

Patent Protection and Global Schumpeterian Growth*

by

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Abstract: The paper develops a dynamic model of scale-invariant global Schumpeterian (R&D-based) growth, North-South trade, and international patent protection. Intellectual property protection takes the form of finite-length and perfectly enforceable global patents awarded to Northern firms that discover new higher-quality products. The model generates product-cycle trade, endogenous long-run Schumpeterian growth, and an endogenous wage gap between Northern and Southern workers. An increase in the global patent length worsens the wage-income inequality between North and South, increases the rate of product imitation and has an ambiguous effect on long-run Schumpeterian growth. If the initial measure of industries protected by patents is sufficiently high, then a rise in the global patent length reduces the long-run rate of global innovation and growth. Globalization that takes the form of an expansion in the size of the South increases the rate of imitation, does not affect the long-run rate of innovation and growth, and worsens the wage-income distribution between Northern and Southern workers.

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1. Introduction

Arguably, patent protection of intellectual property rights has acquired the same importance in the “new” knowledge-based global economy as the tariff had in the “old” materials-based global economy. Since patent regimes regulate the creation and international transfer of new products and processes, changes in patent protection can have profound effects on global economic efficiency and income distribution between innovating advanced countries (the “North”) and imitating developing countries (the “South”).

The economic effects of global patent protection are elusive and difficult to explore for a number of reasons. First, changes in global patent protection generate *income-transfer* effects. The vast majority of new products are discovered by firms in the North and copied by firms in the South. Since patents discourage imitation of new technologies and thereby provide temporary monopoly power to inventors, higher patent protection results in short-run income transfers from Southern consumers to Northern firms.¹ Second, patent-regime changes affect the *knowledge-spillover process* within and between countries. For example, although it is possible technologies with expired patents to generate information that enhances the discovery of new inventions, the threat of litigation against possible patent infringement may limit the usefulness of technical information on patented products aimed at the discovery of new products. In addition, changes in patent protection may in principle induce firms to switch to, or from, other mechanisms that provide intellectual property protection (such as trade secrecy). Third, changes in patent protection generate *resource-reallocation* effects. By changing the length of temporary monopoly power, patent protection affects the allocation of economic resources between manufacturing of new products and R&D investment. An increase in patent length, for instance, could reduce the amount of R&D investment and the rate of innovation by transferring resources from R&D investment to manufacturing of patented products. For these reasons, it is difficult to evaluate the effects of patent protection without considering formal dynamic economic models.

It is not surprising then that the signing of the General Agreement on Trade-Related Aspects of Intellectual Property Rights (the TRIPs Agreement) in the Uruguay Round – which calls for all World Trade Organization (WTO) members to adopt a set of global minimum (Northern) standards on intellectual property rights protection – has been met with skepticism by prominent economists.²

¹ The opposite is true as well. Baldwin (1988) reports that U.S. firms lose about \$8 billion annually from international patent and copyright infringements.

² Maskus (2000), among others, details the factors affecting intellectual property protection and the TRIPS agreement. Bhagwati (2004) argues that the TRIPS agreement is a prime example of regulatory capture of WTO by Northern multinationals. He expresses his opposition to it as follows:

What is surprising is the relative scarcity of formal economic analyses of the role of patent protection on global growth and poverty. Several new studies have built dynamic growth models to analyze the determinants of international technology diffusion (Eaton and Kortum, (1996, 1999)), the effects of globalization on growth and global income distribution (Dinopoulos and Segerstrom (2004), Sener (2002), Segerstrom et al. (1990), Grossman and Helpman (1991)), the effects of patent policy on welfare (Iwaisako and Futagami (2003)), and the welfare effects of differential intellectual property protection between countries (Grossman and Lai (2004)). However, by assuming that the world population level remains constant over time, these studies either did not explicitly incorporate the role of finite-length patents into the analysis, or they have abstracted from the scale-effects problem.³

This paper develops a North-South model of Schumpeterian (R&D-based) growth and finite-length global patent protection. Schumpeterian growth is a particular type of growth that is generated by the endogenous introduction of new products and/or processes and is based on the process of creative destruction (Schumpeter (1942)). The model generates product-cycle trade, endogenous international technology transfer, and a North-South wage gap. Northern firms develop higher-quality final-consumption products by devoting labor into R&D activities. Each new product is protected by an international and perfectly enforceable patent of finite time duration $T > 0$. When a patent expires, the product becomes generic and all firms in the North know how to produce it. As a result, at each instant in time, a fraction of Northern industries produces generic products under conditions of pure competition, obtaining zero economic profits. Southern firms target Northern generic products to appropriate their technology and transfer the location of production in the South. In addition, Northern firms target industries without patent protection that produce generic products, either in the South or the North, to discover higher-quality products that would replace the production

“Clearly the rules sought by the pharmaceutical industries are unnecessarily harmful to poor countries. In particular, (1) TRIPs should not be in the WTO at all, (2) twenty-year patents at the WTO are excessive, and (3) access to generic drugs produced in developing countries, such as India and Brazil, that have manufacturing capacity should be freed for the poor countries, such as Botswana, that do not have such capacities but have medical emergencies such as AIDS, as certified by the World Health Organization, for example” (pp. 183-185).

In the same spirit, Stiglitz (2003) also highlights the importance of intellectual property rights and knowledge spillovers by echoing similar concerns:

“No one denies the importance of intellectual property rights. But these rights need to balance out the rights and interests of producers with those of users – not only users in developing countries but producers in developed countries ... after all, knowledge is the most important input into research, and stronger intellectual property rights might actually increase the price of this input” (p. 245).

³ Grossman and Helpman (1991), Grossman and Lai (2004) and Segerstrom et al. (1990) develop endogenous growth models with scale effects. Jones (1999), and Dinopoulos and Sener (2004) provide more details of the issues related to the scale-effects property of earlier endogenous growth models.

of generic ones. Within the context of the present model, the assumption of international patent enforcement is convenient but not necessary. If the market size of the North is at least as large as the market size of the South, and the North adopts a policy that prohibits the importation of Southern generic products in industries with active patents, then Southern firms will not have an incentive to imitate Northern products protected by patents. As a result, unilateral enforcement of Northern patents establishes an effective global patent independently of the Southern patent regime. For this reason, the present model is not appropriate for analyzing whether or not intellectual property protection must be part of global trade negotiations.

The model highlights the role of patents in governing the evolution of knowledge spillovers across industries protected by patents and those industries whose patents have expired. By introducing a parameter that assigns different weights to these two types of industries, the model generates endogenous long-run scale-invariant Schumpeterian growth. The long-run rate of innovation and per capita growth is proportional to the exogenous rate of population growth (as in models developed by Jones (1995), Kortum (1997), and Segerstrom (1998)); however, per capita growth also depends on the length of global patents. The dependence of long-run growth on patent length, which is a novel result, is governed by the structure of knowledge spillovers (Proposition 1). If knowledge spillovers that affect the evolution of R&D difficulty are symmetric between products with active patents and products with expired patents, then changes in patent protection do not affect the rate of long-run growth. However, if knowledge spillovers from industries with patents differ from those of industries without patents, then patent protection affects long-run growth.

In addition to the long-run growth effects, patent protection has a permanent impact on the rate of imitation and on global income distribution measures by the North-South wage gap (Proposition 3). An increase in the patent length raises permanently the rate of imitation. The effect of patent length on the North-South wage gap can be positive or negative depending on the initial measure of Northern industries under patent protection relative to the parameter measuring the degree of asymmetric knowledge spillovers. In Proposition 3 we show that, if the initial fraction of Northern industries with patents is sufficiently high (say, if more than one half of the high-tech industries enjoy patent protection), then an increase in the global patent length affects adversely the degree of global inequality by raising the relative wage of Northern workers. Such parameter values are also consistent not only with the notion that stricter intellectual property protection (measured by an increase in the length of patents) reduces the long-run global rate of innovation and growth and worsens the global income distribution (Proposition 1).

