

# Globalization, Factor Endowments, and Scale-Invariant Growth\*

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## Abstract

The paper develops a two-country dynamic general-equilibrium model of growth without scale effects to explore the effects of globalization on long-run growth and wages. Higher quality products are endogenously discovered through stochastic and sequential global innovation contests in which challengers devote resources to R&D and technology leaders undertake rent-protection activities (RPAs) to prolong the expected duration of temporary monopoly power by frustrating the R&D effort of challengers. Globalization (i.e., a move from autarky to an integrated trading equilibrium) for two countries with identical relative factor abundance and possible differences in size does not affect the long-run growth rate of either country. However, the country that is abundant in the factor used intensively in the production of R&D services grows faster in autarky. Moreover, factor prices (adjusted for quality) and national long-run growth rates converge and are eventually equalized. Depending on international per-capita differences in factor abundance, the model also generates intra-sectoral trade, vertical and horizontal multinationals, and international outsourcing of services (R&D investment or RPAs). The growth effects of globalization between countries with different relative factor endowments are larger for smaller countries.

*JEL classification:* F1, O3, O4

*Key words:* Economic growth, scale effects, R&D, rent-protecting activities, innovation, wages.

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## 1. Introduction

Endogenous growth theory is now more than ten years old. Nonetheless, our understanding of the relationship between globalization, economic growth and income distribution remains incomplete. Empirical studies on the determinants of economic growth that rely on cross-country growth regressions either treat each country as a closed economy or introduce ad hoc variables correlated with economic openness. These studies have found that globalization has a small and rather insignificant effect on long-run growth.<sup>1</sup> In contrast, earlier research on endogenous growth analyzed the effects of globalization on long-run growth in various contexts. Perhaps the most dominant channel through which the introduction of trade affects (positively) the level of long-run growth [e.g., Rivera Batiz and Romer (1991a)] has been the size of markets. By expanding the size of each country's market, international trade raises the profitability of R&D in all trading partners, thus accelerating the introduction of new products and resulting in faster global long-run growth. This seemingly obvious insight has given researchers the impetus to explore how market size affects long-run growth [e.g., Grossman and Helpman (1991, Chapter 5)] and to explore the effects of globalization for countries with identical factor endowments, [e.g., Rivera Batiz and Romer (1991a,b)].

The dependence of long-run growth on market size in earlier endogenous growth models can be traced to the property of scale effects which is a consequence of the assumption that the growth rate of knowledge (i.e., technological progress) is directly proportional to the level of resources devoted to R&D.<sup>2</sup> Jones (1995a) has argued that the scale effects property of earlier endogenous growth models is inconsistent with post-war time-series evidence which shows an exponential increase in R&D resources and a more-or-less constant rate of per-capita GDP growth in all major advanced countries. In addition, the introduction of population growth in earlier endogenous growth models generates unbounded (infinite) per-capita long-run growth. Jones' criticism and the desire to explicitly incorporate the rate of population growth in R&D-based growth models have stimulated the development of a new class of models that generate growth without scale effects.<sup>3</sup> However, the theoretical literature on growth without

scale effects has focused either on the effects of trade liberalization in the case of structurally identical economies, or more recently on the effects of globalization on growth and poverty in the context of North-South models of trade and technology transfer.<sup>4</sup> Importantly, this small but expanding literature has not addressed the question of how globalization affects economic growth, especially when countries differ in relative factor endowments. This paper complements the aforementioned literature by placing at center stage the role of factor endowments and skill intensities in the determination of the dynamic effects of globalization.

The rise of the anti-globalization movement has renewed the policy and academic debate on the pros and cons of globalization. The role of trade liberalization, short term capital flows, multinational corporations, global institutions, and the outsourcing of services and jobs to China and India, on poverty and income distribution within and across countries are central elements of this debate. Bhagwati, (2004) and Stiglitz (2003) respectively provide influential overviews and analysis of globalization. Given the policy importance of these issues and the inherent problems with the quality of international data, there is a need to formally and systematically analyze the economic forces that govern the complex effects of globalization. This paper constructs a two-country dynamic-general equilibrium model of scale-invariant growth to investigate the dynamic effects of globalization.

In the model, the scale-effects property is removed by the introduction of rent-protecting activities (RPAs), as in the closed-economy model developed by Dinopoulos and Syropoulos (1991).<sup>5</sup> These are activities undertaken by firms that produce state-of-the art quality products and aim to prolong their temporary monopoly power by increasing the difficulty of R&D among challengers who try to discover higher quality products. Examples of these activities include investment in trade secrecy, camouflage of innovations through technological complexity, employment of legal teams to litigate potential patent infringements, and patent-blocking (i.e., building a patent fence around a major invention by patenting several related secondary inventions without necessarily introducing the latter into the market).<sup>6</sup>

In the model, there are two countries, Home and Foreign, that may differ in size and or in (relative)

factor abundance. In each country, there is a continuum of structurally identical industries producing final consumption goods, and two factors of production, high-skilled labor and low-skilled labor, with each factor being equal to a fixed fraction of each economy's population. The population in each country grows at a common and exogenously given rate, equal to the growth rate of each factor of production. There are three activities in each industry: manufacturing of final goods, rent-protecting activities (RPAs), and R&D services. Production in each of these activities requires the employment of both factors (though in different proportions when evaluated at the same factor prices) and exhibits constant returns to scale.<sup>7</sup> This framework allows us to use insights from the traditional Heckscher-Ohlin trade model in our study of the dynamic effects of globalization. As in the Grossman and Helpman (1991, Chapter 4) version of the quality-ladders growth model, the quality of each final good can be improved through endogenous innovation. The arrival of innovations in each industry is governed by a memoryless Poisson process whose intensity depends on the ratio of R&D to RPAs. Thus, the present model views innovation as the outcome of sequential and stochastic R&D contests (as opposed to R&D races among challengers).

The analysis generates several novel insights. The market-equilibrium growth rate equals the ratio of the unit-cost function of RPAs over the unit-cost function of R&D services. Since this ratio plays a role very similar to one played by the terms of trade (relative price of exports in terms of imports) in traditional trade theory, we christen this ratio an economy's "terms-of-growth" (TOG). In the long run, the TOG remain constant over time and, owing to constant returns to scale, depends only on factor prices and a parameter related to the effectiveness of RPAs. In other words, long-run growth turns out to be proportional to the "opportunity cost" of RPAs measured in units of R&D services (i.e., the "relative price" of RPAs). A permanent increase in the relative wage of high-skilled labor raises the opportunity cost of RPAs (and thus and the growth rate) if and only if high-skilled labor is used more intensively in RPAs than in R&D (Lemma 1). As a consequence, any policy that causes relative wages to change affects long-run growth through the familiar Stolper and Samuelson (1941) channel that links relative

price changes to changes in factor rewards. In short, Lemma 1 provides a formal link between changes in income distribution and long-run Schumpeterian growth through the intensity ranking of two conflicting forces that determine the expected frequency of innovations: rent-protecting activities and R&D investment.

Lemma 1 provides a novel insight on the long-run effects of one dimension of stronger intellectual property protection. In the model, this effect can be captured by exogenously changing a parameter that captures the effectiveness of RPAs. In a global regime with stronger intellectual property protection, incumbent firms are able to slow down the rate of creative destruction by being more effective in limiting the knowledge spillovers to challengers for any given relative wage level. The model implies that higher protection of intellectual property shifts resources from investment related activities – such as R&D and RPAs – to manufacturing of final consumption goods and therefore benefits the factor of production used intensively in manufacturing (say, less-skilled labor). In addition, under reasonable restrictions on intensities and abundance, Proposition 2 establishes that stronger intellectual right protection reduces long-run growth and innovation. This result complements similar findings in Sener (2003) and Dinopoulos and Segerstrom (2004) which have analyzed the implications of stronger intellectual property protection in the context of North-South models of scale-invariant growth with endogenous imitation. In these models, increasing the difficulty of copying Northern products by Southern firms results in slower growth. Consequently, contrary to the popular notion, dynamic trade theory suggests that agreements like TRIPs (Trade-Related-Intellectual-Property Rights) might have an adverse effect on dynamic R&D competition, innovation and growth.

Armed with Lemma 1, we then put the model to work to analyze the growth effects of introducing trade between two countries that initially differ only in size captured by their level of population. A move from autarky to free trade generates inter-sectoral trade as each country contains a fraction of quality leaders producing the state-of-the-art quality product and enjoying global (temporary) monopoly power at each instant in time. Each country's share of global monopolists is proportional to its size.

However, in the absence of scale effects, a move from autarky to free trade does not affect the relative wage of high-skilled labor and on long-run growth (Proposition 3). In this case, globalization simply redistributes per-capita resources within manufacturing of final consumption goods in each country, but does not affect per-capita resources devoted to R&D and RPAs. In other words, in the model of growth without scale effects considered here, a move from autarky to free trade among similar countries does not affect long-run economic growth. We think that this result remains valid in other models of scale-invariant growth and clarifies the main insight obtained by Dinopoulos and Segerstrom (1999b) where reciprocal tariff reductions affect the level of scale-invariant growth and the relative wage by changing the relative price of innovation (i.e., the TOG).

We also analyze the move from autarky to the integrated world equilibrium (i.e., the equilibrium that would emerge if, in addition to free trade in goods, all factors of production were also internationally mobile). Since the three activities (RPAs, R&D and manufacturing) correspond to different vertical stages of production and there is no outside-good sector, trade in goods is not sufficient to replicate the integrated world equilibrium. In the presence of differences in skill abundance across the two countries, the integrated world equilibrium generates a rich and realistic pattern of global production. Suppose the production of RPAs is more high-skilled labor intensive than the production of R&D services, with manufacturing being the least skilled labor intensive activity. In this case, as the skill abundance of say Home increases relative to the skill abundance of Foreign, the integrated world equilibrium can be maintained, first, through the formation of Home multinationals that establish manufacturing facilities in Foreign to serve each domestic market (horizontal DFI) or to serve the world market (vertical DFI). The same equilibrium is consistent with outsourcing of manufacturing production and jobs from Home to Foreign. However, as the skill abundance differential between Home and Foreign increases, in addition to multinationals and/or manufacturing outsourcing, Home engages in outsourcing R&D services (i.e., exporting high-tech jobs) to Foreign.

We then examine the effects of globalization which we identify with a move from autarky to the

integrated-world equilibrium under the assumptions that the distribution of national factor endowments lies within the factor price equalization set and Home is skill abundant. Under the assumption on the ranking of skill intensities across activities mentioned earlier, Home has a lower relative wage than Foreign under autarky due to its skill abundance and experiences a lower long-run growth rate than Foreign (Proposition 3). In this case, globalization causes the relative wage of skilled labor to be equalized across the two countries and long-run growth rates to converge to a common level. As a result, the high-skilled abundant country's growth rate rises while the low-skilled abundant country's growth rate falls. Exactly the opposite is true if the production of R&D is more high-skilled labor intensive than the production of RPAs (Proposition 5).

