)$ is the steady-state market interest rate, and $s = \tau - t$ is an integration variable. Therefore, the long-run value of an innovation (protected by a Northern patent) at time t can be obtained by substituting (5) into (7) and performing the integration

$$V(t) = \psi(T)\varepsilon\left[1 - \frac{\omega}{\lambda}\right]\bar{c}\bar{L}(t). \tag{8}$$

The first term in the right-hand side of (8) is given by

$$\psi(T) = \frac{1 - e^{-(\rho - g_L)T}}{\rho - g_L} \tag{9}$$

and captures the effects of patent duration T and the effective discount rate $\rho - g_L$ on expected discounted profits. The value of a Northern patent is proportional to the size of the market, measured by the level of population $\bar{L}(t) = \bar{L}_0 e^{g_L t}$. As the latter grows exponentially over time, newly granted Northern patents become more valuable as well. Therefore the aggregate value of Northern patents grows exponentially over time at the rate of population growth.

We model the process of international technology transfer by assuming that Southern firms engage in costly imitative R&D investments to copy Northern products. Consider next the pricing behavior of a successful Southern imitator who holds an imitative patent (utility model) of $T^* > 0$ duration. The patent is enforced with an exogenous instantaneous probability $1 \geq \varepsilon^* > 0$. The enforcement policy is administered by the South and prevents other Southern firms from imitating the patented technology. The assumption of no parallel imports implies that Southern firms target only Northern perfectly competitive industries with expired patents to copy their products. A successful Southern imitator maximizes profits by charging a limit price $p^* = w$, which equals the unit cost of a typical Northern firm. This price drives out of the market all rivals who could produce a product of quality one step below the quality of the copied product because condition (6) implies that $\lambda w^* > p^* = w$. As long as the price charged by a successful Southern imitator is below λw^*, consumers do not purchase inferior-quality goods, even if these products could be sold at lower prices that are equal to unit-production costs.

These considerations imply that a typical Southern imitator enjoys an expected flow of global profits equal to

$$\pi^*(t) = [p^* - w^*]\bar{q}\varepsilon^* = [w - w^*]\frac{\bar{c}\bar{L}(t)}{w}\varepsilon^* = \left[1 - \frac{1}{\omega}\right]\bar{c}\bar{L}(t)\varepsilon^*. \tag{10}$$

The steady-state market value of a Southern patent is given by

$$V^*(t) = \int_t^{t+T} \pi^*(\tau) e^{-\rho(\tau - t)} d\tau = \int_0^T \pi^*(t+s) e^{-\rho s} ds = \psi(T^*)\varepsilon^* \left[1 - \frac{1}{\omega}\right] \bar{c}\bar{L}(t). \qquad (11)$$

The function $\psi(\cdot)$ is defined in (9) and its properties were explained. In the case of imitative patents, $\psi(\cdot)$ is evaluated at the Southern patent length T^*. Condition (6) implies that, in the steady-state equilibrium, a typical Northern generic product (manufactured under perfect competition) commands a higher price than a typical Southern generic product ($p = w > p^* = w^*$).

Innovation and Imitation

Northern firms target industries producing Southern or Northern generic products for further innovation by engaging in innovative R&D. The innovation process is deterministic and follows the lead of Romer (1990) and Jones (1995). Assume that one unit of innovative R&D services requires γ units of labor and denote with R_j firm j's output of R&D services. If firm j employs γR_j researchers to engage in innovative R&D for a time interval dt, that firm discovers $dA_j = R_j dt/D(t)$ patentable designs that allow it to produce a measure of dA_j state-of-the-art quality products. The term $D(t)$ captures the difficulty of conducting innovative R&D and will be defined below. The economy-wide rate of innovation is given by $dA = [Rdt]/D(t)$, where $dA = \Sigma_j dA_j$ is the aggregate flow of Northern patents and $R = \Sigma_j R_j$ is the economy-wide innovative R&D investment.

The removal of scale effects is achieved by assuming that the difficulty of R&D is increasing exponentially over time. Following Dinopoulos et al. (2008), we assume the following specification of R&D difficulty: $D(t) = e^{\phi X(t)}$. As will become clear below, if $X(t)$ is a linear function of time, then this specification of R&D difficulty results in a constant steady-state flow of patents.[4] Substituting $D(t)$ into the expression for dA and dividing both sides by dt yields the aggregate flow of innovations

$$\dot{A}(t) = R(t) e^{-\phi X(t)}, \qquad (12)$$

where $\dot{A}(t) \equiv dA/dt$, and a dot over a variable denotes its time derivative.