The model also permits an analysis of the dynamic effects of globalization. Motivated by the entrance of China in the world trading system since 1978, and following Dinopoulos and Segerstrom

(2004), we analyze the effects of one dimension of globalization, namely the geographic expansion of the world trading system. This dimension of globalization can be captured in the model by analyzing the effects of an increase in the size of the South, measured by the level of its population. Proposition 2 of the paper shows that a permanent expansion of the size of the South worsens the long-run wage-income distribution between North and South – by permanently raising the wage of Northern workers relative to the wage of Southern workers – and increases the rate of technology transfer from North to South without affecting the long-run rate of global innovation and growth. This result differs from the one obtained by Dinopoulos and Segerstrom (2004) where globalization just reduces the North-South wage gap.

The next section of the paper describes the basic elements of the model. Section 3 establishes the uniqueness of the steady-state equilibrium and derives explicit solutions for the endogenous variables. Section 4 uses the equations derived in Section 3 to analyze the steady-state properties of the model and to describe the basic findings. Lastly, Section 5 summarizes the conclusions and provides several suggestions for future research.

2. The Model

This paper develops a North-South model of scale-invariant, endogenous, steady-state Schumpeterian (R&D-based) growth. Specifically, we generalize the North-South model of endogenous growth developed by Segerstrom et al. (1990) by adding an endogenous resource-using imitation process and by introducing positive global population growth. The model uses the deterministic R&D technology introduced in the seminal work of Romer (1990) in a context of a quality-ladders model of Schumpeterian growth. The use of a deterministic R&D production process simplifies the analysis and differentiates the model from other quality-ladder growth models which view the discovery process as sequential and stochastic R&D races. We remove the scale-effects property by assuming that R&D becomes more difficult over time as in Jones' (1995) version of Romer's (1990) model. However, unlike Jones' model, we assume that the rate by which R&D difficulty increases over time depends only on the flow of patent creation. This assumption is consistent with the notion that patents not only exclude imitation, but also reduce the degree of knowledge spillovers that might be used in the discovery of other products.⁴ This structural asymmetry across

⁴ The literature on the economics of patents provides many examples which support this assumption. For instance, companies develop patent fences around a basic invention which prevent other firms from discovering similar products; and the threat of litigation on possible patent infringements by patent holders prevents challengers from exploiting fully possible knowledge spillovers associated with accessibility of the information contained in patent applications. Levin et al. (1987) provide ample evidence based on a survey of U.S. manufacturing firms and many examples supporting a variety of mechanisms including patents that are used by firms to protect their intellectual property.

industries suffices to generate endogenous long-run Schumpeterian growth which depends on the patent length.

The model differs from the closed-economy model of Dinopoulos and Syropoulos (2001) in both the mechanism that generates endogenous growth and the questions analyzed. It complements a few recently developed growth models of North-South trade and growth by Dinopoulos and Segerstrom (2004) and Sener (2004) and the North-North models developed by Eaton and Kortum (1996, 1999), among others, by incorporating the role of finite-length patents into the analysis explicitly.

2.1 Consumer Behavior

The global economy consists of two regions: The innovating North and the imitating South both of which engage in free trade. There is a fixed measure of identical dynastic households with infinitely lived members. The size of each household grows exponentially at the exogenous rate $g_L > 0$ as new household members are born continually. By normalizing the initial size of each household to unity, one can write the size of each household, measured by the number of its members, at time t as $e^{g_L t}$. Denote with $L_N(t) = \bar{L}_N e^{g_L t}$ the level of population in the North at time t , where $\bar{L}_N$ is a parameter capturing the number of Northern households at time zero. Similarly, denote with $L_S(t) = \bar{L}_S e^{g_L t}$ the corresponding level of Southern population at time t , where $\bar{L}_S$ is the initial Southern population. The world population level at time t is then given by $L(t) = \bar{L} e^{g_L t} = L_N(t) + L_S(t) = (\bar{L}_N + \bar{L}_S) e^{g_L t}$. Assuming that each household member is endowed with one unit of labor that is supplied inelastically to the market, $L(t)$ is also equal to the global supply of labor at time t .

There is a continuum of industries indexed by $\theta \in [0,1]$ and producing final consumption goods whose quality can be improved through innovative R&D. The knowledge-creation process and the international technology-transfer mechanism will be described later. Products of different quality levels in each industry θ are indexed by j , which is restricted to integer values and denotes the number of innovations in each industry. The quality level of a product in industry θ is given by $\lambda^{j(\theta,t)}$, where $\lambda > 1$ is the quality increment generated by each innovation – which is identical across all industries – and $j(\theta,t)$ is the number of all innovations in industry θ at time t . Each identical dynastic household maximizes the following discounted lifetime utility:

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

where $\rho > g_L$ is the subjective discount rate of a typical household member; and the instantaneous per capita utility function at time t is defined by

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

Equation (2) defines the standard quality-augmented Cobb-Douglas utility function across all industries $\theta \in [0,1]$. Variable $q(j, \theta, t)$ is the per-capita quantity demanded of a product in industry θ at time t and quality level λ^j .

The consumer maximization problem is solved in three steps. First, the consumer allocates her budget across products within each industry by spending all her income on the product with the lowest quality-adjusted price $p(j, \theta, t) / \lambda^j$; we assume that, if two products within an industry have the same quality-adjusted prices, the consumer buys only the highest-quality product although she is formally indifferent.⁵ Second, the consumer allocates her budget on lowest quality-adjusted price products across all industries. The solution to this static maximization problem yields the per-capita demand function for the lowest quality-adjusted product in industry θ at time t

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

where $c(t)$ is per-capita consumption expenditure at time t . Third, the consumer maximizes (1) subject to the standard intertemporal wealth constraint

$$\dot{z}(t) = r(t)z(t) + w - c(t) - g_L z(t)$$

where $z(t)$ denotes the level of consumer assets, $r(t)$ is the market interest rate, and w is the consumer's income (wage). The solution to this dynamic maximization problem determines the optimal division between her consumption and savings. Using (3) in (2) and the resulting expression in (1) yields an expression that depends on per-capita consumption expenditure and product prices.

The solution to this maximization problem yields the standard differential equation

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

Equation (4) implies that, at the steady-state equilibrium with constant per-capita consumption expenditure, $c(t)$, the market interest rate equals the constant subjective discount rate (i.e., $r(t) = \rho$).

⁵ Dinopoulos and Waldo (2005) have analyzed the case where consumers migrate gradually from lower to higher quality products.

2.2 Product Markets

By assumption only Northern firms engage in innovative R&D and compete with each other in a Bertrand price-competition fashion. When a Northern firm discovers a new product in industry θ , it becomes the only firm in the world that knows how to produce the state-of-the-art quality product in this industry. Henceforth, we call this firm “Northern quality leader.” We assume that a Northern-quality leader obtains a perfectly enforceable patent of finite duration $T > 0$ that applies to its newly discovered product. When a patent expires, the product becomes “generic” only in the North – every firm in the North knows how to produce generic products. As a result, all generic products could be produced under competitive conditions in the North. Southern firms select generic products as targets for copying their technology and for transferring their production to the low-wage South. When a Southern firm copies a Northern generic product by expending resources to imitative R&D, it enjoys a manufacturing cost advantage that enables it to drive its Northern competitors out of the market. For notational purposes, we call these firms “Southern quality” leaders. A Southern quality leader enjoys global monopoly power for a limited time because a Northern firm will eventually discover a new higher-quality product in industry θ that will replace its Southern competitor through limit pricing.