Section 2 of the paper develops the two-country model. Section 3 analyzes the properties of the steady-state integrated-world equilibrium. Section 4 examines the effects of globalization on long-run growth. Finally, Section 5 summarizes our findings and identifies several avenues for future research.

## **2. The Model**

We build a two-country dynamic general-equilibrium model of scale-invariant growth that focuses on the effects of globalization on long-run growth and wages. We model the innovation process as a contest between each incumbent global quality leader and challengers. This stands in contrast to traditional quality-ladders growth models which view the discovery of new products as an R&D race among challengers. In the present model, each incumbent quality leader can prolong the expected duration of its global monopoly by engaging in rent-protection activities that reduce the instantaneous probability of further innovation. At the same time, however, challengers in both countries engage in R&D to discover the next higher-quality product that would replace the global quality leader.

In order to simplify the analysis, we assume that all firms in the global economy know how to produce all products that are at least one step below the state-of-the-art quality product in each industry. This assumption prevents the incumbent monopolist from engaging in further R&D and maintains the

inertia-incumbency hypothesis [see Arrow (1962)] which is a standard assumption in most quality-ladders growth models. In other words, incumbent monopolists engage only in RPAs and challengers perform only R&D.<sup>8</sup> It should be noted that the model abstracts from issues of international technology transfer and international knowledge spillovers.<sup>9</sup>

For clarity of exposition, we adopt the following notational conventions. Superscripts identify countries; in particular, superscripts “h” and “f” identify functions and variables of the “Home” and “Foreign” countries, respectively. Functions and variables without superscripts are associated with the global economy. Subscripts identify activities and firms within an industry. The time argument indicates that a variable is growing in the steady-state equilibrium; its absence means that the particular variable remains constant over time.

## 2.1 *The Knowledge-Creation Process*

Each of the two economies is populated by a continuum of structurally identical industries indexed by  $\theta \in [0, 1]$ . In each industry  $\theta$  there are global, sequential and stochastic R&D contests that result in the discovery of higher-quality final products. At time  $t$ , each challenger  $k$  that is located in country  $j \in \{h, f\}$  targeting a quality leader in country  $m \in \{h, f\}$  engages in R&D in industry  $\theta$  that leads to the discovery of the next higher-quality product with instantaneous probability  $I_k^j(\theta, t)$ , where

$$I_k^j(\theta, t) = \frac{Y_k^j(\theta, t)}{D^m(\theta, t)}, \quad (1)$$

with  $Y_k^j(\theta, t)$  denoting the level of R&D services, and  $D^m(\theta, t)$  being a function that captures the difficulty of conducting R&D in industry  $\theta$  at time  $t$ . As will be explained shortly, this function captures the level of rent protection activities (RPAs)

Under the standard assumption (routinely adopted in quality-ladders growth models), that the returns to R&D investment are independently distributed across challengers, countries, industries and



over time, the industry-wide probability of innovation in each country  $j$  is obtained from (1) by summing the levels of R&D services across all challengers in that country

$$I^j(\theta, t) = \frac{Y^j(\theta, t)}{D^m(\theta, t)}, \quad (2)$$

where  $Y^j(\theta, t) = \sum_k Y_k^j(\theta, t)$ . The arrival of innovations in each industry follows a memoryless Poisson process with intensity  $I(\theta, t) = \sum_j Y^j(\theta, t)/D^m(\theta, t)$  which equals the global rate of innovation in a typical industry. An increase in the rate of innovation results in faster long-run economic growth.

We assume that the difficulty of conducting R&D in (1) and (2) [i.e.,  $D^m(\theta, t)$ ] is proportional to the level of RPAs undertaken by a typical quality leader located in country  $m \in \{h, f\}$ ; that is,

$$D^m(\theta, t) = \delta X^m(\theta, t), \quad (3)$$

where  $X^m(\theta, t)$  is the level of RPAs produced by an incumbent global quality leader located in country  $m$ . Parameter  $\delta$  captures the effectiveness (or productivity) of RPAs in increasing the difficulty of conducting R&D. We can think of  $\delta$  as a parameter capturing the efficiency of institutions that safeguard intellectual property.

Equations (2) and (3) reveal that the instantaneous probability of discovering the next higher-quality good is homogeneous of degree zero in R&D and RPAs. Moreover, if an incumbent monopolist does not engage in RPAs, the discovery of the next higher-quality product occurs instantaneously since  $I(\theta, t) \rightarrow \infty$  in this case. In addition, for any finite level of R&D services, the innovation process stops if  $X^m(\theta, t) \rightarrow \infty$ .

## 2.2 *Production Technology*

There are three distinct activities in each industry: manufacturing of final products, rent-protecting services, and R&D services. Each activity is produced under constant returns to scale and employs two

factors of production, high-skilled and low-skilled labor. Let  $w_H^j$  and  $w_L^j$  respectively denote the wages of high-skilled and low-skilled labor in country  $j$ . Moreover, denote with  $Z^j(\theta, t)$ ,  $X^j(\theta, t)$ , and  $Y^j(\theta, t)$  the output of manufactures, RPAs and R&D services produced in country  $j$ , respectively. The technology for each of the three activities can be described by the following cost functions:

$$\alpha_Z(w_H^j, w_L^j)Z^j(\theta, t) \tag{4}$$

$$\alpha_X(w_H^j, w_L^j)X^j(\theta, t) \tag{5}$$

$$\alpha_Y(w_H^j, w_L^j)Y^j(\theta, t), \tag{6}$$

where  $\alpha_i(w_H^j, w_L^j)$  is the unit-cost function associated with activity  $i=Z, X, Y$ . This function is increasing, concave, homogeneous of degree one in its arguments, and has positive cross-partial derivatives. Note that the absence of a superscript in the unit cost functions implies that they are the same across countries, industries and goods of different quality levels.<sup>10</sup>

### 2.3 Population and Households

Let  $N^j(t)$  be country  $j$ 's population at time  $t$ . We assume that each country's population is growing at a common, constant, exogenously given rate  $g_N = \dot{N}^j(t)/N^j(t) > 0$ , and that it is partitioned into high and low-skilled workers. In order to keep the analysis as simple as possible, we assume that each worker supplies one unit of labor and that a (fixed) fraction  $s^j \in (0, 1)$  of country  $j$ 's population consists of high-skilled workers with the remaining population fraction consisting of low-skilled workers. Consequently, country  $j$ 's endowment of high-skilled labor is  $H^j(t) = s^j N^j(t)$ , whereas its endowment of low-skilled labor is  $L^j(t) = (1 - s^j) N^j(t)$ . Over time, both endowments grow exponentially at the rate  $g_N$ ; that is,

$$\frac{\dot{H}^j(t)}{H^j(t)} = \frac{\dot{L}^j(t)}{L^j(t)} = \frac{\dot{N}^j(t)}{N^j(t)} = g_N, \tag{7}$$

where  $N(t) = N^h(t) + N^f(t)$  is the world population at time  $t$ .<sup>11</sup>

In each country  $j$  there is a continuum of identical households of measure  $N_0^j$ . Each household consists of infinitely-lived members and is modeled as a dynastic family whose size grows over time at an exogenous rate  $g_N$ . Country  $j$ 's population, as well as the number of each household's members, at time  $t$  is  $N^j(t) = N_0^j e^{t g_N}$  where  $N_0^j$  is the initial population. All households within a country are identical but countries may differ in the fraction of high-skilled workers. Each household in country  $j$  maximizes the discounted utility

$$U \equiv N_0^j \int_0^{\infty} e^{g_N t} e^{-\rho t} \log u(t) dt, \quad (8)$$

where  $\rho > 0$  is the subjective discount rate,  $\rho - g_N > 0$  is the effective discount rate, and  $\log u(t)$  is the per-capita utility at time  $t$ , defined as

$$\log u(t) \equiv \int_0^1 \log \left[ \sum_i \lambda^i Z(i, \theta, t) \right] d\theta. \quad (9)$$

$Z(i, \theta, t)$  is the quantity consumed of a good of quality  $i$  (i.e., a product that has experienced  $i$  quality improvements) and produced in industry  $\theta \in [0, 1]$  at time  $t$ . Parameter  $\lambda > 1$  measures the size of quality improvements (i.e., the magnitude of innovations).

At each instant in time each household allocates income to maximize (9) taking product prices as given. The solution to this maximization problem yields a Cobb-Douglas demand function

$$Z^j(i, \theta, t) = \frac{c^j(t) N^j(t)}{p^j(t)}, \quad (10)$$

where  $c^j(t)$  is country  $j$ 's per-capita consumption expenditure and  $p^j(t)$  is the relevant market price for each good. Because within each industry goods adjusted for quality are by assumption identical [see (9)], only the good with the lowest quality-adjusted price is consumed, since there is no demand for any

other good.<sup>12</sup> The global demand for a particular product is given by aggregating (9) across all consumers in the global economy to obtain  $Z(i, \theta, t) = Z^h(i, \theta, t) + Z^f(i, \theta, t)$ .

Maximizing (8) subject to the standard inter-temporal budget constraint and taking into account (10) generates the standard differential equation that governs the evolution of per-capita consumption expenditure

$$\frac{\dot{c}^j(t)}{c^j(t)} = r^j(t) - \rho, \quad (11)$$

where  $r^j(t)$  is the instantaneous market interest rate that prevails in country  $j$  at time  $t$ . Equation (11) implies that a constant per-capita consumption expenditure is optimal when the instantaneous interest rate in each country equals the consumer's subjective discount rate  $\rho$ .

#### 2.4 *Innovation Contests*

At each instant in time, a typical industry is served by a quality leader, the only global producer of the state-of-the-art quality product. This producer is targeted by challengers from both countries who engage in R&D to discover the next higher-quality product and replace the incumbent technology leader. The latter enjoys temporary global monopoly power and spends resources on rent protection activities (RPAs) in order to prolong its market position. We assume that firms compete in prices in product markets, each incumbent quality leader chooses the level of RPAs optimally to maximize expected discounted profits and so does each challenger when choosing the level of R&D. Challengers enter each innovation contest until expected discounted profits associated with R&D are driven down to zero.

Since the arrival of innovations in each industry is governed by a Poisson process with intensity  $I(Y, X)$ , we can model the strategic interactions between a typical incumbent and its challengers as a differential game for Poisson jump processes. In Dinopoulos and Syropoulos (2001) we formally solve this game. In this paper, we provide an informal and intuitive derivation of the equilibrium conditions

that closely follows the methodology employed by quality-ladders growth models.

At each instant in time, a global quality leader located in country  $j$  produces the state-of-the-art quality product and earns a flow of profits

$$\pi^j(t) = \sum_{k \in \{h, f\}} \left( \left[ p^k(t) - \alpha_Z(w_H^k, w_L^k) \right] \frac{c^k(t)N^k(t)}{p^k(t)} \right) - \alpha_X(w_H^j, w_L^j)X^j(t), \quad (12)$$

where the summation denotes the flow of monopoly profits in country  $k$ . The last term in (12) captures the cost of RPAs a quality leader incurs at time  $t$ . Expression (12) assumes that both the manufacturing of final goods and the production of RPAs is located in country  $j$ . Section 4 relaxes this assumption. The argument  $\theta$ , which indexes a particular industry, is omitted for notational simplicity because all industries are structurally identical. Following Dinopoulos and Segerstrom (1999), we assume that all firms in the world know how to produce products that are one or more steps below the highest-quality available good in each industry's quality ladder prevents the incumbent monopolist from engaging in R&D to discover the next higher-quality product. Therefore, as mentioned above, each incumbent quality leader engages in RPAs, and each challenger invests in R&D.