We postulate that the evolution of $X(t)$ is governed by

$$\dot{X}(t) = \frac{dX}{dt} = \dot{A}(t) n^{-\beta}, \qquad (13)$$

where n denotes the set—and measure—of Northern industries producing generic products under perfect competition; and $\beta \in [0, \infty)$ is a parameter that governs the strength of "productive" knowledge spillovers.

This specification of R&D difficulty captures in a simple way two novel features of knowledge spillovers. First, it assumes that the difficulty of R&D depends on the measure of competitive industries located in the North but not on the measure of Southern competitive industries. This assumption is consistent with the notion of localized knowledge spillovers and expands the set of parameters that affect long-run scale-invariant growth. Secondly, this specification highlights the inherent asymmetry between industries with active patents and industries with expired patents in regulating the evolution of knowledge spillovers: as the measure of Northern competitive industries increases, the flow of R&D difficulty declines and, as a result, innovative R&D becomes easier. This assumption then embeds the notion that active patents discourage innovation (i.e. they do not provide any useful knowledge spillovers), whereas expired patents generate positive (useful) knowledge spillovers. Note that if $\beta = 1$ in (13), then the R&D difficulty becomes a function of the "average" flow of innovations across all Northern industries producing generic products. If $\beta \to \infty$ or if $n \to 0$, then $\dot{X} \to 0$, and consequently the long-run rates of innovation and growth exhibit scale effects and become unbounded (infinite).

The specification of R&D difficulty adopted here differs from Dinopoulos et al. (2008), where the R&D difficulty is modeled as an increasing function of the measure of Northern industries under active patent protection. This difference has drastic implications for the range of parameters that affect long-run growth. In Dinopoulos et al. (2008) only the duration of patents T affects long-run growth, whereas in the present model virtually all policy-related parameters affect long-run growth.

In quality-ladder growth models, each innovation increases the level of instantaneous utility by a fixed proportion and therefore bounded long-run growth requires that the flow of innovations $\dot{A}(t)$ is constant over time. We will therefore focus on the analysis of a steady-state equilibrium with a constant rate of innovation $A(t) = \dot{A}$. Further insights can be obtained by observing that the measure of Northern industries producing generics $n \in (0, 1)$ is bounded and must be constant over time in the steady-state equilibrium. Therefore, integration of (13) yields

$$X(t) = \int_0^t \dot{A} n^{-\beta} ds = t\dot{A} n^{-\beta}. \tag{14}$$

The last equality in (14) is derived under the assumption that the economy starts at the steady-state equilibrium (otherwise, one has to add an inconsequential constant). In addition, observe that (12) can be written as $\dot{A}(t) = [R(t)/\bar{L}(t)]\bar{L}(t)e^{-\phi X(t)}$, where $R(t)/\bar{L}(t)$ is global per capita R&D. Since the fraction of labor devoted to innovative R&D $\gamma R(t)/\bar{L}(t)$ is bounded, and therefore its steady-state value must be constant over time, the steady-state value of global per capita R&D must be constant over time as well. Consequently, the long-run rate of innovation $\dot{A}(t)$ is constant over time only if the term $\bar{L}(t)e^{-\phi X(t)} = \bar{L}_0 e^{tg_L} e^{-\phi X(t)} = \bar{L}_0 e^{t[g_L - \phi \dot{A} n^{-\beta}]}$ is constant. The above reasoning yields the following two steady-state conditions:

$$\dot{A} = \frac{g_L}{\phi} n^{\beta}, \tag{15}$$

which is derived by setting the term in square brackets equal to zero; and

$$\bar{L}(t)e^{-\phi X(t)} = \bar{L}_0. \tag{16}$$

Southern firms target Northern generic products to copy their technology through R&D investments. The process of imitation is modeled similarly to the process of innovation. We assume that one unit of imitative R&D services requires γ^* units of Southern labor. In addition, we postulate that if a Southern firm hires $\gamma^* R_j^*$ researchers to engage in imitative R&D for an infinitesimal time period dt, that firm manages to copy instantaneously $dA_j^* = [R_j^* dt]/D^*(t)$ Northern designs, where $D^*(t) = e^{\phi X^*(t)}$ is the level of imitative-R&D difficulty at time t. As in the case of innovation, the economy-wide rate of imitation is given by $dA^* = R^* e^{-\phi X^*(t)} dt$, where $dA^* = \Sigma_j dA_j^*$ and $R^* = \Sigma_j R_j^*$ are the aggregate flows of designs copied and imitative R&D services, respectively. Dividing both sides by dt yields the aggregate (economy-wide) imitation rate