We assume that labor is the only factor production and that it is inelastically supplied. One unit of labor produces one unit of output independently of the geographic location of productions and of the product quality level; therefore, marginal (and average) manufacturing costs are equal to the wage rate in each of the two regions. We focus on the case of product-cycle trade and international technology transfer in the presence of a North-South wage gap. Under such circumstances, the following condition will be satisfied at the steady-state equilibrium:

$$w_S \lambda > w_N > w_S \quad (5)$$

where w_S and w_N are the long-run equilibrium Southern and Northern wages respectively. Inequality (5) implies a positive North-South wage gap $w_N > w_S$, that is not very large relative to the size of each quality improvement $\lambda > 1$. Inequality $w_S \lambda > w_N$ imposes an upper bound on the wage gap that allows a Northern firm with the state-of-the-art quality product to drive its Southern competitor out of the market.

A Northern quality leader producing the state-of-the-art quality product j in industry θ faces competition from a competitive Northern fringe producing generic product $j-1$ if the product has not been copied by a Southern firm⁶. By charging price $p_N = \lambda w_N$, this firm can drive its Northern

⁶ In this paper, we assume that the patent protection is global. If the patent protection is not global and Southern firms can also target Northern state-of-the-art quality products whose patents have not expired, then a typical producer of a generic product can at most charge a price equal to $p_S^j = \lambda w_S$, since it only faces

competitors out of the market and enjoy temporary global monopoly power for a period $T > 0$. We assume that, if product $j-1$ has been successfully copied by a Southern firm, the Northern quality leader follows the following trigger pricing strategy: To drive the Southern quality leader out of the market it first charges a limit price $p'_N = \lambda w_S < \lambda w_N$, and then, when it learns that its Southern competitor is out of business, it charges a price $p_N = \lambda w_N$. Assuming that there are substantial costs associated with reentry in the South, this trigger strategy allows the Northern quality leader to charge a higher price except for an instance in time when the new product is discovered.⁷

The above reasoning implies that a Northern quality leader earns the flow of global profits $\pi_N = (p_N - w_N)(q_N L_N + q_S L_S)$, where $p_N = \lambda w_N$ is the price charged. Variables q_N and q_S are the per-capita quantities demanded by Northern and Southern consumers described in (3). For notational purposes denote with $c = (c_N \bar{L}_N + c_S \bar{L}_S) / \bar{L}$ the per capita global consumption expenditure. Using (3), we can write the flow of profits π_N as

$$\pi_N = \frac{(\lambda - 1)}{\lambda} cL(t), \quad (6)$$

where $L(t) = \bar{L}e^{g_L t}$ is the level of world population at time t .

A Southern quality leader drives its Northern competitors out of the market by charging the limit price $p_S = w_N$. We assume that there are no reentry costs in generic products, since they are produced under conditions of pure competition in the North. The typical Southern quality leader earns a flow of global profits $\pi_S = (p_S - w_S)(q_N L_N + q_S L_S)$, where $p_S = w_N$. Using (3), we can write the flow of Southern profits as

$$\pi_S = \frac{(w_N - w_S)}{w_N} cL(t) = \left(1 - \frac{1}{\omega}\right) cL(t) \quad (7)$$

competition from the quality follower in the South. Since the product enjoys patent protection in the North, it cannot be exported; therefore, the product can be sold only to Southern consumers generating a flow of monopoly profits equal to $\pi_S^I = (\lambda w_S - w_S) q_S L_S$. If the same firm targets a Northern generic product whose patent has already expired, the successful Southern imitator would be able to sell the product to both Northern and Southern consumers and earn a higher flow of profits $\pi_S = (w_N - w_S)(q_N L_N + q_S L_S)$, provided that the Northern market is at least as large as the Southern market (i.e., $c_N L_N \geq c_S L_S$). Since the cost of imitation is the same across all industries, free entry in imitative R&D activities targeting generic Northern products would drive expected discounted profits down to zero and would imply negative expected discounted net benefits from targeting Northern products with active patents. In other words, Southern imitators do not have an incentive to target Northern products with active patents as long as there generic products produced by Northern firms at the steady-state equilibrium.

⁷ Howitt (1999) has introduced this trigger strategy in the context of a Schumpeterian growth model and has provided more details about it. In the absence of reentry costs, the Northern quality leader can always drive its Southern competitor out of the market by charging the limit price $p'_N = \lambda w_S < \lambda w_N$. The assumption of (large) market reentry costs in the South simplifies the exposition and algebra.

where $\omega = w_N / w_S > 1$ is the relative wage of Northern workers, c is per capita global consumption expenditure, and $L(t) = \bar{L}e^{g_L t}$ is the level of world population at time t .

2.3 Innovation

The temporary flow of global monopoly profits provides strong incentives for Northern firms to engage in innovative R&D. Following the standard practice of the literature on North-South growth models, we will focus on the balanced-growth equilibrium properties of the model. The process of innovation mimics Romer's (1990) pioneering work on endogenous technological progress with some additional features that generate endogenous long-run Schumpeterian growth. A Northern firm i that employs ℓ_i units of labor to engage in innovative R&D for a time interval dt , produces with certainty $dA_i = \alpha \ell_i dt / e^{\varphi x(t)}$ units of state-of-the-art quality products, where α is an innovative-R&D productivity parameter, and $e^{\varphi x(t)}$ is function that captures the R&D difficulty at the long-run equilibrium, where $\varphi > 0$ is a parameter. We may think of dA_i as the instantaneous flow of patents (new product designs) that is directly proportional to the amount of labor devoted to innovative R&D, and inversely proportional to the R&D difficulty parameter. The economy-wide rate of patents is given by $dA = \alpha L_A dt / e^{\varphi x(t)}$, where $dA = \sum_i dA_i$ is the aggregate flow of new products and $L_A = \sum_i \ell_i$ is the aggregate labor devoted to innovative R&D.

We assume that the steady-state evolution of $x(t)$ is given by $\dot{x}(t) = [\nu_p(t)]^\beta \dot{A}(t)$, where $0 < \nu_p(t) < 1$ is the measure of industries with active patents at time t (that is, the measure of industries with Northern quality leaders); $\dot{A}(t) = dA(t)/dt$ is the steady-state instantaneous flow of new products per industry and the economy as a whole since the measure of industries is of unit length by assumption; as it will become clear later, $\beta \in (-1, 1)$ is a parameter that determines the long-run correlation between the patent length and Schumpeterian growth. This specification of $x(t)$, especially the term $[\nu_p(t)]^\beta$, captures two competing features of patent-based intellectual property protection. On the one hand, patents facilitate the innovation process by making public the knowledge embedded in each patent application relative to other industries. This feature is captured by values of parameter β that are strictly negative – an increase in the measure $\nu_p(t)$ of industries protected by patents reduces the rate of increase in the R&D difficulty and makes the discovery of new products relatively easier. On the other hand, patents reduce the flow of knowledge spillovers in a number of ways. For example, firms may build patent portfolios to exclude other firms from

discovering similar products; or, alternatively, they may threaten to resort to patent-infringement litigation, which hinders the research efforts of incumbents, etc. This feature is captured by strictly positive values of parameter β . In this case, an increase in the measure of industries protected by patents $\nu_p(t)$ accelerates the rate of increase in the R&D difficulty and makes the discovery of new products more difficult. Finally, by setting $\beta = 0$ one obtains the case of structural symmetry across all industries, independently of whether they are protected by patents or not.