There is a global stock market that supplies consumer savings to firms engaged in R&D. Since there is a continuum of structurally identical industries, each consumer can diversify completely the industry-specific risk associated with the discovery of new products. In addition, each investor can hold a portfolio of foreign and domestic bonds. This implies that the market interest rate,  $r(t)$ , is the same in both countries and is equal to the rate of return offered by a completely diversified portfolio. At each instant in time, each challenger issues securities promising to pay the flow of global monopoly profits (divided by the number of shares) if the firm wins the innovation contest and zero otherwise. The money earned from the sale of these securities is equal to the wage bill of workers engaged in R&D. At each instant in time, there are two types of securities in the stock market. Those which issued by challengers and those issued by winners of an R&D contest.

Consider now the stock-market valuation of temporary monopoly profits. Let  $V^j(t)$  denote the expected global discounted profits of a successful innovator located in country  $j$ , and let  $I(t)$  be the industry's global rate of innovation, which equals the instantaneous probability of discovering a higher-quality product. Because  $I(t)$  is the industry's hazard rate, a shareholder faces a capital loss equal to  $V^j(t)$  if further innovation occurs. This event occurs with instantaneous probability  $I(t) dt$ . In addition, over a time interval  $dt$ , the shareholder receives a dividend  $\pi^j(t) dt$  and the value of the quality leader's stock appreciates by  $dV^j(t) = [\partial V^j / \partial t] dt = \dot{V}^j(t) dt$  if the incumbent quality leader is not replaced. The survival probability is given by  $1 - I(t) dt$ . The absence of profitable arbitrage opportunities means that the expected rate of return on a stock issued by a successful innovator must equal to the market interest rate; that is,

$$\frac{\dot{V}^j(t)}{V^j(t)} [1 - I dt] dt + \frac{\pi^j(t)}{V^j(t)} dt - \frac{[V^j(t) - 0]}{V^j(t)} I dt = r dt.$$

Taking limits as  $dt$  approaches zero and solving for  $V^j(t)$  yields the following expression for the value of innovation in a particular industry:

$$V^j(t) = \frac{\pi^j(t)}{r + I - \dot{V}^j(t)/V^j(t)}, \quad (13)$$

where the flow of economic profits  $\pi^j(t)$  is defined by (12) and  $I = Y(t)/\delta X^j(t)$  is the hazard rate (i.e., the risk of default) associated with a typical industry whose production is located in country  $j$ .

Let us consider now the economic problem of a typical challenger  $k$  located in country  $j \in \{h, f\}$  targeting a quality leader from country  $m \in \{h, f\}$ . Challenge  $k$ 's expected discounted profits are

$$V^j(t) \frac{Y_k^j(t)}{D^m(t)} dt - \alpha_Y(w_H^j, w_L^j) Y_k^j(t) dt,$$

where  $I_k^j dt = [Y_k^j(t)/D^m(t)] dt$  is the instantaneous probability of discovering the next higher-quality good,  $V^j(t)$  is the reward to R&D, and the last term is the cost of R&D services over an infinitesimal period of time. Free entry into each R&D contest drives each challenger's expected discounted profits down to zero thereby resulting in the following zero-profit condition:

$$\frac{V^j(t)}{D^m(t)} = \alpha_Y(w_H^j, w_L^j). \quad (14)$$

Equation (14) states that the price of innovation adjusted for the difficulty of conducting R&D, which is proportional to the level of rent-protection activities, equals the unit cost of conducting R&D.

We proceed with analyzing the maximization problem of a successful quality leader located in country  $m \in \{h, f\}$  and facing challengers from both countries. This firm chooses the price of its product and the level of RPAs to maximize its expected discounted profits in (13). When maximizing (13) the global quality leader behaves in a Nash fashion taking each challenger's actions and the growth rate of expected discounted profits as given. The assumptions that goods within an industry are identical (when adjusted for quality) and Bertrand price competition in product markets means that each quality leader engages in limit pricing. In addition, the absence of trade barriers and the assumption that the technology of all products with lower quality than the state-of-the-art product in each industry is public knowledge imply that the quality leader charges a single price, which is  $\lambda$  times the lowest manufacturing cost between the two countries (i.e., the lowest possible price of the product one step below in the quality ladder); that is,

$$p = \lambda \min \{ \alpha_Z(w_H^h, w_L^h), \alpha_Z(w_H^f, w_L^f) \}.$$

Maximizing (12) with respect to the level of RPAs,  $X^m(t)$ , yields the following equilibrium condition:

$$\frac{V^m(t)}{D^m(t)} = \frac{\alpha_X(w_H^m, w_L^m)}{\delta I}. \quad (15)$$

Equation (15) relates the rate of innovation to the relative price of rent protection. To see this imagine that RPAs are produced under perfect competition so that their market price equals the unit cost  $\alpha_X$ . Then, the left-hand-side of (15) is proportional to the relative price of innovation, measured by the expected discounted profits adjusted for the difficulty of R&D. Equation (14) implies that the relative price of innovation equals the unit costs of R&D. Consequently, combining these two profit-maximizing conditions and solving for the rate of innovation yields  $I = \alpha_X/\delta\alpha_Y$ . This is simply the dual of (2) and provides one of the main insights of the paper; that is, the rate of innovation is proportional to the relative price of RPAs and depends on relative factor prices. Thus, the removal of scale effects in this model sets comparative-advantage considerations (captured by relative prices) at center stage of scale invariant endogenous growth theory.

## 2.5 Labor Markets

We assume that the market for each type of labor clears instantaneously. In order to derive the full-employment conditions for high- and low-skilled labor, we must calculate the steady-state distribution of Home and Foreign quality leaders across the continuum of industries. Denote with  $\beta^h$  the steady-state fraction (measure) of industries with a Home quality leader and with  $\beta^f (= 1 - \beta^h)$  the fraction of industries with a Foreign quality leader. Since each industry is targeted by both Home and Foreign challengers, with instantaneous probability  $I^h dt = [Y^h(t)/D^f(t)]dt$  a Home challenger discovers a higher quality product and an industry with a Foreign leader is transformed into an industry with a Home leader. Since there are  $\beta^f$  industries with Foreign quality leaders, the flow of industries that are transformed into Home-quality-leader industries is equal to  $\beta^f I^h dt = (1 - \beta^h) I^h dt$ . This flow must be equal to the flow of industries with Home quality leaders that are transformed into industries with Foreign quality leaders  $\beta^h I^f dt = (1 - \beta^f) I^f dt$ , and therefore  $\beta^j = I^j/I$  for  $j=h, f$ .



Using Shephard's Lemma, we may let  $\phi_i(w_H^j, w_L^j) = \partial\alpha_i/\partial w_H^j$  denote the unit-labor requirement for high-skilled labor employed in activity  $i = Z, X, Y$ . Country  $j$ 's full-employment condition for high-skilled labor is derived as follows. The supply of high-skilled labor in country  $j$  equals  $s^j N^j(t)$ . The demand for high-skilled labor has three components. First, there are  $\beta^j$  quality leaders in country  $j$  and each of them supplies the global market with  $Z(t) = [c^h N^h(t) + c^f N^f(t)]/p$  units of final output. Each unit of output requires  $\phi_Z$  units of high-skilled labor. Therefore the demand for manufacturing labor in country  $j$  is  $\beta^j Z(t) \phi_Z$ . Second, the demand for high-skilled labor in rent-protecting activities is  $\beta^j X^j(t) \phi_X$ . There are  $\beta^j$  quality leaders located in country  $j$ , each of which produces  $X^j(t)$  units of RPAs, and each unit of which requires  $\phi_X$  amount of high-skilled labor. Third, the demand for high-skilled labor in R&D in each industry  $j$  is  $Y^j(t) \phi_Y$ . All industries are targeted by challengers, each industry produces  $Y^j(t)$  units of R&D services, and  $\phi_Y$  is the amount of high-skilled labor required for the production of one unit of R&D services. Because each economy has a continuum of structurally identical industries of measure one and all industries are targeted by challengers everywhere, it follows that the demand for high-skilled labor in each industry equals the economy-wide demand for R&D services in country  $j$ . Consequently the full-employment condition for high-skilled labor in country  $j$  ( $= h, f$ ) is

$$s^j N^j(t) = \beta^j Z(t) \phi_Z(w_H^j, w_L^j) + \beta^j X^j(t) \phi_X(w_H^j, w_L^j) + Y^j(t) \phi_Y(w_H^j, w_L^j). \quad (16)$$

Using Shephard's Lemma again, denote with  $\psi_i(w_H^j, w_L^j) = \partial\alpha_i/\partial w_L^j$  the amount of low-skilled labor required for the production of one unit of output in activity  $i = X, Y, Z$ . Calculations similar to the derivation of (16) generate the following full-employment condition for low-skilled labor in country  $j$ :

$$(1 - s^j) N^j(t) = \beta^j Z(t) \psi_Z(w_H^j, w_L^j) + \beta^j X^j(t) \psi_X(w_H^j, w_L^j) + Y^j(t) \psi_Y(w_H^j, w_L^j). \quad (17)$$

The above four full-employment conditions hold at each instant in time under the assumption that there is no multinational production and/or outsourcing of RPAs and R&D across the two countries. We relax

this assumption later in Section 4. Equations (16) and (17) complete the description of the model.