$$\dot{A}^*(t) = R^*(t) e^{-\phi X^*(t)}. \tag{17}$$

Suppose that the difficulty of imitative R&D increases in the rate of imitation $\dot{A}^*(t)$ and declines in the measure of Southern industries producing generic products n^* according to

$$\dot{X}^*(t) = \frac{dX^*}{dt} = \dot{A}^*(t)(n^*)^{-\beta^*}. \tag{18}$$

Following the same reasoning as in the case of innovation, one can derive the following expressions for the steady-state level of $X^*(t)$ and the long-run imitation rate $\dot{A}^*(t)$:

$$X^*(t) = \int_0^t \dot{A}^*(n^*)^{-\beta^*} ds = t\dot{A}^*(n^*)^{-\beta^*}, \tag{19}$$

$$\dot{A}^*(t) = \frac{g_L}{\phi}(n^*)^{\beta^*}, \tag{20}$$

where $\beta^* \in [0, \infty)$ is a parameter that determines the degree (intensity) of knowledge spillovers in imitative R&D. Finally, note that one can readily derive the steady-state condition

$$\bar{L}(t)e^{-\phi X^*(t)} = \bar{L}_0. \tag{21}$$

R&D Conditions

We assume that there is free entry in the innovation and imitation markets that drives expected discounted profits of a typical R&D lab down to zero. The following zero-profit conditions are termed as the *innovative-R&D condition*:

$$\psi(T)\varepsilon\left[1-\frac{\omega}{\lambda}\right]\bar{c}\bar{L}_0 = w\gamma, \tag{22}$$

and the *imitative-R&D condition*:

$$\psi(T^*)\varepsilon^*\left[1-\frac{1}{\omega}\right]\bar{c}\bar{L}_0 = w^*\gamma^*. \tag{23}$$

Each R&D condition sets the value of the marginal product of R&D labor equal to its marginal cost.[5]

Labor Markets

Following the standard practice in Schumpeterian growth theory, we assume that workers can move instantaneously between manufacturing of final goods and R&D investment under flexible wages. Therefore, the demand for labor in each region equals its supply at each instant in time. Equalizing the supply of Northern labor to its demand yields the *Northern full-employment condition*:

$$L(t) = \gamma\dot{A}e^{\phi X(t)} + \frac{s\bar{c}\bar{L}(t)}{\lambda w^*} + \frac{n\bar{c}\bar{L}(t)}{w}. \tag{24}$$

The left-hand side of (24) is the supply of Northern labor at time t, whereas the three terms in the right-hand side of (24) correspond to the demand for labor devoted to

R&D, manufacturing of products with non-expired Northern patents, and manufacturing of products with expired Northern patents (generics), respectively.[6]

Similar considerations apply to the Southern labor market. Setting the Southern supply of labor equal to its demand yields the *Southern full-employment condition*:

$$L^*(t) = \gamma^* \dot{A}^* e^{\phi X^*(t)} + \frac{s^* \bar{c}\bar{L}(t)}{w} + \frac{n^* \bar{c}\bar{L}(t)}{w^*}. \tag{25}$$

The left-hand side of (25) is the supply of Southern labor at time t, whereas the three terms in the right-hand side of (25) correspond to the demand for labor devoted to R&D, manufacturing of products with non-expired Southern patents, and manufacturing of products with expired Southern patents, respectively. This completes the description of the model.

3. Steady-state Equilibrium

We focus on the steady-state equilibrium in which each endogenous variable is growing at a constant rate over time. Let Southern labor serve as the model's numéraire (i.e. let $w^* = 1$) and therefore let $w = \omega > 1$ denote the North–South wage gap.

We start the steady-state analysis with the derivation of an explicit solution for the North–South wage gap. This is achieved by combining the innovative and imitative R&D conditions, (22) and (23), respectively, to obtain

$$\hat{\omega} = \frac{\dfrac{\gamma}{\gamma^*} + \dfrac{\varepsilon\psi(T)}{\varepsilon^*\psi(T^*)}}{\dfrac{\gamma}{\gamma^*} + \dfrac{\varepsilon\psi(T)}{\varepsilon^*\psi(T^*)\lambda}} = \frac{\Gamma + \Phi}{\Gamma + \Phi\lambda^{-1}} > 1, \tag{26}$$

where a hat over a variable denotes its steady-state equilibrium value. Parameter $\Gamma = \gamma/\gamma^*$ is the ratio of unit–labor requirements in innovative and imitative R&D, and parameter $\Phi > 0$ captures North's patent policy relative to that of the South:

$$\Phi = \frac{\varepsilon\psi(T)}{\varepsilon^*\psi(T^*)} = \frac{\varepsilon[1 - e^{-(\rho - g_L)T}]}{\varepsilon^*[1 - e^{-(\rho - g_L)T^*}]}. \tag{27}$$

Equation (26) satisfies condition (6) for all values of the model's parameters, i.e. the steady-state relative wage is always less than the size of quality increments ($\lambda > \hat{\omega} > 1$). Observe also that in the absence of incentives to innovate ($\lambda = 1$ or $T = 0$) the right-hand side of equation (26) is equal to unity. In other words, the North enjoys a higher wage than the South because of its ability to continually discover new higher-quality products.