In the steady-state equilibrium, the measure of industries protected by patents $\nu_p(t)$ is bounded and must, therefore, be constant over time. In addition, the requirement of a bounded (not exploding) per capita long-run growth rate requires that the flow of patents, $\dot{A}(t)$, to be constant over time as well. Ignoring initial level conditions, the steady-state value of R&D difficulty is given by

$$x(t) = [(\nu_p)^\beta \dot{A}]t. \quad (8)$$

Thus, the long-run innovation rate can be written as

$$\dot{A}(t) = \frac{\alpha L_A(t)}{e^{\varphi x(t)}}. \quad (9)$$

Equations (8) and (9) have several desirable properties. First, differentiating (9) with respect to labor yields $\alpha e^{-\varphi x(t)}$, the expression for the productivity of R&D researchers. This expression implies that the R&D productivity of labor (that is, the flow of patents per researcher) decreases over time, and that the innovative-R&D labor requirement increases over time in the steady-state equilibrium.

Second, (8) and (9) imply that parameter β relates the steady-state flow of patents $\dot{A}$ (and long-run Schumpeterian growth) to the patent length T . To see this rewrite equation (9) as

$\dot{A}(t) = \alpha [L_A(t) / L(t)] L(t) e^{-\varphi x(t)}$, where the term in square brackets is the share of world labor devoted to innovative R&D. This share will be constant in the steady-state equilibrium, and therefore the term $L(t) e^{-\varphi x(t)} = \bar{L} e^{[tg_L - \varphi x(t)]}$ will also be constant over time. This means that $g_L = \varphi x(t)/t$ in the steady-state equilibrium. Substituting $x(t)$ from (8) in this expression yields the following steady-state condition

$$\dot{A}(t) = \frac{g_L}{(\nu_p)^\beta \varphi}. \quad (10)$$

According to (10), the steady-state rate of new products is proportional to the rate of population growth g_L and inversely proportional to parameter φ , which is related to the rate of increase in R&D difficulty and the measure of industries with Northern quality leaders raised to the power β . The last

term provides the endogenous link between patent coverage and the rate of innovation $\dot{A}$. If $\beta = 0$, then the steady-state rate of innovation is exogenous. The possibility of asymmetric knowledge spillovers is captured by $\beta \neq 0$ which links the steady-state rate of innovation to the market-determined measure of industries protected by patents and generates endogenous scale-invariant Schumpeterian growth. The rest of the paper investigates the nature of this relationship and identifies the general-equilibrium forces that generate it.

All firms maximize (expected) discounted profits, in the presence of free entry into each innovative activity in the North. We also assume that Northern firms engage in R&D to discover higher-quality products by targeting only industries producing generic products. This assumption simplifies the analysis by eliminating the risk of default from products protected by patents, and can be justified by the existence of patent infringement law suits by firms with active patents against challengers. Since the technology of generic products is assumed to be public knowledge in the North, the possibility of patent infringement law suits against challengers does not arise.

Consider now the profit-maximization decision of Northern firm i when choosing the amount of innovative-R&D labor. Let $V_A(\theta, t)$ denote the market value of a patent at time t in industry θ . This market value is given by

$$V_A(\theta, t) = \int_0^T \pi_N(t+s) e^{-r(t)s} ds, \quad (11)$$

where $\pi_N(\theta, t)$ is the flow of global monopoly profits of a Northern quality leader described by (6). In the steady-state equilibrium, the market interest rate equals the constant subjective discount rate; that is, $r(t) = \rho$. Substituting (6) into (11) and integrating appropriately yields the steady-state market value of a typical patent

$$V_A(t) = \left[\frac{1 - e^{-(\rho - g_L)T}}{\rho - g_L} \right] \frac{(\lambda - 1)}{\lambda} cL(t). \quad (12)$$

The structural symmetry across all industries implies that the value of a patent is identical across all industries, which explains why θ does not appear in V_A . At the steady state equilibrium, the value of a typical patent grows at the rate of population growth, and is increasing in T . In the absence of patent protection ($T = 0$), the value of a patent vanishes; when the length of the patent becomes infinitely large ($T \rightarrow \infty$) the value of an invention equals the flow of steady-state global profits discounted by the effective discount rate, $\rho - g_L > 0$. In addition to the patent length, the value of a patent depends positively on the patent breath, measured by the quality increment, λ , and the rate of population growth, g_L , and negatively on the subjective discount rate, ρ . Equation (12) captures an

important property of patent protection: an increase in the patent length T increases the incentive to innovate by raising the market value of an invention.

A Northern firm i that devotes ℓ_i units of labor to innovative R&D for a time interval dt , discovers with certainty $dA_i = \alpha \ell_i dt / e^{\varphi x(t)}$ new patentable product designs. This action generates a market value $V_A dA_i = [V_A \alpha \ell_i dt] / e^{\varphi x(t)}$, and total costs $(1 - \tau_A) w_N \ell_i dt$, where $\tau_A > 0$ is an ad-valorem subsidy to R&D on innovation. Combining the benefits and costs of innovative R&D yields the following expression for the corresponding discounted net profits:

$$\left[V_A \alpha e^{-\varphi x(t)} - (1 - \tau_A) w_N \right] \ell_i dt.$$

Free entry into innovative R&D results in non-positive economic profits. the term inside the square brackets must be zero, i.e.,

$$V_A \alpha e^{-\varphi x(t)} \leq (1 - \tau_A) w_N. \quad (13)$$

This condition holds with equality for $\ell_i > 0$ (and $dA_i > 0$), and with inequality for $\ell_i = 0$ (and $dA_i = 0$). Romer (1990) derives (13) from the labor market equilibrium. The left-hand side of (13) is the value of the marginal product of labor of an R&D worker (V_A is the value of R&D “output” and $\alpha e^{-\varphi x(t)}$ coincides with the marginal product of labor in research); the right-hand side of (13) is the subsidy-adjusted wage rate (cost per worker). Consequently, the above equation states that each research firm hires workers up to the point where the value of the marginal product of labor is equal to the subsidized wage of labor.⁸

Substituting $x(t)$ from (8) and V_A from (12) into (13), and using the steady-state condition $L(t) e^{-\varphi x(t)} = \bar{L} e^{[tg_L - \varphi x(t)]} = \bar{L}$ generates the following *innovative R&D condition*:

$$\alpha \bar{L} \left[\frac{1 - e^{-(\rho - g_L)T}}{\rho - g_L} \right] \frac{(\lambda - 1)}{\lambda} c \leq (1 - \tau_A) w_N. \quad (14)$$

This condition defines a positive linear relationship between per-capita consumption expenditure and the Northern wage rate. As per-capita consumption increases, the innovation price (the reward to innovation) rises and so must the wage of Northern workers in order to restore the zero discounted profits condition. The market value of a patent plays a role very similar to the role terms of trade play in the static Ricardian trade model. Factors that raise the value of patents and innovation – such as the size of the global market $\bar{L}$, parameter α , the length of patents T , the rate of population growth

⁸ If the equilibrium wage is such that the right-hand-side of the zero-profit condition exceeds its left-hand side, then innovative R&D is not profitable and the innovative activity stops.

g_L , and the size of innovations λ – raise the value of Northern wage income w_N relative to per-capita global consumption c ; thus, patent protection benefits Northern workers.

2.3 Imitation

The process of international technology transfer is endogenous and depends on the amount of Southern resources devoted to imitative R&D. At the steady-state equilibrium, a fraction of Northern industries manufactures state-of-the-art quality products whose patent protection has expired under conditions of perfect competition. Southern firms employ imitative-R&D labor to copy generic products and transfer their production to the low-wage South.