### 3. Steady-State Integrated-World Equilibrium

In this section we establish the existence of a unique steady-state equilibrium for the integrated-world economy. By an integrated-world-economy equilibrium we mean the resource allocation that would arise when goods, services and factors of production are all perfectly mobile across activities and countries. In other words, we will treat the world as a closed economy. In this equilibrium, factor prices are equalized across the two countries and are constant over time, i.e.,  $w_H^j = w_H$  and  $w_L^j = w_L$  for  $j = h, f$ . In addition, all per-capita variables are constant over time as well. For example,  $\dot{c}^j = 0$  and therefore (11) implies  $r(t) = \rho$ ; the per-capita level of RPAs,  $x^j = X^j/N^j(t)$ , is also time invariant. This property together with (14) imply that the levels of RPAs and the reward to innovation grow at the constant rate of population growth [i.e.,  $\dot{X}^j(t)/X^j(t) = \dot{V}^j(t)/V^j(t) = \dot{N}^j(t)/N^j(t) = g_N$ ]. Factor-price equalization implies that the equilibrium price of final consumption goods can be written as

$$p = \lambda \alpha_Z(w_H, w_L). \quad (18)$$

Equation (14) implies that  $V^h(t)/X^h(t) = V^f(t)/X^f(t)$  which means that the level of RPAs does not differ across industries. Substituting (18) into (12) yields the following expression for the flow of monopoly profits

$$\pi(p, X, t) = \frac{(\lambda - 1)}{\lambda} [c^h N^h(t) + c^f N^f(t)] - \alpha_X(w_H, w_L) X(t). \quad (19)$$

Moreover, incorporating the above results into (13) leads to the standard expression for the expected discounted profits in each industry

$$V(t) = \frac{\pi(t)}{\rho + 1 - g_N}. \quad (20)$$

In the spirit of other quality-ladders growth models, we can derive a deterministic expression for the instantaneous per-capita utility  $\log u(t)$ , which is the appropriate measure of real per-capita income in the integrated equilibrium. Substituting per-capita demand for final consumption goods  $z^j = c^j/p$ , where  $p$  is given by (18), into (9) yields<sup>13</sup>

$$\log u(t) = \log [c^j/\lambda \alpha_z] + tI \log \lambda. \quad (21)$$

Subutility  $u(t)$  captures the appropriate quality-weighted (real) consumption index in quality ladder growth models.<sup>14</sup> The economy's per-capita long-run growth can be defined as the growth rate of subutility  $u(t)$  in (21). Differentiating (21) with respect to time yields

$$g_U = \frac{\dot{u}(t)}{u(t)} = I \log \lambda. \quad (22)$$

Because the quality increment  $\lambda$  is a parameter capturing the size of innovations, long-run growth can be affected only through changes in the rate of innovation  $I$ . One can obtain a simple expression for the latter by combining (14) and (16) and using the linear homogeneity of unit input requirements in factor prices; that is,

$$I = \frac{\alpha_X(w_H, w_L)}{\delta \alpha_Y(w_H, w_L)} = \frac{\alpha_X(\omega, 1)}{\delta \alpha_Y(\omega, 1)}, \quad (23)$$

where  $\omega = w_H/w_L$  is the relative wage of high-skilled labor.

Equation (23), which holds both out and in the steady-state equilibrium, provides several insights on the channels that affect long-run growth. According to (23), the rate of innovation is proportional to the ratio of two unit-cost functions  $\alpha_X(\omega, 1)/\alpha_Y(\omega, 1)$ . The numerator of this ratio is the unit-cost function of rent-protecting activities and the denominator is the unit-cost function of R&D services. We

christen this ratio the economy's "terms of growth" (TOG) because it can be interpreted as the "relative price" of rent-protecting activities" expressed in units of R&D services, and it plays a role which is very similar to the role of terms of trade in static models of international trade. An economy with higher TOG experiences faster long-run economic growth.

Parameter  $\delta$  can be interpreted as a measure of intellectual property protection because higher values of this parameter imply that incumbents can limit more easily the flows of knowledge spillovers to challengers. For instance, stronger protection of intellectual property established by the TRIPs (Trade Related Intellectual Property Rights) agreement in the Uruguay Round, implies that patent infringement litigation becomes more effective for any given level of RPAs. What is the impact of stronger intellectual rights protection on long-run growth? It is obvious from (23) that, for any given value of the relative wage  $\omega$ , an increase in the productivity of RPAs,  $\delta$ , causes the long-run growth to fall.

Because we are interested in the effects of globalization on long-run growth, it is useful to establish the precise mechanism by which a change in the relative wage of high-skilled labor affects the rate on innovation and long-run growth. Differentiating (23) with respect to  $\omega$  yields

$$\frac{\partial I}{\partial \omega} = \frac{\Psi_X \Psi_Y}{\delta (\alpha_Y)^2} \left( \frac{\Psi_X}{\phi_X} - \frac{\Psi_Y}{\phi_Y} \right) = \frac{\Psi_X \Psi_Y}{\delta (\alpha_Y)^2} (h_X - h_Y), \quad (24)$$

where  $h_i \equiv \psi_i / \phi_i$  denotes the skill intensity (ratio of high-skilled to low-skilled labor) in activity  $i=X,Y,Z$ .

The Appendix provides the detailed derivation of (24). The following lemma summarizes the above results:

**Lemma 1:** *(Long-Run Growth Channels) An increase in intellectual property rights protection*

*captured by the effectiveness of rent-protecting activities,  $\delta$ , reduces the rate of innovation,  $I$ , for any given value of the relative wage  $\omega = w_H/w_L$ . In the absence of factor intensity reversals, an increase in the relative wage of high-skilled labor  $\omega$  raises the economy's terms of growth (TOG)*

*and the rate of innovation,  $I$ , if and only if the production of rent-protecting activities uses high-skilled labor more intensively than the production of R&D services (i.e., iff  $h_X > h_Y$ ).<sup>15</sup>*

**Proof:** See (23) and (24).

The intuition behind Lemma 1 is straightforward. An increase in the relative wage of high-skilled labor raises the unit costs of both R&D and RPAs. However, an increase in  $\omega$  causes the unit cost of the activity that uses high-skilled labor intensively (i.e., has a higher share of unit costs associated with high-skilled labor) to rise relatively more causing an increase in the TOG and the rate of innovation.

Lemma 1 has interesting implications for the empirics of long-run growth. For example, it provides a possible explanation of why many variables have been correlated with long-run growth in cross-country regressions [Barro and Sala-i-Martin (1995)]. According to Lemma 1, any variable that is correlated with the relative wage,  $\omega$ , will also be correlated with the rates of innovation and long-run growth. However, if factor intensity reversals do not arise and the technology of RPAs differs across countries, then these correlations will be weak. Further, Lemma 1 introduces into the analysis the familiar Stolper-Samuelson mechanism that links changes in relative wages to the rate of innovation (as opposed to Rybczynski type of effects that relate changes in factor endowments with long-run growth, as emphasized in earlier models of Schumpeterian growth.)<sup>16</sup>

Because the TOG depend on the relative wage of skilled labor, which is an endogenous variable that is affected by virtually all parameters, we proceed to analyze the steady-state market equilibrium and examine how relative factor abundance and country size affect the relative wage of high-skilled labor. Factor price equalization implies that the unit-labor requirements and units cost of production do not differ across the two countries. Therefore, we can aggregate the supply and demand for high-skilled and low-skilled labor of the world economy, respectively, and derive two (as opposed to four) full-employment conditions for the steady-state integrated-world equilibrium.

Let  $H(t) = s^h N^h(t) + s^f N^f(t)$  and  $L(t) = (1-s^h)N^h(t) + (1-s^f)N^f(t)$  be the world endowments of high-skilled labor low-skilled labor, respectively, which grow at the rate of population growth  $g_N$ . Also, let  $z = Z(t)/N(t)$ ,  $x = X(t)/N(t)$ ,  $y = Y(t)/N(t)$  be the per-capita world levels of final consumption good, rent-protecting activities and R&D services, respectively. Equation (16) help obtain the per-capita full employment condition for high-skilled labor in the integrated-world equilibrium:

$$\frac{H(t)}{N(t)} = z\varphi_Z(w_H, w_L) + x\varphi_X(w_H, w_L) + y\varphi_Y(w_H, w_L). \quad (25)$$

Similarly, (17) yields the per-capita full-employment condition for low-skilled labor:

$$\frac{L(t)}{N(t)} = z\psi_Z(w_H, w_L) + x\psi_X(w_H, w_L) + y\psi_Y(w_H, w_L). \quad (26)$$

The integrated-world equilibrium can be established by combining (25) and (26) and expressing the per-capita levels  $z$ ,  $x$  and  $y$  as functions of the relative wage of high-skilled labor. Let  $\sigma_i(\omega) \equiv w_H \varphi_i / \alpha_i$  be the share of high-skilled labor in the unit cost of activity  $i = Z, X, Y$ . In the Appendix we provide the algebraic details on the derivation of following equation that determines the equilibrium relative wage of high-skilled labor  $\omega$  as a function of the model's parameters:

$$\frac{H(t)}{L(t)} = \frac{1}{\omega} \left[ \frac{\frac{1}{\lambda-1} \left[ 2 + (\rho - g_N) \frac{\delta\alpha_Y(\omega)}{\alpha_X(\omega)} \right] \sigma_Z(\omega) + \sigma_X(\omega) + \sigma_Y(\omega)}{\frac{1}{\lambda-1} \left[ 2 + (\rho - g_N) \frac{\delta\alpha_Y(\omega)}{\alpha_X(\omega)} \right] [1 - \sigma_Z(\omega)] + [1 - \sigma_X(\omega)] + [1 - \sigma_Y(\omega)]} \right]. \quad (27)$$

The left-hand-side of (27) is the world economy's relative supply of high-skilled labor (i.e., the world's skill abundance). Because both  $H(t)$  and  $L(t)$  grow at the rate of population growth, the world economy's skill abundance remains constant over time. The right-hand-side of (27) is the relative

demand for high-skilled labor. We will focus on the standard case in which the right-hand-side of (27) is a decreasing function of the relative wage of high-skilled labor, which essentially requires the relative demand for high-skilled labor to be downward-sloping. It is easy to identify sufficient conditions that ensure this. For example, if RPAs are more intensive in high-skilled labor as compared to R&D, then it is sufficient to assume that the elasticity of substitution between high-skilled and low-skilled labor in production of each of the three activities is greater or equal to unity. The latter assumption ensures that each per-unit cost share of high-skilled labor is a non-increasing function of the relative wage of high-skilled labor. If the skill intensity of RPAs is lower than that of R&D, then a sufficient condition for a downward-sloping relative demand for high-skilled labor is that the elasticity of factor substitution in manufacturing of final goods must be sufficiently greater than one and that the elasticities of factor substitution in the other two activities must be equal or greater than unity. From now on, we assume that these conditions are satisfied. These ideas can be summarized as follows:

**Proposition 1:** *The integrated world economy has a unique steady-state equilibrium such that*

- a) *the rate of innovation,  $I$ , per capita consumption expenditure,  $c$ , the relative wage of high-skilled labor,  $\omega$ , per-capita RPAs,  $x$ , and per-capita R&D investment,  $y$ , are all constant over time and bounded;*
- b) *long-run Schumpeterian growth,  $g_U$ , is endogenous and does not exhibit scale effects.*

The endogeneity of long-run growth has been established by Lemma 1, since any policy change that affects the relative wage of high-skilled labor (i.e., an R&D subsidy, a relative wage subsidy, a tariff) has a permanent impact on the TOG, the rate of innovation and long-run growth. Fig. 1 illustrates the steady-state integrated world equilibrium by plotting the relative supply and relative demand curves for high-skilled labor. The relative supply curve, RS, corresponds to the left-hand-side of (27) and is the vertical line in the figure. The relative demand for high-skilled labor RD corresponds to the right-hand-

side of (27) and is the negatively-sloped curve. The unique intersection between the two curves at point E determines the steady-state value of the relative wage  $\omega^*$ . Once the equilibrium relative wage is determined, the rest of the endogenous variables are determined as well.