The consumer's utility function $u(t)$ defined in (2) constitutes the appropriate index of each consumer's quality-adjusted consumption bundle. Following Dinopoulos et al. (2008) and using (15), one can derive the following expression for long-run scale-invariant Schumpeterian growth:

$$g_u = \frac{\dot{u}(t)}{u(t)} = [\ln\lambda]\dot{A} = [\ln\lambda]\frac{g_L}{\phi}n^{\beta}. \tag{28}$$

In addition, the Appendix derives the following equations that determine the steady-state measures of Northern and Southern competitive industries $\hat{n}$ and $\hat{n}^*$:

$$L_0 = \frac{g_L}{\phi}\left[\gamma + \frac{\varepsilon T}{(\lambda - 1)}\left(\frac{\gamma}{\varepsilon\psi(T)} + \frac{\gamma^*}{\varepsilon^*\psi(T^*)}\right)\right]\hat{n}^{\beta} + \frac{1}{(\lambda - 1)}\left(\frac{\lambda\gamma}{\varepsilon\psi(T)} + \frac{\gamma^*}{\varepsilon^*\psi(T^*)}\right)\hat{n}, \tag{29}$$

$$L_0^* = \frac{g_L}{\phi}\left[\gamma^* + \frac{\varepsilon^* T^*}{(\lambda - 1)}\left(\frac{\lambda\gamma}{\varepsilon\psi(T)} + \frac{\gamma^*}{\varepsilon^*\psi(T^*)}\right)\right](\hat{n}^*)^{\beta^*} + \frac{\lambda}{(\lambda - 1)}\left(\frac{\gamma}{\varepsilon\psi(T)} + \frac{\gamma^*}{\varepsilon^*\psi(T^*)}\right)\hat{n}^*. \tag{30}$$

Equations (28) and (29) determine the long-run properties of global Schumpeterian growth g_u, and equations (20) and (30) pin down the long-run determinants of the imitation rate $\dot{A}^*(t)$. The right-hand sides of (29) and (30) are increasing functions of $\hat{n}$ and $\hat{n}^*$, respectively, starting at zero. Therefore, for sufficiently low values of L_0 and L_0^*, the model has a unique steady-state equilibrium where $\hat{n} \in (0, 1)$ and $\hat{n}^* \in (0, 1)$. The following proposition summarizes the results of our analysis.

PROPOSITION 1. *There exists a steady-state equilibrium which is unique and generates bounded scale-invariant, endogenous global rates of innovation $\dot{A}$, imitation $\dot{A}^*$, and Schumpeterian growth g_u. The steady-state equilibrium exhibits an endogenous wage gap $\hat{\omega}$ and product-cycle trade.*

4. Patent Policy Regimes

Parameters β and β^* capture the degree (intensity) of asymmetric knowledge spillovers that generate endogenous long-run rates of innovation, imitation, and growth. Inspection of equations (29) and (30) reveals that one can obtain an explicit solution for n and n^* without sacrificing the policy effects on long-run growth by setting $\beta = \beta^* = 1$. In this case, the rate of R&D difficulty depends on the flow of patents per competitive industry; and equations (14) and (18) become $X(t) = t\dot{A}/n$ and $X^*(t) = t\dot{A}^*/n^*$, respectively. This parameter restriction is similar in spirit to the assumption adopted by human-capital-based models of endogenous growth, where knowledge externalities depend on the average (as opposed to aggregate) level of human capital (e.g. Lucas, 1988).