We model the process of endogenous imitation along the lines considered in Grossman and Helpman (1991, Chapter 11) and Dinopoulos and Segerstrom (1999). In particular, we assume that a Southern firm j that hires ℓ_j units of Southern labor to engage in imitative R&D for the time interval dt succeeds in copying $dM_j = \mu \ell_j dt / L(t)$ generic products manufactured in the North, where μ is an imitation productivity parameter. The level of global population $L(t) = \bar{L}e^{g_L t}$ appears in the denominator of the imitation production function in order to capture the notion that copying products becomes more difficult over time as the size of the global economy, measured by the level of population, increases.⁹ Summing up over all firms engaged in imitative R&D yields the following aggregate rate of imitation

$$\dot{M}(t) = \frac{\mu L_M(t)}{L(t)}, \quad (15)$$

where $\dot{M}(t) = dM / dt$ is the economy-wide rate of imitation, $dM = \sum_j dM_j$, and $L_M(t) = \sum_j \ell_j$.

Equation (15) states that the aggregate rate of imitation is a function of the share of global resources devoted to imitative R&D.

The next step is to analyze the R&D choice of Southern imitators. Denote with $V_M(\theta, t)$ the expected discounted profits of a successful imitator j that manages to copy the state-of-the-art quality product in industry θ at time t . By employing ℓ_j units of Southern labor in imitative R&D for the

⁹ This specification of imitative R&D difficulty corresponds to the permanent effects of growth (PEG) specification of the knowledge production process in Dinopoulos and Segerstrom (1999) and its purpose is to remove the scale-effects property inherent in all Schumpeterian growth models. Other specifications are also possible. For example, it is possible to use the level of Southern population, $L_S(t)$, the level of quality of the state-of-the-art generic product targeted for imitation, or the number of products discovered up to time t . We choose the simplest specification to minimize the complexity of algebra.

time interval dt , a firm can copy $dM_j = \mu \ell_j dt / L(t)$ Northern generic products and thereby create a market value of $V_M \mu \ell_j dt / L(t)$. The cost of this investment equal the subsidy-adjusted wage bill $(1 - \tau_M) w_S \ell_j dt$, where τ_M is an ad valorem subsidy to imitative R&D. As in the case of innovative R&D, we assume that there is free entry into the imitative R&D process that generates non-positive net benefits $V_M [\mu \ell_j dt / L(t)] - (1 - \tau_M) w_S \ell_j dt \leq 0$ from imitative R&D, thus yielding the *imitative R&D condition*

$$V_M(\theta, t) \frac{\mu}{L(t)} \leq (1 - \tau_M) w_S. \quad (16)$$

Equation (16) states that the value of the marginal product of labor devoted to imitative R&D cannot exceed the subsidy-adjusted wage in the South.

We assume that there is a global stock market capable of channeling global savings to Northern and Southern firms engaging in R&D. The stock market valuation of Southern monopoly profits yields another market-clearing condition which relates the flow of Southern monopoly profits π_S to the “price” of imitative R&D, V_M . The stock market valuation of Northern monopoly profits, V_A , is given by (12). Following the standard practice of Schumpeterian growth models, we derive the stock market valuation of Southern monopoly profits by setting up the no arbitrage stock-market equilibrium condition.

Let ν_N be the measure (and set) of Northern industries producing generic products under perfect competition, and denote with ν_S the measure (set) of industries with Southern quality leaders. In other words, $1 = \nu_P + \nu_N + \nu_S$, where ν_P is the measure of industries with active (as opposed to inactive) patents. At each instant in time, a Southern quality leader earns the flow of profits $\pi_S dt$ during an interval of length dt . This firm faces a “creative-destruction” risk of default that the next higher-quality product will be discovered by a Northern firm engaged in innovative R&D. We calculate this risk as follows. In an interval of length dt , $\dot{A}(t)dt$ new higher quality products are discovered in the North. With random selection (due the structural symmetry across all industries), a Southern quality leader loses all its profits with instantaneous probability $\dot{A}(t)dt / (\nu_S + \nu_N)$; this probability equals the instantaneous flow of innovations per industry without patent protection. If this event occurs, the Southern quality leader loses its monopoly power and suffers a loss equal to $(0 - V_M)$. If this event does not occur, the firm experiences a capital gain (loss) equal to $dV_M = \dot{V}_M dt$; therefore, the no-arbitrage condition, expressed in terms of rates of return, is

$$\frac{\pi_S dt}{V_M} + \left[1 - \frac{\dot{A} dt}{(\nu_S + \nu_N)} \right] \frac{\dot{V}_M dt}{V_M} + \frac{\dot{A} dt}{(\nu_S + \nu_N)} \frac{(0 - V_M)}{V_M} = r(t) dt. \quad (17)$$

The left-hand side of equation (17) is the expected rate or return to a dollar invested in a stock issued by a Southern quality leader. The right-hand side is the return to a dollar invested in a completely diversified stock portfolio which yields the riskless rate of return.¹⁰ Taking limits as dt approaches zero and solving for the market value of a Southern quality leader generates

$$V_M = \frac{\pi_S}{r + \frac{\dot{A}}{(\nu_S + \nu_N)} - \frac{\dot{V}_M}{V_M}}, \quad (18)$$

the standard stock-market valuation of temporary monopoly profits. Equation (18) discounts the flow of profits by the market interest rate plus the risk of default, which is related to the rate of innovation, minus the growth rate of the firm value. In the steady-state equilibrium, (18) takes the form

$$V_M = \frac{[1 - (1/\omega)]cL(t)}{\rho + \frac{\dot{A}}{(\nu_S + \nu_N)} - g_L}, \quad (19)$$

where the steady-state expressions $r(t) = \rho$, $\dot{V}_M/V_M = g_L$, and $\pi_S = [1 - (1/\omega)]cL(t)$ have been substituted into (19).¹¹ Substituting (19) into the zero-profit condition (16) gives the *imitative-R&D condition*

$$\mu[1 - (1/\omega)]c = (1 - \tau_M)w_S \left[\rho + \frac{\dot{A}}{(\nu_S + \nu_N)} - g_L \right]. \quad (20)$$

2.4 Labor Markets

We assume that there is perfect labor mobility across all industries and activities within each trading region. The wage rate is flexible and adjusts instantaneously to ensure that full employment prevails and that the demand for labor equals its supply in each instant of time. These assumptions generate two full-employment labor conditions: One for the North and another for the South.

Consider the Northern labor market first. There are three components of the demand for Northern workers at the steady-state equilibrium: Labor employed by firms engaged in innovative R&D, labor employed by Northern quality leaders to manufacture their products, and labor devoted to

¹⁰ See Grossman and Helpman (1991, Chapter 11) for more details on this issue in a context of a growth model based on variety accumulation.

¹¹ These three expression have been derived from equations (4), (16), and (7) respectively.

manufacturing of generic products produced in the North. Equations (8) and (9) generate the following expression for the demand for innovative-R&D labor: $L_A(t) = \dot{A} e^{t(\phi A \nu_p^\beta)} / \alpha$. Each Northern quality leader manufactures $cL(t) / \lambda w_N$ units of output and there are ν_p industries with Northern quality leaders. Since, by assumption, each worker produces one unit of output, the aggregate demand for manufacturing labor employed by Northern quality leaders is $\nu_p cL(t) / \lambda w_N$. Observing that the competitive price in each Northern industry producing generic products is $p_N = w_N$ (instead of $p_N = \lambda w_N$), and that there are ν_N Northern industries producing generic products, the aggregate demand for labor in this sector has to be $\nu_N cL(t) / w_N$. Setting the aggregate demand for labor in the North equal to its supply, $L_N(t)$, generates the Northern full-employment of labor condition

$$L_N(t) = \frac{\dot{A} e^{t(\phi A \nu_p^\beta)}}{\alpha} + \nu_p \frac{cL(t)}{\lambda w_N} + \nu_N \frac{cL(t)}{w_N}. \quad (21)$$