Also notice that, in the absence of population growth (i.e.,  $g_N = 0$ ), the integrated-world economy experiences positive and endogenous long-run growth. In contrast, a class of Schumpeterian growth models [e.g., Jones (1995b) and Segerstrom (1998), among others] yield zero long-run growth if the economy's population is not growing. Consequently, the present model represents a novel generalization of earlier endogenous-growth models.

We proceed with analyzing the effect of various parameter changes on the rate of innovation, long-run growth and wages. In order to structure the discussion and exposition, for the remaining analysis we will assume a particular ranking of skill intensity across all three activities: rent protection activities is the activity with the highest skill intensity followed by R&D, which in turn exceeds the skill intensity of manufacturing. In other words, without loss of generality, we will assume that  $h_X > h_Y > h_Z$ . The reader can easily modify the results of the analysis to alternative assumptions regarding the intensity ranking across activities. We will also assume that there are no factor-intensity reversals, namely that the above skill intensity ranking holds for all values of admissible factor prices (i.e., for all values of  $\omega$ ).

Equation (23) and Fig. 1 can be used to perform standard comparative statics exercises. For example, an increase in the growth rate of population,  $g_N$ , or a decline in the subjective discount rate,  $\rho$ , raises the demand of high-skilled labor, for any given value of the relative wage,  $\omega$ , if and only if manufacturing is the least high-skilled labor intensive activity [i.e., iff  $(\sigma_X - \sigma_Z) + (\sigma_Y - \sigma_Z) > 0$  which follows from the assumption  $h_X > h_Y > h_Z$ ]. In this case, an economy with faster population growth, or lower interest rates, enjoys a higher wage of high-skilled labor and a higher rate of long-run growth if and only if rent-protecting activities use high-skilled labor more intensively than R&D services (see Lemma 1). In other words, the growth effect of a change in the rate of population growth is governed by factor intensity rankings across activities. Consequently, changes in the rate of population growth have



an ambiguous effect on long-run growth. This prediction is consistent with cross-country growth regressions reported in Dinopoulos and Thompson (2000), where the correlation between per-capita long-run growth and population growth is not statistically significant.

What are the general-equilibrium steady-state effects of stronger intellectual property protection, captured by an increase in  $\delta$ , on long-run growth and income distribution? An increase in  $\delta$  reduces the relative demand for high-skilled labor in Fig. 1 if manufacturing is the least high-skilled labor intensive activity and lowers the relative wage of high-skilled labor. The Appendix of the paper establishes that, as long as the relative demand of skilled labor is sufficiently steep, or if rent-protection activities are more skilled-labor intensive than R&D, an increase in intellectual property protection reduces the rate of innovation and long-run growth. This result is consistent with similar theoretical findings in dynamic North-South models developed by Dinopoulos and Segerstrom (2004) and Sener (2003). In these models, Northern products are copied endogenously by Southern firms, and stronger intellectual property is modeled as an increase in the difficulty of imitation. Both of these studies find that stronger intellectual property protection reduces temporary or permanently the rate of economic growth and widens the North-South wage gap. Consequently, this model suggests that agreements like TRIPs will be supported by owners of factors that are used intensively in manufacturing and opposed by owners of factors used intensively in investment activities. In addition, unlike the popular perception, the TRIPs agreement might not necessarily promote long-run growth and innovation.

The following proposition describes the effects of stronger intellectual property protection:

**Proposition 2:** *Stronger intellectual property protection, captured by parameter,  $\delta$ , benefits the factor of production used more intensively in manufacturing of final consumption goods (i.e., lower-skilled labor). A global economy with stronger-intellectual property protection experiences slower long-run growth and innovation if rent-protection activities are sufficiently more skilled-labor intensive than R&D (if  $h_x > h_y$ ), if the elasticity of factor substitution in each activity is equal to*

unity, or if the economy's skill abundance ( $h = H(t)/L(t)$ ) is sufficiently high.

**Proof:** See the Appendix.

It is also straight forward to analyze the effects of an increase in factor abundance  $H(t)/L(t)$  on long-run growth and wages with the help of Fig. 1. An economy with higher skill abundance is characterized by lower relative wage of skilled-labor (this is a purely supply effect), but the effects of a higher relative wage of skilled labor on growth are ambiguous and depend on the skill intensity ranking between RPAs and R&D. The following proposition summarizes the effects of higher factor abundance:

**Proposition 3:** *An economy with higher skilled-labor abundance,  $H(t)/L(t)$ , has a lower relative wage of high-skilled labor,  $\omega$ , and experiences lower long-run growth if and only if the skill intensity of rent-protecting activities exceeds the skill intensity of R&D (i.e., iff  $h_x > h_y$ ).*

**Proof:** It follows from Fig. 1 and Lemma 1.

Proposition 3 states that an economy experiences faster long-run growth, if R&D uses its abundant factor more intensively than RPAs. This is so because the opportunity cost of R&D services is “cheaper” than that of RPAs in economies with higher relative skill abundance.

#### **4. Globalization, Comparative Advantage and Long-Run Growth**

This section analyzes the effects of a move from autarky (closed economy) to the steady-state integrated world equilibrium by considering two distinct cases. First, we consider the case of two countries that are identical in all respects except the sizes of their population. Second, we examine the growth and income distribution effects of globalization in the more general case where Home and Foreign have different proportions of high-skilled workers. For specificity (but no loss of generality) we assume that Home is

high-skilled labor abundant. We also assume that the per-capita distribution of world factor endowments across the two countries lies within the “factor-price-equalization set” (to be defined below). This assumption simply means that trade will bring about (productivity-adjusted) factor price equalization. This case allows us to highlight the interaction between differences in activity-specific skill intensities and differences in factor proportions across the two countries. The phrase “a move from autarky to the integrated-world equilibrium” is used loosely to imply a comparison between two structurally identical economies with one economy in autarkic steady-state and the other in the integrated-world steady-stage equilibrium. In other words, we abstract from analyzing the transitional dynamics from autarky to free trade. Finally, it should be noted that when countries differ in factor abundance, trade in consumption goods is not sufficient to equalize the relative wage of skilled labor between the two countries. In addition to intra-sectoral trade, the model generates multinationals and outsourcing of manufacturing and/or services.

The first case can be illustrated with the help of Fig. 1. By assumption,  $s^h = s^f = s$  but  $N^h \neq N^f$ , therefore, the relative supply of high-skilled labor in each country coincides with that of the integrated world economy; that is,  $H(t)/L(t) = H^j(t)/L^j(t) = s/(1 - s)$ . Since (27) describes both the autarky and integrated-world equilibria, each country’s relative supply curve will coincide with RS in Fig. 1. Further, as can be seen in (27), both countries grow at the same rate and have the same autarkic relative wage,  $\omega^*$ , regardless of their exact differences in population-size. A move from autarky to the integrated world equilibrium does not affect the rate of innovation and long-run growth in either of the two countries.

Nonetheless, globalization generates intra-sectoral trade between the two countries even if it does not change their growth rates. This is so because a fraction  $\beta^j = N^j(t)/N(t)$  of industries are populated by country  $j$ ’s quality leaders enjoying temporary global monopoly power and serving consumers in both Home and Foreign. In the absence of multinational enterprises, each industry experiences random shifts in the location of production, and resources devoted to exports and imports in each country grow at the rate of population growth.

**Proposition 4:** *Assume that Home and Foreign differ only in size measured by the level of population.*

*A move from autarky to trade generates intra-sectoral trade, but does not have any effects on the relative wage of high-skilled labor,  $\omega$ , or long-run growth,  $g_U$ .*

**Proof:** It follows from Fig. 1 and Lemma 1.

Proposition 4 highlights the difference between this model and earlier models of endogenous growth with scale effects that have analyzed the impact of globalization in the context of two structurally identical economies [e.g., Rivera-Batiz and Romer (1991a)]. The older models generate a positive effect of trade on long-run growth which is based on the existence of scale effects. Here the growth scale effects are removed by introducing rent-protecting activities and the introduction of trade does not affect factor prices and endogenous long-run growth.

To see the intuition for this result more clearly consider the case of two structurally identical economies, as in Rivera-Batiz and Romer (1991a), or as in Dinopoulos and Segerstrom (1999b) where  $N^h(t) = N^f(t)$  and  $s^h = s^f$ . In this case, a move from autarky to free trade results in each country having quality leaders in fifty percent of all industries. There is a resource reallocation from import competing to exporting industries in each country, but since in the integrated equilibrium the number of consumers served by each quality leader is twice as large as the number of consumers served in autarky, the introduction of trade does not change per-capita resources devoted to R&D and RPAs. Thus, the removal of scale effects removes the market-size impact of international trade that was discovered and discussed extensively in earlier endogenous growth models [e.g., Grossman and Helpman (1991, Chapter 5)].

The second case focuses on the effects of globalization on the relative wage,  $\omega$ , and on long-run growth,  $g_U$ , when countries differ in skill abundance. Fig. 2 illustrates this case, under our assumption that Home is skill-abundant [i.e.,  $H^h(t)/L^h(t) > H(t)/L(t) > H^f(t)/L^f(t)$ ]. This case arises if a higher proportion of Home's population is high-skilled workers (i.e.,  $s^h > s^f$ ). Since this implies that Home's

relative supply of high-skilled labor,  $RS^h$ , is located to the right of Foreign's relative supply,  $RS^f$ , and both countries face the same downward-sloping relative demand curve RD, Home's relative wage of high-skilled labor is lower than Foreign's (i.e.,  $\omega^h < \omega^f$ ). Thus, a move from autarky to the integrated-world equilibrium causes Home's relative wage to rise  $\omega^h$  to  $\omega^*$  and Foreign's relative wage to fall from  $\omega^f$  to  $\omega^*$ . At the integrated-world equilibrium, both countries enjoy the same rate of long-run growth. Therefore, as in the traditional static Heckscher-Ohlin trade model, globalization brings equalization in factor prices and benefits the abundant factor of production.

Given our assumptions on no factor intensity reversals (i.e., the ranking of skill intensities across the three activities remains unchanged for all values of  $\omega$ ) and the skill intensity of RPAs exceeds the skill intensity of R&D (i.e.,  $h_X > h_Y$ ), Home's long-run growth is lower than Foreign's at the initial equilibrium. In this case globalization raises Home's long-run growth but reduces Foreign's growth.<sup>17</sup>

Finally, notice that the relative supply of world high-skilled labor can be expressed as

$$\frac{H(t)}{L(t)} = \left( \frac{H(t)^h}{L(t)^h} \right) \frac{L(t)^h}{L(t)} + \left( \frac{H(t)^f}{L(t)^f} \right) \frac{L(t)^f}{L(t)}. \quad (28)$$

Because  $L(t) = L(t)^h + L(t)^f$ , the world's relative supply of high-skilled labor is a weighted sum of the national relative factor endowments of high-skilled labor with the weights being equal to the share of low-skilled labor that is associated with each of the two countries. In other words, curve RS in Fig. 2 is closer to curve  $RS^h$  the higher is the fraction of world's low-skilled workers living in the Home country. It is obvious from Fig. 2 that the relative wage and growth effects of globalization are larger for the country with a smaller fraction of world's endowment of low-skilled labor. Thus, we have

**Proposition 5:** *Assume that the two countries differ in skill abundance and that there are no factor intensity reversals. Then a move from autarky to the integrated-world equilibrium results in:*

- a) *equalization of the wage of high-skilled labor,  $\omega$ , the TOG, and the long-run growth rate,*

$g_U$ , between the two countries;

- b) a rise (fall) in the relative wage,  $\omega$ , of the high-skill (low-skill) abundant country;
- c) a rise in the long-run growth rate,  $g_U$ , of the high-skilled abundant country, and a fall in  $g_U$  for the low-skilled abundant country if and only if the skill intensity of rent-protecting activities is higher than the skill intensity of R&D,  $h_X > h_Y$ .
- d) the magnitude of the above-mentioned effects is inversely related to the relative size of each country (measured by the fraction of its low-skilled labor in world population),  $L^j/L$ .