The rest of the paper adopts this parametric restriction which simplifies the algebra and enhances the intuition of the results. Solving (29) for n and substituting the resulting expression in (28) yields an explicit solution for long-run Schumpeterian growth:

$$g_u = \frac{L_0 \ln\lambda}{\gamma + \frac{\varepsilon T}{(\lambda - 1)}\left(\frac{\gamma}{\varepsilon\psi(T)} + \frac{\gamma^*}{\varepsilon^*\psi(T^*)}\right) + \frac{\phi}{g_L(\lambda - 1)}\left(\frac{\lambda\gamma}{\varepsilon\psi(T)} + \frac{\gamma^*}{\varepsilon^*\psi(T^*)}\right)}. \tag{31}$$

Similarly, solving (30) for n^* and substituting into (20) generates an explicit solution for the rate of international technology transfer:

$$\dot{A}^* = \frac{L_0^*}{\gamma^* + \frac{\varepsilon^* T^*}{(\lambda - 1)}\left(\frac{\lambda\gamma}{\varepsilon\psi(T)} + \frac{\gamma^*}{\varepsilon^*\psi(T^*)}\right) + \frac{\phi}{g_L}\frac{\lambda}{(\lambda - 1)}\left(\frac{\gamma}{\varepsilon\psi(T)} + \frac{\gamma^*}{\varepsilon^*\psi(T^*)}\right)}. \tag{32}$$

Equations (31), (32), and (26) will be used in the rest of the paper to analyze the effects of patent policies.

Patent Harmonization

The effects of unilateral harmonization can be analyzed by inspecting equations (31), (32), and (26). The following proposition summarizes these results:

PROPOSITION 2. *Starting at a steady-state equilibrium where innovating North has stronger IPR protection than imitating South ($T > T^*$ and $\varepsilon > \varepsilon^*$), unilateral harmonization of patent policies that raises T^* and ε^*: (a) accelerates the rate of global Schumpeterian growth g_u; (b) improves the global wage–income inequality by reducing the relative wage $\hat{\omega}$; and (c) generates an ambiguous change in the rate of international technology transfer $\dot{A}^*$.*

Within the context of the present model, unilateral harmonization, which brings Southern patent policies closer to Northern ones, increases global growth and reduces the North–South wage gap. Consequently, because the TRIPs agreement calls for the adoption of longer and stricter enforcement of patents by Southern countries, it raises long-run growth. This prediction is consistent with the empirical results reported in Gould and Gruben (1996), who found that stronger IPR protection is significantly correlated with higher economic growth in a sample of 95 countries.

We continue by analyzing the effects of IPR protection in a global economy under a TRIPs regime (i.e. a global economy that has adopted a common global patent policy $\overline{T}$ and $\overline{\varepsilon}$). The following proposition summarizes these effects:

PROPOSITION 3. *If the global economy is governed by a common patent-policy regime ($\overline{T} = T = T^*$ and $\overline{\varepsilon} = \varepsilon = \varepsilon^*$), then: (a) the global wage–income distribution is invariant to changes in the common patent policy; (b) stronger common patent enforcement $\overline{\varepsilon}$ increases long-run growth and the rate of international technology transfer; and (c) an increase in the duration of global patents $\overline{T}$ has an ambiguous effect on long-run growth and the rate of international technology transfer.*

Part (b) of Proposition 3 implies that, under a common patent policy, the rate of global Schumpeterian growth is maximized when both the North and South offer perfect (maximum) patent enforcement ($\overline{\varepsilon} = 1$).

Endogenous Patent Regimes

One argument in favor of patent harmonization focuses on the presence of uncertainty and transaction costs. A global regime with differences in laws and regulations across countries raises the transaction costs on trade and technology transfer. Under a common global standard of IPR protection, firms would face less uncertainty and lower international business transaction costs. Proposition 3 states that a move towards patent harmonization that generates stronger IPR protection accelerates the long-run rate of global economic growth. However, is patent harmonization the best (as opposed to a better) global growth-maximizing policy? What are the effects of patent-length harmonization on the patent enforcement levels?

We address these questions by allowing countries to choose their patent enforcement policies for any given patent lengths. Although one can treat the duration of patents as choice variable as well, we do not pursue this avenue of analysis. International agreements have reduced considerably the dispersion of patent duration across countries by establishing common patent-duration standards (20 years from the date of patent application or 17 years from the date a patent is granted). According to Park and Wagh (2002, Table 2), patent duration has become rather uniform across countries, especially since the year 2000. Moreover, the solution to the non-cooperative game, where each government chooses two policy instruments, consists of a rather complex and intractable system of four equations in four unknowns. In addition, one could argue that governments have more flexibility in choosing their patent enforcement policies than the duration of their patents since the former are multidimensional in nature and usually involve the degree of patent coverage, membership in various international treaties, litigation of patent disputes (including preliminary injunctions and burden-of-proof reversals), extent of compulsory licensing, and other patenting restrictions. Ideally, one would like to make endogenous the degree of patent enforcement by introducing welfare considerations into the model, following the work of Grossman and Lai (2004). However, the presence of complex transitional dynamics makes this task intractable as well.