Dividing the above equation by the level of population and using (10), yields the per-capita version of *Northern full-employment condition*

$$\frac{\bar{L}_N}{\bar{L}} = \frac{g_L}{(\nu_p)^\beta \phi \bar{L}} + \left[\frac{\nu_p}{\lambda} + \nu_N \right] \frac{c}{w_N}. \quad (22)$$

Similar considerations apply to the Southern labor market, where labor is employed either by firms engaged in imitative R&D or by Southern quality leaders manufacturing state-of-the-art quality products. The demand for Southern labor in imitative R&D is given by equation (15) and equals

$L_M(t) = \dot{M} L(t) / \mu$. Each of the ν_s Southern quality leaders charges a price $p_s = w_N$ and produces $q_s = cL(t) / p_s$ units of output to serve the global market; therefore, the economy-wide demand for manufacturing labor is $\nu_s cL(t) / w_N$. Setting the aggregate demand for Southern labor equal to its supply, $L_s(t)$, yields the Southern full employment of labor condition

$$L_s(t) = \frac{\dot{M} L(t)}{\mu} + \nu_s \frac{cL(t)}{w_N}. \quad (23)$$

Dividing both sides by the level of global population yields the per-capita version of the *Southern full-employment condition*

$$\frac{\bar{L}_s}{\bar{L}} = \frac{\dot{M}}{\mu} + \nu_s \frac{c}{w_N}. \quad (24)$$

The derivation of the Southern full-employment condition completes the description of the model.

3. The Unique Steady-State Equilibrium

In this section, we establish the existence of the unique steady-state equilibrium and describe its properties, under the assumption that T is strictly positive. We focus on a balanced growth equilibrium in which each variable grows at a constant rate over time. Several variables are constant in the steady-state equilibrium, including the market interest rate, $r(t) = \rho$, per-capita consumption expenditure, c , all product prices, wage rates, w_S and w_N , the rate of innovation (which equals the steady-state flow of patents), $\dot{A}$, the rate of imitation, $\dot{M}$, and the measures of industries with Northern quality leaders, ν_P , with Southern quality leaders, ν_S , and with Northern firms producing generic products ν_N . Although per-capita variables are constant over time, several variables (quantities produced, resources allocated to various activities, the flow of Southern and Northern profits, and the market value of quality leaders) grow at the constant rate of population growth. Lastly, the steady-state utility of each consumer grows at the same growth rate as total factor productivity generated by the process of creative destruction as new higher quality products are discovered and produced in the North or South.

Following the standard methodology of Schumpeterian growth models, we let Southern labor serve as the numeraire (i.e., $w_S = 1$) so that $\omega = w_N > 1$ captures the relative wage of Northern workers as well as the North-South wage gap. In the steady-state equilibrium, the measure of industries with Northern quality leaders is related to the strictly positive patent length as follows¹²

$$\nu_P = \int_0^T \dot{A} ds = \dot{A} T. \quad (25)$$

Equation (25) states that, since patent protection is finite and the rate of patents is constant over time, the measure of industries with active patent protection is equal to the rate of innovation times the patent length $T > 0$. Equations (10) and (25) yield the steady state solution for the measure of Northern quality leaders

¹² In the absence of patent protection (i.e., $T = 0$), the model has a steady-state equilibrium without growth. If $T = 0$ the reward to innovation becomes zero, and thus $\nu_P = 0$. This stops innovation activity (i.e., $\dot{A} = 0$) and firms have no demand for Northern researchers (i.e., $L_A = 0$). This effect pushes the Northern wage down and Southern labor-cost advantage diminishes. In addition, the probability $\dot{A}(\nu_N + \nu_S)$ of replacing a Southern quality leader drops to zero. Southern quality leaders, safe from being replaced by further innovation, target all Northern industries that produce generics. Eventually all Northern products are copied by Southern firms, the relative wage of Northern workers becomes equal to the Southern wage, and the global economy reaches a steady-state equilibrium without trade, innovation, imitation and growth. For the remaining of the analysis, we focus on the steady-state equilibrium with strictly positive patent duration.

$$\nu_P = \left(\frac{Tg_L}{\phi} \right)^{\frac{1}{1+\beta}}, \quad (26)$$

where the parameter restriction $\phi > Tg_L$ ensures the measure of industries with patent protection is less than unity. According to (26), the fraction of industries with Northern quality leaders increases in the rate of population growth and the patent length for all values of parameter $\beta \in (-1, 1]$. Thus, the model generates the intuitive prediction that, *ceteris-paribus*, longer global patent protection (for example, an increase in the patent length from 18 to 20 years) raises the number of Northern monopolies and results in a transfer of profits from Southern consumers to Northern firms.

Substituting (26) into equation (10) generates the steady-state solution for the rate of global innovation which equals the flow of patents:

$$\dot{A} = \left(\frac{g_L}{\phi} \right)^{\frac{1}{(1+\beta)}} T^{\frac{-\beta}{(1+\beta)}}. \quad (27)$$

The long-run rate of global innovation is increasing in the rate of population growth and decreasing in parameter ϕ . An increase in ϕ raises the level of R&D difficulty and reduces the rate of innovation. This result is standard in models of exogenous long-run Schumpeterian growth without scale effects.¹³ What is novel about the present model is the role of parameter β in the long-run rate of innovation (and growth). If this parameter takes the value of zero – which implies that there is no asymmetry across industries in the generation of knowledge spillovers – the rate of innovation is independent of the length of patent protection $T > 0$. Negative values of parameter β capture the “benevolent” case in which patents increase the rate of knowledge spillovers (decrease the rate of innovative R&D difficulty, $x(t)$, at each instant in time t – according to equation (8)). In this case, an increase in global patent protection raises the steady-state rate of innovation. However, strictly positive values of parameter β unveil the “malign” case of patent protection whereby stronger patent protection reduces the rate of global innovation, in addition to transferring income in the form of higher profits from Southern consumers to Northern firms.

The mathematical structure of the model is simple enough to render feasible the calculation of explicit steady-state solutions for all variables of interest. Denoting with a hat ($\hat{}$) the long-run equilibrium values of endogenous variables, we can combine the innovative and imitative-R&D conditions (14) and (20) to solve for the steady-state values of global per-capita consumption expenditure and the North-South wage gap

¹³ See, for example, Jones (1995), Segerstrom (1998) and Dinopoulos and Segerstrom (2004), among many others.

$$\hat{c} = \frac{(1-\tau_A)(\rho - g_L)}{\alpha \bar{L}(1 - e^{-(\rho - g_L)T})} \frac{\lambda}{(\lambda - 1)} + \frac{(1-\tau_M)(\rho - g_L + \psi)}{\mu} \quad (28)$$

$$\hat{\omega} = 1 + \left[\frac{\alpha (1-\tau_M) (\lambda - 1)}{\mu (1-\tau_A) \lambda} \right] \left[1 + \frac{\psi}{(\rho - g_L)} \right] \bar{L}(1 - e^{-(\rho - g_L)T}) \quad (29)$$

where ψ is the risk of default for a Southern quality leader associated with the process of creative destruction

$$\psi = \frac{\dot{A}}{1 - \nu_P} = \frac{1}{T} \left\{ \left(\frac{\varphi}{Tg_L} \right)^{\frac{1}{(1+\beta)}} - 1 \right\}^{-1}. \quad (30)$$

Equations (26) and (27) were used in the derivation of (30). The long-run North-South wage gap depends on virtually all parameters of the model. The wage of Northern workers exceeds that of Southern workers ($\hat{\omega} > 1$). Furthermore, the wage gap is increasing in factors that enhance the process of innovation – such as the productivity of labor, α , in innovative R&D, the subsidy τ_A to innovative R&D, and the magnitude of innovations, λ . In contrast, parameters that encourage the transfer of technology from North to South – such as the labor productivity μ in imitative R&D, and subsidy τ_M to imitative R&D – have a positive impact on global wage inequality. The effect of patent protection on the North-South wage gap is ambiguous and depends on the relationship between the patent length and the steady-state rate of innovation described in (30).