The prediction of factor price equalization, despite apparent total factor productivity differences (captured here by aggregate quality differentials) across the two countries, is consistent with empirical studies following Trefler's (1993, 1995) seminal work. These studies have found that factor price equalization across countries holds when production factors are adjusted for uniform productivity differences.<sup>18</sup> In addition, Lemma 1 offers a novel link between relative wages and total factor productivity growth! The main result of proposition 5 complements and clarifies the finding of Dinopoulos and Segerstrom (1999b) where trade liberalization in the form of reciprocal tariff reductions between two countries with identical endowments and sizes generates growth effects. In both cases, scale invariant growth is affected by policies that change the relative price of innovation and/or relative factor prices. Of course, in the present model countries differ in factor endowments and therefore long-run the TOG move in opposite directions, whereas in Dinopoulos and Segerstrom (1999b) the two countries are structurally identical and, as a result, each country's TOG move in the same direction.

We conclude this section by describing the rich production patterns that emerge in the steady-state integrated-world equilibrium. These patterns are consistent with various facets of globalization, such as, for example, the formation of multinationals and outsourcing, which play a prominent role in the ongoing academic and policy debate on the pros and cons of globalization (Bhagwati, 2004). Fig. 3 illustrates the per-capita factor price equalization set of the integrated-world economy. The diagonal of the box

diagram corresponds to the per-capita vector of high-skilled and low-skilled labor  $H(t)/N(t)$ ,  $L(t)/N(t)$ , respectively. The vectors  $OA = O^*A'$ ,  $AB = A'B'$ , and  $BO^* = B'O$  represent the per-capita amounts of high-skilled and low-skilled labor employed in the production of rent protecting services, R&D services, and manufacturing of final goods. The slopes of these vectors reflect the assumption that the skill intensity of RPAs is the highest, followed by the skill intensity of R&D services, which in turn is higher than that of manufacturing (i.e.,  $h_X > h_Y > h_Z$ ).

The factor price equalization set (FPE) is defined as the set of all per-capita factor endowment allocations between the two countries such that each country can fully employ its resources using the integrated-world equilibrium skill intensities of each activity. The FPE set is represented by the area inside the hexagon  $OABO^*A'B'$ . Points  $O$  and  $O^*$  respectively represent the origins of Home and Foreign.

Suppose that the per-capita distribution of the two factor endowments across the two countries is given by point  $E_0$  which lies on the diagonal  $OO^*$  of the box diagram. In this case, the two countries have identical skill abundance ratios which equal to the slope of the box's diagonal [i.e.,  $H^h(t)/L^h(t) = H(t)/L(t) = H^f(t)/L^f(t)$ ]. The fraction of industries that contain Home quality leaders is given by  $\beta^h = N^h(t)/N(t) = OE_0/OO^*$ . By drawing vectors  $CD$ ,  $DF$ , and  $FG$  that are parallel to vectors  $AB$ ,  $BO^*$  and  $B'A'$ , respectively, one could illustrate the per-capita quantity of resources devoted to each of the three activities by each country. For example, the Home country's per-capita endowment vector is  $OE_0 = OC + CD + DE_0$ , where  $OC$ ,  $CD$  and  $DE_0$  are the vectors that correspond to the amount of Home country resources devoted to the production of rent protection, R&D services, and manufacturing of final goods. This allocation of resources is consistent with its two per-capita full employment conditions [see (16) and (17)] and the activity-specific production techniques of the integrated equilibrium. To see this observe that triangle  $OAB$  is similar to triangle  $OCD$ , and triangle  $OBO^*$  is similar to  $ODE_0$ . This means that the ratios  $OC/OA = CD/AB = DE_0/BO^* = OE_0/OO^*$  are equal to  $\beta^h = I^h/I = N^h(t)/N(t)$ . In other words, Home's share of resources devoted to each of the three activities equals  $\beta^h$ , its share of world R&D

investment in each industry. Similar considerations apply to Foreign, whose per-capita factor endowment vector is given by  $O^*E_0 = O^*G + GF + FE_0$ . Foreign's per-capita resources account for a fraction  $\beta^f = 1 - \beta^h$  of each activity which equals its share of world R&D in each industry.

For any distribution of factor endowments on the diagonal  $OO^*$  determined by a point such as  $E_0$ , international trade in final consumption goods suffices to equalize factor prices and long-run growth rates between the two countries. However, if the two countries differ in factor abundance, then factor price equalization can be achieved through multinational-firm formation or outsourcing, in addition to trade in final consumption goods. The reasons for this property can be traced to the assumption that all industries are symmetric, and that the different activities in each industry have to be specifically tied to each other through dynamic linkages. One could add another degree of freedom by assuming the existence of an outside-good sector produced under perfect competition, as in Dinopoulos et al. (1993) and Grossman and Helpman (1991), or by introducing differences in skill intensities in the production of final goods. This extension of the model is straightforward.

In the model, if the point that determines the distribution of per-capita factor endowments lies inside triangle  $OBO^*$ , say point  $E_1$  in Fig. 3, the integrated world equilibrium can be obtained with the formation Home-based multinational companies. In this case, Home would devote  $OC$  resources to RPAs,  $CD$  resources to R&D services, and would have quality leaders in  $\beta^h$  industries, as before. However, it can devote only  $DE_1$  resources to the production of final consumption goods. The integrated-world equilibrium can be replicated if Home quality leaders devote  $DE_0$  resources in the production of final consumption goods by hiring  $DE_1$  resources at Home and  $E_1E_0$  resources at Foreign. One possible pattern of multinational production that is consistent with this equilibrium is for each Home quality leader to produce a fraction equal  $E_1E_0/DE_0$  at Foreign. This is the case of the formation of horizontal multinationals (these firms produce the same product at Home and Foreign to serve the domestic market). Another symmetric pattern of multinational production is that a fraction  $E_1E_0/DE_0$  of Home quality leaders transfers all their production of final output to the Foreign country. This is the case



of vertical Home multinationals that engage in RPAs at Home, manufacture all output in Foreign and export from Foreign to Home. Of course, since there is a continuum of industries, both patterns of multinational production can coexist. In addition, the above patterns are consistent also with outsourcing of manufacturing from Home to Foreign. These patterns of multinational production and manufacturing outsourcing are consistent with constant returns to scale technology in production, although the latter is associated with a higher volume of intra sectoral trade. The production pattern of Foreign quality leaders remains the same as the one analyzed in the previous case.

If the point that determines the distribution of per-capita factor endowments between the two countries lies inside triangle OAB, such as point  $E_2$  in Fig. 3, then all final-goods production takes place in the Foreign country, and the Home country transfers a fraction of R&D activities to the Foreign country as well. In other words, the model generates outsourcing of R&D services (i.e., the establishment of Home-owned R&D labs at Foreign), multinational production, and trade in final consumption goods. Finally, if the skill intensity of R&D is higher than that of RPAs, then for endowment-distribution points located in the interior of triangle OAB, the model generates outsourcing of RPAs (as opposed to R&D services). Therefore, the integrated world equilibrium is consistent with a rich pattern of production and globalization which depends on the magnitude of skill-abundance differences between the two countries.

In other words, as the difference in skilled abundance between the two countries increases, the skill abundant country transfers the production of skill-intensive activities to the less skill-abundant country through outsourcing or the formation of multinationals. As in the traditional Heckscher-Ohlin, the driving force that generates these patterns is differences in the relative wage of skilled workers. This prediction sheds light to the ongoing outsourcing of high-tech services from the US to countries like China and India.

## 5. Concluding Remarks

The present paper developed a two-country scale-invariant Schumpeterian growth model to address the effects of globalization on long-run growth and wages. The introduction of rent-protecting activities – that prolong the expected duration of monopoly power for incumbents by reducing the expected innovation payoffs for challengers – removes the scale effects property, however, without foregoing the (policy) endogeneity of long-run growth. Interestingly, growth is proportional to the opportunity cost of RPAs measured in units of R&D services, which depend only on factor prices under constant returns to scale. The absence of scale effects make steady-state predictions of the analysis consistent with post-war time-series evidence presented by Jones (1995a), and generates long-run growth that is bounded and constant over time, even in the presence of positive population growth.

The removal of scale effects has profound implications for the literature concerned with the effects of trade on long-run growth. Unlike earlier models of endogenous growth which have emphasized the positive impact of market-size expansion on long-run growth, the absence of scale effects neutralizes the market-size trade-related effect on long-run growth. In the present model, a move from autarky to free trade between two growing economies that differ only in population size does not effect long-run growth. In this case, there is reallocation of per-capita resources in manufacturing of final goods within each country and globalization generates intra-sectoral trade as some domestic quality leaders become global quality leaders while others are replaced by Foreign quality leaders producing superior quality products. However, under constant returns of scale in production, this type of resource reallocation does not affect factor prices and the per-capita allocation of resources between RPAs and R&D. Consequently, long-run growth under trade and autarky for each country do not differ.

The model also allows us to analyze how cross-country differences in factor abundance condition the effects of globalization on long-run growth. A move from autarky to the integrated world equilibrium generates convergence in long-run growth rates that follows from factor price equalization across the two countries. The direction of change in each country's growth rate depends on the rankings of factor

abundance across countries and factor intensities across activities. For example, if Home is skilled-abundant and production of R&D services is the most skill intensive activity, Home has a lower relative wage and grows faster than Foreign under autarky. Globalization, captured by a move from autarky to the integrated world equilibrium, equalizes the growth rates in both countries by causing Home's growth rate to fall and Foreign's to rise. The integrated equilibrium is consistent with a rich pattern of production including intra-sectoral trade, the formation of multinationals and outsourcing of R&D and RPAs. This pattern of production is analogous to the one analyzed in earlier models of Schumpeterian growth but, of course, these models exhibit scale effects.