Here we propose an alternative way to make the degree of patent enforcement endogenous. We analyze a non-cooperative game between North and South in which the North chooses ε to maximize the long-run rate of innovation $\dot{A}$, and the South chooses ε^* to maximize the long-run rate of imitation $\dot{A}^*$. In doing so, each government takes the patent policy of the other country as given and treats even its own patent duration as an exogenous parameter. Because long-run growth is proportional to the rate of innovation (see equation (28)), the solution to the non-cooperative game can be interpreted as a "golden" rule which maximizes long-run Schumpeterian growth. The Appendix derives the solutions to the non-cooperative policy game between the innovating North and imitating South, and proves the following proposition:

Proposition 4. *Assume that the two countries engage in a non-cooperative policy game in which the North chooses the level of patent enforcement to maximize the rate of innovation (and global growth) and the South chooses the level of patent enforcement to maximize the rate of imitation. Then: (a) the level of growth-maximizing patent enforcement increases in the size of innovation and decreases in the country's patent duration; (b) harmonization of patent-enforcement policies is neither a necessary nor sufficient condition for maximum global growth; and (c) the North chooses stronger IPR protection than the South.*

The result that harmonization of patent policies does not maximize long-run growth is similar in spirit to the result obtained by Grossman and Lai (2004), who established that patent policy harmonization is not a welfare- (as opposed to growth-) maximizing policy. Of course, the reader must be aware that the present model does not take into account the beneficial effects of patent harmonization on uncertainty and transaction costs, and therefore these results must be interpreted with caution.

5. Concluding Remarks

This paper developed a two-country (innovative North and imitating South) general-equilibrium model of product-cycle trade, Schumpeterian (R&D-based) growth, and national patent policies. The model's unique steady-state equilibrium exhibits scale-invariant, fully endogenous, long-run Schumpeterian growth; product-cycle trade; endogenous rate of international technology transfer; and an endogenous wage gap captured by the relative Northern wage. We used the model to study the effects of patent policies on long-run growth, the rate of international technology transfer and global wage–income inequality.

The analysis generated several novel results. The model removes the scale-effects property by postulating that only industries with expired patents provide useful knowledge spillovers that enhance the discovery of new higher-quality products. This novel mechanism generates fully endogenous long-run growth. A unilateral move towards harmonization of patent policies (i.e. an increase in the strength of Southern IPR protection) improves the global wage–income distribution, accelerates long-run growth and generates an ambiguous effect on the rate of international technology transfer. A move towards harmonization of patent policies is beneficial to long-run growth and income distribution. However, long-run growth can be higher if each country chooses the level of patent enforcement optimally. In this case, the North has an incentive to choose stronger IPR protection than the South. Finally, if one considers a world economy with harmonized patent policies (e.g. a common patent length and a common level of patent enforcement), then: (a) stronger global patent-enforcement increases long-run global growth; (b) accelerates the rate of international technology transfer; and (c) does not affect the North–South wage gap.

Finally, we would like to state a few caveats and extensions for future research. Feasibility considerations do not permit us to analyze the model's transitional dynamics. The presence of unexplored transitional dynamics renders the welfare analysis of patent policies intractable as well. Transitional dynamics, welfare analysis, and simulation exercises are beyond the limited scope of the present paper and constitute fruitful avenues for further research. Other possible extensions are the introduction of uncertainty in the R&D process, international technology transfer via the formation of multinational firms, and incomplete labor mobility between the manufacturing and R&D activities.

Appendix

Derivation of Equations (29) and (30)

The law of large numbers implies that the steady-state measure of industries with active innovative patents is given by $s = \int_0^{\varepsilon T} \dot{A} dt = \varepsilon T \dot{A}$ and the steady-state measure of industries with active imitative patents is given by $s^* = \int_0^{\varepsilon^* T^*} \dot{A}^* dt = \varepsilon^* T^* \dot{A}^*$. Substituting (26) and the definitions of Φ and Γ into the imitative-R&D condition (23) yields:

$$\bar{c} = \frac{\lambda\left(\dfrac{\gamma^*}{\varepsilon^*\psi(T^*)} + \dfrac{\gamma}{\varepsilon\psi(T)}\right)}{L_0(\lambda - 1)}. \tag{A1}$$

Substituting (26) and the definitions of Φ and Γ into the innovative-R&D condition (22) yields:

$$\frac{\bar{c}}{\omega} = \frac{\dfrac{\lambda\gamma}{\varepsilon\psi(T)} + \dfrac{\gamma^*}{\varepsilon^*\psi(T^*)}}{\bar{L}_0(\lambda - 1)}. \tag{A2}$$