Equations (28)-(30) will be used in the next section to analyze the consequences of globalization and the strength of intellectual property protection. We proceed by solving the model for the steady-state value of the rate of imitation. Adding the Northern and Southern full-employment conditions (22) and (24) yields the following per-capita full employment condition:

$$1 = \frac{g_L}{(\nu_P)^\beta \varphi \bar{L}} + \left(\frac{\nu_P}{\lambda} + (1 - \nu_P) \right) \frac{c}{\omega} + \frac{\dot{M}}{\mu}.$$

Substituting the endogenous variables c and ν_P in the above equation, and using the innovative-R&D condition (14) and equation (26), we may solve for the steady-state global imitation rate $d\hat{M}/dt$ to obtain

$$\frac{d\hat{M}}{dt} = \mu \left\{ 1 - \frac{(g_L / \varphi)^{\frac{1}{(1+\beta)}}}{\bar{L}(T)^{\frac{\beta}{(1+\beta)}}} - \left[1 - \frac{(\lambda - 1)}{\lambda} \left(\frac{Tg_L}{\varphi} \right)^{\frac{1}{(1+\beta)}} \right] \frac{\lambda}{(\lambda - 1)} \frac{(1-\tau_A)(\rho - g_L)}{\alpha \bar{L}(1 - e^{-(\rho - g_L)T})} \right\}, \quad (31)$$

where the term in square brackets is equal to $\nu_s + \nu_N + \nu_p / \lambda$, which is positive and less than unity. Substituting (31) and the innovative R&D condition (14) into the Southern full-employment condition (24), yields the steady-state value of the measure of industries with Southern quality leaders $\hat{\nu}_s$.

4. Globalization, Intellectual-Property Protection, and R&D Subsidies

The model generates a steady-state equilibrium with several desirable properties: New higher-quality products are discovered in the North as a result of innovative R&D investments undertaken by Northern firms; each newly discovered product is produced in the North and enjoys global patent protection for a finite period of time, T ; products whose patents have expired (generics) are produced in the North under conditions of perfect competition; the know-how of some generic products is transferred to the South (as a consequence of imitative R&D there) and these product are exported back to the North by Southern quality leaders until they are replaced by higher-quality products discovered in the North; other generic products are produced in the North until they are replaced by other newly discovered ones. This global process of Schumpeterian creative destruction generates product-cycle trade, long-run scale-invariant Schumpeterian growth, and a North-South wage gap.

Before proceeding with the comparative steady-state analysis, it is useful to derive an expression for the long-run growth rate of each consumer's utility function; in other words, we would like to derive an expression for long-run Schumpeterian growth. Since the measure of industries is normalized to unity and all industries are structurally identical, $A(t)$ denotes the economy-wide number of innovations at time t , as well as the "average" number of innovations per industry. At each instant in time, there are ν_p industries with Northern quality leaders. The average number of innovations in each of these industries is $j(\theta, t) = A(t)$ and the quantity produced by each Northern quality leader equals $q(\theta, t) = c / \lambda \omega$. Similarly, each of the remaining industries $\nu_N + \nu_s$ is characterized by an average number of innovations $j(\theta, t) = A(t)$ – the quantity produced equals $q(\theta, t) = c / \omega$ because both every Southern quality leader and every competitive firm in the North producing generic products charges a price equal to the Northern wage $w_N = \omega$. Thus, the instantaneous utility of a typical household member at time t is

$$\ln u(t) = \int_{\nu_p} \ln \left[\lambda^{A(t)} \frac{c}{\lambda \omega} \right] d\theta + \int_{\nu_N + \nu_s} \ln \left[\lambda^{A(t)} \frac{c}{\lambda} \right] d\theta.$$

Performing the integration yields the level of the instantaneous utility at time t

$$\ln u(t) = A(t) \ln \lambda + \nu_p \ln \left[\frac{c}{\lambda \omega} \right] + (\nu_N + \nu_s) \ln \left[\frac{c}{\omega} \right]$$

In the steady-state equilibrium, all variables of the right-hand side of the above expression are constant over time, except for the number of innovations $A(t) = \dot{A}t$. Differentiating the level of instantaneous utility with respect to time and using (27) yields

$$g_U = \frac{\dot{u}}{u} = \dot{A} \ln \lambda = \left(\frac{g_L}{\varphi} \right)^{\frac{1}{(1+\beta)}} T^{\frac{-\beta}{(1+\beta)}} \ln \lambda. \quad (32)$$

The model generates endogenous long-run Schumpeterian growth without scale effects. As in a recent class of Schumpeterian growth models, growth is proportional to the rate of innovation, $\dot{A}$, which is equal to the steady-state flow of patents.¹⁴ However, in the present model, the rate of innovation depends on patent protection. The nature of this dependence is governed by parameter $\beta \in (-1,1)$ which captures the structure of knowledge spillovers. We may summarize the properties of long-run Schumpeterian growth as follows:

Proposition 1: *Under the assumption that $T > 0$, the model's unique steady-state equilibrium is characterized by endogenous scale-invariant global Schumpeterian growth, g_U , with the following properties:*

- (a) *Long-run Schumpeterian growth is increasing in the rate of population growth, g_L , and the size of innovations, λ , but decreasing in difficulty of innovative-R&D, φ .*
- (b) *The relationship between long-run Schumpeterian growth and patent length T depends on the structure of knowledge spillovers measured by parameter β : In the case of symmetric knowledge spillovers (i.e., $\beta = 0$), long-run growth is exogenous; if patents suppress the dissemination of useful knowledge (i.e., $\beta \in (0,1)$), then an increase in patent protection (higher T) decreases long-run Schumpeterian growth; in contrast, if patents enhance the dissemination of useful knowledge (i.e., $\beta \in (-1,0)$), an increase in patent protection increases long-run Schumpeterian growth.*

Proof: See equation (32). QED.

¹⁴ See Segerstrom (1998) and Dinopoulos and Segerstrom (1999, 2004), among others, for models of scale-invariant Schumpeterian growth with this property.

We are now in a position to analyze the long-run affects of globalization and intellectual property protection in a post-TRIPs Schumpeterian North-South economy. As it is well known, the process of globalization is multidimensional and its components include trade liberalization policies, the formation of multinational enterprises, international migration, etc. Following Dinopoulos and Segerstrom (2004), we envision a three-region global economy that consists of an open North, an open South, and a closed South, to address one dimension of globalization: An increase in the size of the South. Initially, free trade prevails between open South and open North, whereas the closed South follows an autarkic policy. Examples of closed-South countries would include pre-1978 China, pre-1991 communist countries in Europe and Cuba, among others. In other words, one can think of the geographic dimension of globalization as a process by which countries in the closed South join the open South region by adopting free-trade policies with both open North and South. The long-run effects of geographic expansion of the market economy can be analyzed by considering the effects of permanent increase in the size of Southern population, $\bar{L}_S$, which implies an increase in the size of global population $\bar{L} = \bar{L}_S + \bar{L}_N$. The following proposition summarizes the effects of this type of globalization:

Proposition 2: *Globalization, viewed as a permanent expansion in the size of the South ($\bar{L}_S \uparrow$)*

- (a) *worsens the long-run wage-income distribution between North and South by raising the relative wage of Northern workers ($\omega \uparrow$);*
- (b) *permanently increases the rate of technology transfer from North to South ($\dot{M} \uparrow$),*
- (c) *does not affect the long-run rates of innovation ($\dot{A} \leftrightarrow$) and Schumpeterian growth ($g_U \leftrightarrow$).*

Proof: The proof can be established with the help of equations (29), (31), and (32). Notice that the term inside the square brackets of equation (31) equals $\nu_S + \nu_N + \nu_P / \lambda$ and it is positive. QED.