The analysis and insights of this paper have several interesting implications for the empirics of R&D-based growth in open economies. The model provides a novel explanation for the absence of a strong correlation between measures of trade openness and growth in cross-country regressions [see, for example, Dinopoulos and Thompson (2000)]. In a global economy experiencing scale-invariant Schumpeterian growth, trade in high-tech industries among countries with similar factor endowments has minimal (if any) effect on long-run growth. In addition, higher levels of globalization among countries with different factor proportion is associated with slower or faster long-run growth depending on whether or not a country is high-skilled or low-skilled labor abundant relative to the skill abundance of the global economy and on the skill intensity ranking across various production activities. In other words, the model predicts that the effects of globalization on growth are conditional on the same mechanisms that capture the forces of comparative advantage in the traditional static Heckscher-Ohlin trade model.

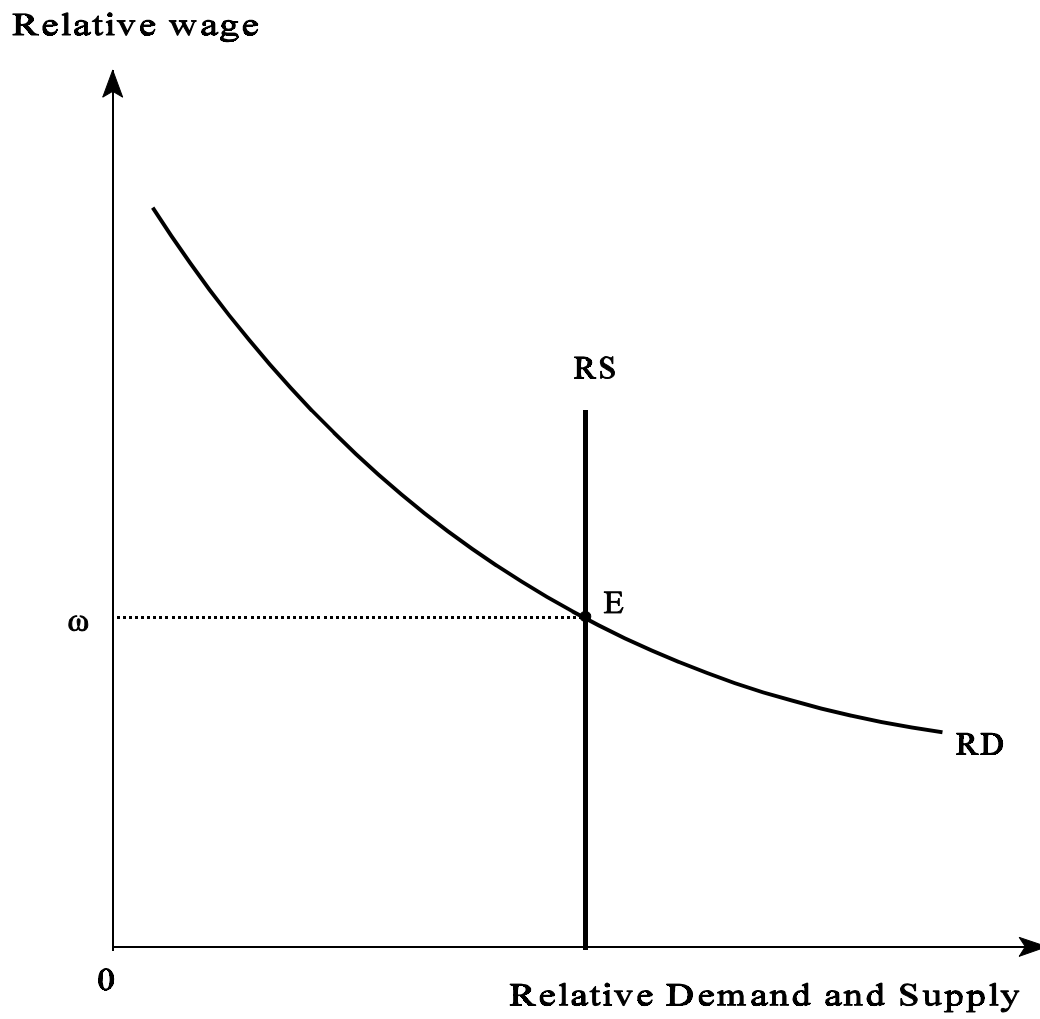
The analysis opens several new avenues for research. A variety of trade policy instruments (e.g., tariffs, export taxes and subsidies) could be introduced in the model to analyze their growth effects when countries differ in size or factor endowments. This generalization would complement a recent strand in the literature that analyzes the effects of tariffs on growth without scale effects, based on the restrictive assumption that all countries are structurally identical without any differences in factor abundance and/or population size [e.g., Dinopoulos and Segerstrom (1999a, 1999b)].

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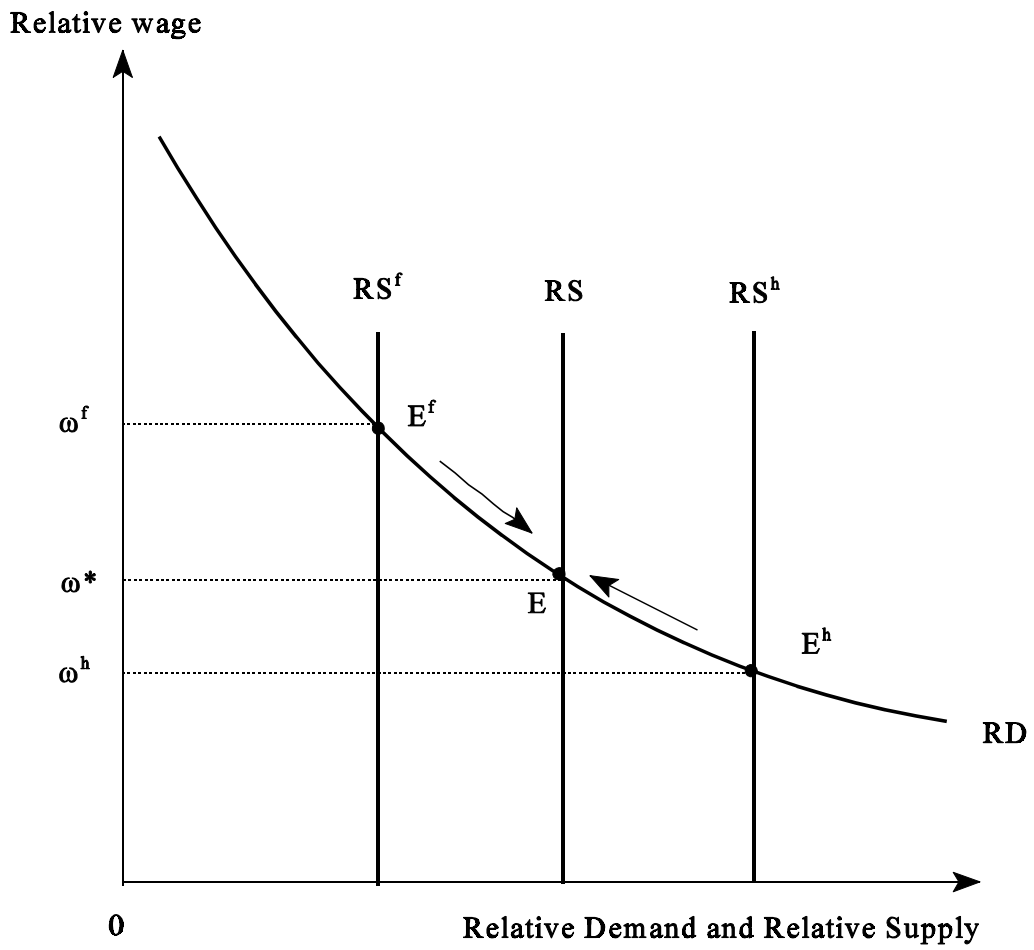
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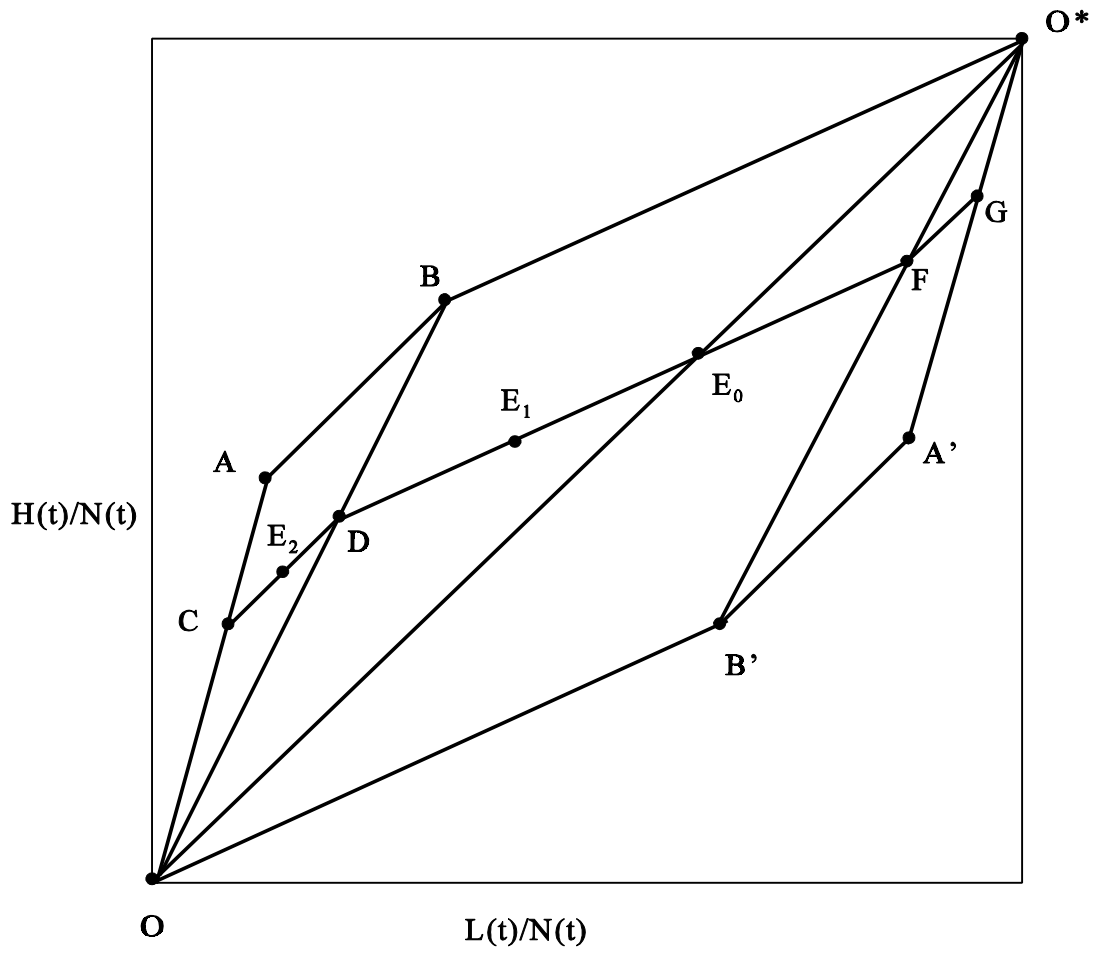


**FIGURE 1:**  
**Steady-State Integrated-World Equilibrium.**



**FIGURE 2:**  
**Globalization and Relative Wages**





**FIGURE 3:**  
**Production Patterns in the Integrated-World Equilibrium**

## Appendix

### 1. Derivation of Equation (24)

Differentiating (23) with respect to the relative wage  $\omega$  yields

$$\frac{\partial I}{\partial \omega} = \frac{\varphi_X(\omega, 1)\alpha_Y(\omega, 1) - \varphi_Y(\omega, 1)\alpha_X(\omega, 1)}{\delta[\alpha_Y(\omega, 1)]^2}. \quad (\text{A1})$$

The linear homogeneity of unit-cost functions implies  $\alpha_i(\omega, 1) = \varphi_i(\omega, 1)\omega + \psi_i(\omega, 1)$  for  $i=X, Y, Z$ .