Dividing (24) by the level of global population $\bar{L}(t) = \bar{L}_0 e^{g_L t}$ and using (15), (16), and $s = \varepsilon T \dot{A}$ yields:

$$\frac{L_0}{\bar{L}_0} = \frac{\gamma g_L n^{\beta}}{\phi \bar{L}_0} + \frac{\varepsilon T g_L n^{\beta} \bar{c}}{\phi \lambda} + n\frac{\bar{c}}{\omega}. \tag{A3}$$

Similarly, dividing (25) by $\bar{L}(t) = \bar{L}_0 e^{g_L t}$ and using (20), (21), and $s^* = \varepsilon^* T^* \dot{A}^*$ yields:

$$\frac{L_0^*}{\bar{L}_0} = \frac{\gamma^* g_L (n^*)^{\beta}}{\phi \bar{L}_0} + \frac{\varepsilon^* T^* g_L (n^*)^{\beta}}{\phi}\frac{\bar{c}}{\omega} + n^* \bar{c}. \tag{A4}$$

Substituting (A1) and (A2) into (A3) yields equation (29) in the main text which determines the steady-state measure of Northern competitive industries $\hat{n}$. Substituting (A1) and (A2) into (A4) yields equation (30) in the main text that determines the steady-state measure of Southern competitive industries $\hat{n}^*$.

Proof of Proposition 3

If $\bar{T} = T = T^*$ and $\bar{\varepsilon} = \varepsilon = \varepsilon^*$, then it is obvious from (26) and (27) that the wage gap becomes $\hat{\omega} = (\gamma + \gamma^*)/(\gamma + \gamma^* \lambda^{-1}) > 1$ and is independent of the common patent policy. Using $\bar{T}$ and $\bar{\varepsilon}$ to denote the harmonized patent regime, equations (31) and (32) can be written as:

$$g_u = \frac{L_0 \ln \lambda}{\gamma + \frac{\bar{T}}{\psi(\bar{T})(\lambda - 1)}(\gamma + \gamma^*) + \frac{\phi}{g_L \bar{\varepsilon} \psi(\bar{T})(\lambda - 1)}(\lambda\gamma + \gamma^*)}, \tag{A5}$$

$$\dot{A}^* = \frac{L_0^*}{\gamma^* + \frac{\bar{T}}{\psi(\bar{T})(\lambda - 1)}(\lambda\gamma + \gamma^*) + \frac{\phi}{g_L}\frac{\lambda}{\bar{\varepsilon}\psi(\bar{T})(\lambda - 1)}(\gamma + \gamma^*)}. \tag{A6}$$

These two equations determine the effects of the model's parameters under a common patent-policy regime: an increase in the common patent length $\bar{T}$ has an ambiguous effect on term $\bar{T}/\psi(\bar{T})$, long-run growth, and the rate of imitation. However, an increase in the degree of common patent enforcement policy $\bar{\varepsilon}$ increases both the long-run global growth rate and the rate of imitation. □

Proof of Proposition 4

Equations (31) and (32) constitute the objective functions of North and South, respectively. It is straightforward to establish by differentiation that the second-order conditions for the maximization problem are satisfied. Maximizing (31) with respect to ε yields the Northern reaction function

$$\varepsilon^2 = \left(\frac{\phi}{g_L}\frac{\gamma}{\gamma^*}\frac{\lambda}{T}\frac{\psi(T^*)}{\psi(T)}\right)\varepsilon^*.$$

Similarly, maximizing (32) with respect to ε^* yields the Southern reaction function

$$(\varepsilon^*)^2 = \left(\frac{\phi}{g_L}\frac{\gamma^*}{\gamma}\frac{\psi(T)}{\psi(T^*)\lambda}\right)\varepsilon.$$

Using these two reaction functions one can obtain the closed-form solutions:

$$\hat{\varepsilon} = \lambda^{2/3} \frac{\phi}{g_L} \left(\frac{\gamma}{\gamma^*} \right)^{1/3} \left(\frac{\psi(T^*)}{\psi(T)} \right)^{1/3} \frac{1}{(T)^{2/3} (T^*)^{1/3}}, \tag{A7}$$

$$\hat{\varepsilon}^* = \lambda^{1/3} \frac{\phi}{g_L} \left(\frac{\gamma^*}{\gamma} \right)^{1/3} \left(\frac{\psi(T)}{\psi(T^*)} \right)^{1/3} \frac{1}{(T^*)^{2/3} (T)^{1/3}}. \tag{A8}$$