The long-run effects of patent protection can be analyzed with the help of equations (29), (31), and (32). Proposition 1(b) established the long-run growth effects of strengthening global protection of intellectual property by increasing the patent length $T > 0$. The following proposition

identifies the long-run effects of longer enforceable patents on wage income inequality and the rate of imitation:

Proposition 3: *A permanent increase in the global patent protection generated by an increase in the patent length ($T \uparrow$)*

- (a) *raises permanently the rate of technology transfer from North to South ($\dot{M} \uparrow$);*
- (b) *permanently exacerbates the wage income inequality between North and South ($\omega \uparrow$) if the following sufficient, but hardly necessary, condition holds:*

$$\hat{\nu}_p = (Tg_L / \varphi)^{\frac{1}{(1+\beta)}} \geq \beta / (1 + \beta). \quad (33)$$

Proof: The proof follows from equations (31) and (29). Condition (33) is derived by assuming that $d\psi/dT \geq 0$, where the risk of default ψ is defined by equation (30). QED.

The economic intuition of part (a) is as follows. The innovative-R&D condition (14) implies that an increase in the patent length raises the value of innovation and requires a decrease in the ratio c/ω – the cost of innovation per dollar of consumption expenditure must increase – to ensure that the zero-profit condition is satisfied. An increase in T causes a permanent increase in the measure of industries with patent protection ν_p (see equation (26)). These two implications mean that longer patent protection shifts resources away from manufacturing and innovative R&D towards imitative R&D. This resource relocation effect is apparent from the per capita global resource condition

$$1 = \frac{g_L}{(\nu_p)^\beta \varphi \bar{L}} + \left(1 - \nu_p \frac{(\lambda - 1)}{\lambda}\right) \frac{c}{\omega} + \frac{\dot{M}}{\mu},$$

where a decline in c/ω and an increase in ν_p imply a

permanent increase in the rate of global imitation $\dot{M}$. This result highlights the general equilibrium forces that could intensify North's demand for stronger intellectual property protection in the form of a longer patent length. Longer patents generate higher rates of imitation and shorter product cycles; in addition, they raise the rate of labor turnover in the global economy. The demand for stronger intellectual property protection might be even stronger if longer patents result in a slower rate of global innovations (see Proposition 1).

The effects of patent protection on the North-South wage gap, which are summarized in part (b) of Proposition 2, depend on whether longer patents increase or reduce the risk of default ψ for a Southern quality leader. From (30) it can be seen that the sign of $d\psi/dT$ is ambiguous. (This is so because an increase in T increases the measure of industries with patents and has an ambiguous effect

on the rate of innovation.) The sufficient condition (33) guarantees that higher patent protection increases the risk of default ($d\psi/dT > 0$) for each Southern quality leader. Condition (33) is satisfied if the measure of industries with patent protection is sufficiently high ($\nu_p \geq \beta/(1+\beta)$) relative to parameter $\beta \in (-1,1)$. For instance, if longer patents increase the rate of innovation and growth (i.e., $\beta \in (-1,0)$), or if the measure of industries with patent protection is higher than 1/2, then an increase in T raises the risk of default ψ . In all these cases, longer patent protection discourages imitation by increasing the risk of default for a successful Southern imitator and encourages innovation by increasing the duration of monopoly power enjoyed by Northern quality leaders. Equation (29) states that these two effects generate an unambiguous permanent increase in the North-South wage inequality.

We conclude this section by describing the effects of innovative and imitative R&D subsidies τ_A and τ_M , respectively. These effects are summarized in the following proposition and can be derived by inspecting equations (29) and (31):

Proposition 4: *A permanent increase in the innovative R&D subsidy ($\tau_A \uparrow$) exacerbates wage-income inequality ($\hat{\omega} \uparrow$) and raises the rate of imitation ($\dot{M} \uparrow$). In contrast, a permanent increase in the imitative R&D subsidy ($\tau_M \uparrow$) reduces the degree of North-South wage-income inequality ($\hat{\omega} \downarrow$) and does not affect the rate of imitation ($\dot{M} \leftrightarrow$).*

Proof: See equations (29) and (31). QED.

The apparent asymmetry between the impact of innovative and imitative R&D subsidies on the rate of imitation can be explained by their differential impact on the ratio c/ω . The innovative R&D condition (14) pins down the value of c/ω , which depends on the innovative R&D subsidy, τ_A , but not the imitative R&D subsidy, τ_M . Since τ_M does not affect the long-run values of ν_p and ψ , and does not appear explicitly either in the innovative or in the global-resource condition, it does not affect the long-run rate of imitation in this model. It is obvious then from the imitative R&D condition (20) that a permanent increase in τ_M reduces both global consumption per capita c and the wage gap ω without affecting their ratio.

5. Concluding Remarks

We developed a North-South model of scale-invariant endogenous Schumpeterian growth, product-cycle trade and global patent protection. The model combines the deterministic R&D-based knowledge creation function, introduced by the seminal works of Romer (1990) and Jones (1995), with the demand and market structures of quality-ladders Schumpeterian growth models. This combination renders possible the analysis of finite patents in a relatively simple analytical framework that permits the calculation of explicit analytical solutions.

The model generates unique steady-state equilibrium with several novel properties: New higher quality products are discovered in the innovating North through R&D investments; these products are manufactured in the North and exported to the South for a finite period of time which coincides with the length of a perfectly enforceable global patent; products whose patents have expired (generics) are produced in the North initially under conditions of perfect competition; generic products are targeted by Southern firms that engage in imitative R&D and manage to copy a fraction of these products; Southern firms producing generics supply the global market until they are replaced by Northern firms that discover new higher quality products. This equilibrium generates endogenous product cycle trade, endogenous North-South wage gap, and endogenous rates of innovation and imitation.

The model highlights the role of patented products in the rate of knowledge spillovers that can enhance or suppress the production of new products. If products with active patents suppress the rate of knowledge spillovers more than products with expired patents, then an increase in patent length decreases the long-run rate of innovation and growth. If products with active patents enhance the rate of knowledge spillovers more than products with expired patents, higher patent length increases the long-run rate of innovation and growth. The model generates several novel predictions for the long-run effects of globalization and patent protection: Geographic expansion of the global market, caused by an increase in the size of the South worsens the North-South income distribution, does not affect the rate of innovation and growth, and increases the rate of imitation; an increase in the patent length (stricter global protection of intellectual property) increases the rate of imitation; for a sufficiently large fraction of industries covered by patents, longer patents generate more global inequality; and in the case that patents suppress the rate of knowledge spillovers, longer patents decrease the long-run rate of innovation and growth. These results justify the concerns of many economists that North's demands for longer patents may worsen the disparities in world income and may suppress long-run Schumpeterian growth. The model is also consistent with a less pessimistic scenario; that is, even though longer patents worsen the wage-income distribution, they also reduce global poverty by boosting long-run global total factor productivity growth.

As usual, these results depend on the model's assumptions: We abstracted from the inherent uncertainty in innovative R&D; we did not analyze the case of asymmetric patent protection across the two regions; we did not analyze the stability and the welfare properties of the model due to the analytical complexity associated with dynamic North-South models; we assumed that patenting is the only mechanism that protects new inventions; and we did not deal with other important aspects of globalization such as trade liberalization, international labor migration and multinationals. We believe that the simple structure of the model allows a variety of generalizations that could relax these restrictive assumptions and generate new insight on the prospects and problems of globalization.

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