Inspection of equations (A7) and (A8) establishes part (a) of Proposition 4. To establish parts (b) and (c) divide (A7) by (A8) to obtain

$$\frac{T^{1/3} [\psi(T)]^{2/3} \hat{\varepsilon}}{(T^*)^{1/3} [\psi(T^*)]^{2/3} \hat{\varepsilon}^*} = \lambda^{1/3} \left(\frac{\gamma}{\gamma^*} \right)^{2/3} > 1. \tag{A9}$$

The assumption that the size of each quality increment is greater than unity ($\lambda > 1$), which is required for profitable innovation, and the standard assumption that innovation is more difficult than imitation ($\gamma > \gamma^*$) imply that the level of enforcement chosen by the North is greater than that chosen by the South. These two assumptions imply that maximum-growth patent enforcement requires greater protection of IPR in innovative advanced countries compared to protection offered by less-advanced imitative countries. In other words, harmonization of patent policies does not maximize long-run global Schumpeterian growth. □

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Notes

1. McCalman (2001) estimates the implied income transfers caused by TRIPs-ridden patent harmonization. According to his analysis, these cross-country income transfers benefit the US, Germany, France, Italy, Sweden, and Switzerland. All other countries, including poor countries, experience a net loss from adopting tighter IPR protection.
2. Schumpeterian growth is a particular type of economic growth which is generated through the endogenous introduction of new products and/or processes according to Schumpeter's (1942) description of endogenous technological progress. The scale effects property implies that more resources devoted to R&D generate higher total factor productivity growth. In these models, the presence of positive population growth leads to unbounded (infinite) steady-state growth. See Jones (1999) and Dinopoulos and Sener (2007) for overviews of the literature on scale-invariant Schumpeterian growth models.
3. Maskus and McDaniel (1999) found that utility models were the primary channel of technology diffusion and technological progress for Japan over the period 1960–93. In addition, according to La Croix and Konan (2002, Table 1), there has been a rapid growth in the number of patents granted to Chinese residents by China's Patent Office, from 111 in 1985 to 61,378 in 1998. A large fraction of these patents aim at protecting acquired technological innovations and can be classified as imitative patents.
4. A constant flow of patents is a steady-state property which is shared by the quality-ladder growth model (see, for instance, Segerstrom, 1998).
5. We derive these conditions as follows. A Northern firm that hires γR_j researchers to conduct innovating R&D for a time interval dt incurs a cost equal to $w\gamma R_j dt$. This firm discovers with certainty $dA_j = R_j e^{-\phi X(t)} dt$ patentable designs which can be used to manufacture new higher-quality products. The market value of this discovery is $V(t)dA_j = V(t)[R_j e^{-\phi X(t)} dt]$, where $V(t)$ is the market value of a typical patent defined in (8). The net benefit of innovating R&D is $[V(t)e^{-\phi X(t)} - w\gamma]R_j dt$, and free entry with positive R&D investment $R_j > 0$ requires that the term in square brackets must be equal to zero. Substituting $V(t)$ from (8) and using (16) generates (22) in the main text. Similar considerations apply to imitative R&D. A Southern R&D firm can hire $\gamma^* R_j^*$ researchers for a period dt and copy with certainty $dA_j^* = R_j^* e^{-\phi X^*(t)} dt$ state-of-the-art Northern generic products. The net benefits of this action are $[V^*(t)e^{-\phi X^*(t)} - w^*\gamma^*]R_j^* dt$. Free

entry into the activity with $R_j^* > 0$ requires that the term in square brackets is zero. Substituting the value of $V^*(t)$ from (11) and using (21) yields (23) in the main text.

6. The Northern supply of labor is $L(t) = L_0 e^{g_L t}$. The demand for workers engaged in innovative R&D is $\gamma R(t)$ where $R(t) = \dot{A} e^{\phi X(t)}$ from (12). Each Northern monopolist manufactures $q_m = \bar{c}\bar{L}(t)/p_m$ units of output, demands an equal amount of labor, and charges the limit price $p_m = \lambda w^*$. Consequently, the aggregate demand for manufacturing labor in the sector with active patents is $s\bar{c}\bar{L}(t)/\lambda w^*$, where s is the measure of the set of Northern industries producing goods with active patents. The demand for each Northern generic product is $q_c = \bar{c}\bar{L}(t)/p_c$, where $p_c = w$. The economy-wide demand for labor in Northern generic products is given by $n\bar{c}\bar{L}(t)/w$, where n is the measure of Northern competitive industries. Setting the labor demand equal to its supply yields the Northern full-employment condition (24) in the main text. Similar calculations generate the Southern full-employment condition (25).