Substituting this expression in (A1) together with some algebraic manipulation yield (24).

### 2. Derivation of Equation (27)

Let  $c = [c^h N^h(t) + c^f N^f(t)]/N(t)$  be the per-capita world consumption expenditure. Equation (10) and the limit pricing condition  $p = \lambda \alpha_z(\omega)$  imply that the per-capita level of final output in the integrated world equilibrium is given by

$$z = \frac{c}{\lambda \alpha_z(\omega)}. \quad (\text{A2})$$

Equations (2) and (3) imply that  $I = Y/\delta X$ . Combining this expression with (23) yields

$$y = \delta x I = x \frac{\alpha_X(\omega)}{\alpha_Y(\omega)}. \quad (\text{A3})$$

Structural symmetry of the model across industries means that the each quality leader devotes the same amount of per-capita rent-protecting activities  $x$  in the integrated-world equilibrium. Substituting (3) and (13) into the zero-profit condition (14) and evaluating the relevant variables in the integrated-world equilibrium yields the following per-capita zero profit condition:

$$\frac{(\lambda - 1)c}{\lambda} - \alpha_X(\omega)x = \delta x \alpha_Y(\omega)(\rho + I - g_N). \quad (\text{A4})$$

Substituting  $\delta = \alpha_X(\omega)/\alpha_Y(\omega)I$  in (A4) [see (23)] and combining the resulting expression with (A2) yields the following expression for  $z$ :

$$z = \frac{\alpha_X(\omega)x}{(\lambda - 1)\alpha_Z(\omega)} \left[ 2 + \frac{(\rho - g_N)}{I} \right] = \frac{\alpha_X(\omega)x}{(\lambda - 1)\alpha_Z(\omega)} \left[ 2 + \frac{(\rho - g_N)\delta\alpha_Y(\omega)}{\alpha_X} \right], \quad (\text{A5})$$

where (23) has been used to express the rate of innovation as a function of the relative wage of high-skilled labor.

Equations (A3) and (A5) provide expressions for the levels of per-capita R&D and final output as functions of the relative wage of high-skilled labor  $\omega$ . Substituting these expressions into the two per-capita full employment conditions (25) and (26), using the definition of the share of high-skilled labor in the unit cost of each activity  $\sigma_i(\omega) = w_H \phi_i / \alpha_i$  (for  $i=Z, X, Y$ ), and dividing the resulting equations yields (27).

#### 4. *Effects of Stronger Protection Intellectual Property*

The general-equilibrium effects of an increase in parameter  $\delta$  are determined by the following two equations:

$$I = I(\omega, \delta) \quad (\text{A6})$$

$$h = \frac{1}{\omega} f(\omega, I) \quad (\text{A7})$$

Equations (A6) and (A7) are the same as equations (23) and (27) respectively, where  $h = H(t)/L(t)$  is the economy's skill abundance, and  $f(\omega, I)$  is given by the bracketed term in equation (27):

$$f(\omega, I) = \frac{\frac{1}{\lambda - 1} \left[ 2 + \frac{\rho - g_N}{I} \right] \sigma_Z(\omega) + \sigma_X(\omega) + \sigma_Y(\omega)}{\frac{1}{\lambda - 1} \left[ 2 + \frac{\rho - g_N}{I} \right] [1 - \sigma_Z(\omega)] + [1 - \sigma_X(\omega)] + [1 - \sigma_Y(\omega)]} \quad (\text{A8})$$

Lemma 1 implies that the sign of  $\partial I / \partial \omega$  is indeterminate, whereas  $\partial I / \partial \delta < 0$ . In addition, differentiating (A8) yields  $\partial f / \partial \omega \leq 0$  -as long as the factor elasticity of substitution is not less than unity- and sign  $\partial f / \partial I = \text{sign} [(\sigma_X - \sigma_Z) + (\sigma_Y - \sigma_Z)] > 0$  given our assumption on skill-intensity ranking across activities (i.e., manufacturing is the least skilled-labor intensive activity). This condition, implies that an increase in parameter  $\delta$  reduces the steady-state relative wage of skilled-labor.

Totally differentiating (A6) and (A7) and solving for  $dI/d\delta$  yields the following expression

$$\frac{dI}{d\delta} = \frac{\partial I}{\partial \delta} \left[ 1 + \frac{\frac{\partial f}{\partial \omega} \frac{\partial f}{\partial I}}{h - \frac{\partial f}{\partial \omega} \frac{\partial f}{\partial I} \frac{\partial I}{\partial \omega}} \right] \quad (\text{A9})$$

Equation (A9) reveals the direct and indirect effects of stronger intellectual property rights on the rate of innovation and long-run growth. The former effect is captured by  $\partial I / \partial \delta < 0$  and slows the long-run rate of innovation and growth for any given relative wage. The second term in the bracketed expression captures the indirect effect of stronger intellectual rights protection. In general, the sign of the indirect effect is indeterminate, but one could easily impose sufficient conditions to ensure that the sign of (A9) is negative. Notice that as long as the absolute value of second term in square brackets is less than unity, the direct effect dominates. For example, our assumption on intensity rankings  $h_X > h_Y > h_Z$  implies that  $\partial f / \partial \omega < 0$  and that  $\partial I / \partial \omega < 0$ , and therefore for a sufficiently large difference in  $h_X - h_Y$  (see equation (24) the denominator of the second term in square brackets becomes negative. In this case, the sign of (A9) is negative, and stronger intellectual rights protection decreases the relative wage of skilled workers and long-run growth.

If the elasticity of factor substitution across activities is unity, then the right hand side of (A8) does

not depend on the relative wage (i.e.,  $\partial f/\partial \omega = 0$ ) and the indirect effect vanishes. Again, the sign of (A9) is negative in this case. Finally, even in the case where R&D is the most skilled-labor intensive activity ( $h_Y > h_X > h_Z$ ) and the denominator of the second term in square brackets becomes positive giving rise to a possible sign ambiguity, for a sufficiently high value of skilled-labor abundance  $h$ , the absolute value of the denominator of this term exceeds that of the numerator, and again the sign of (A9) remains negative. These reasonable sufficient conditions strongly suggest that an increase in intellectual property rights protection is very likely to reduce the long-run rate of innovation and growth by making the R&D effort of challengers more difficult.

## Endnotes

1. See, for example, Barro and Sala-i-Martin (1995, Chapter 12), and Dinopoulos and Thompson (2000) among many others.
2. Earlier closed-economy endogenous growth models include the ones developed by Aghion and Howitt (1992), Grossman and Helpman (1991, Chapter 4), Romer (1990) and Segerstrom et al. (1990).
3. Jones (1999), Dinopoulos and Thompson (1999), and Dinopoulos and Sener (2003) provide more details on this issue.
4. See Dinopoulos and Segerstrom (1999a,b) and Sener (2001) for an analysis of the effects of symmetric tariff reductions in the context of two structurally identical countries. Krugman (1979), Sener (2003), and Dinopoulos and Segerstrom (2004) have developed North-South models with one factor of production, technology transfer and scale-invariant growth to study the effects of globalization on the North-South wage gap.
5. The term Schumpeterian growth refers to a particular type of R&D-based (endogenous or exogenous) long-run growth generated through the introduction of new products and processes according to Schumpeter's (1934) description of the process of creative destruction.
6. Dinopoulos and Syropoulos (2001) provide more examples of these activities, and Cohen et al. (2000) supply survey based data on the extent of these activities.
7. In contrast, in Dinopoulos and Syropoulos (2001) we assume that the production of RPAs uses only high-skilled labor, whereas the production of R&D services and manufacturing of final products uses only low-skilled labor.
8. Arrow (1962) was the first to establish that as long as an incumbent monopolist faces the same probability as a challenger of discovering a new process or product innovation, the former's reward to engaging in R&D investment is lower than the latter's due to the replacement effect. The presence of the replacement effect prevents the incumbent from engaging in further R&D especially if there is free entry in each R&D race. If the incumbent faces a higher probability than each challenger to discover the next process or product innovation, then the incumbency-inertia property does not hold. In the present model, each incumbent engages in RPAs which reduce endogenously the R&D effectiveness of challengers, but these activities do not create an R&D advantage for a typical incumbent at the (symmetric) equilibrium.  
The assumption that every firm in the world knows how to produce the product which is one step below the state-of-the-art quality product is sufficient to exclude any R&D effort by an incumbent firm. If an incumbent firm discovers the next higher-quality product, say product  $k+1$ , the technology of product  $k$  becomes common knowledge and therefore the monopolist continues to earn the same flow of profits as before. Thus the return to incumbent's R&D investment is zero and there is no incentive for the monopolist to engage in innovative R&D. Thus, the Arrow effect is still present and prevents incumbents from engaging in further R&D. However, the incumbent has an incentive to delay the discovery of product  $k+1$  by engaging in RPAs and by making the R&D effort of challengers more difficult.
9. Eaton and Kortum (1996, 1997, 1999) have developed dynamic general equilibrium models of international technology diffusion and growth. Keller (2004) offers an excellent survey of the voluminous literature on this important topic which lies beyond the limited scope of the present paper.

10. See Varian (1992) for more details on the properties of unit-cost functions.
11. A proper modeling of skill formation requires an endogenous division of population between high-skilled and low-skilled labor that results in higher wage for high-skilled workers compared to that of low-skilled ones [see Dinopoulos and Segerstrom (1999) for a model of Schumpeterian growth with endogenous skill formation that has these features]. In the present paper we abstract from issues associated with endogenous skill formation in order to focus on the interaction between factor abundance and factor intensities which are the basic ingredients of comparative advantage.
12. We also assume that if two products command the same quality-adjusted price, consumers buy the higher quality product although they are formally indifferent between the two products.
13. See Grossman and Helpman (1991, Chapter 4) for further details.
14. For instance, in quality-ladders growth models where innovation improves the quality of intermediate inputs or results in process improvements,  $u(t)$  captures the level of final output. See Grossman and Helpman (1991) for further details on this point.
15. The assumption of no-factor intensity reversals implies that the ranking of the two ratios evaluated at the same relative wage is not reversed for all possible values of the relative wage of high-skilled labor.
16. See, for example, Grossman and Helpman (1991).
17. However, if the skill intensity of R&D exceeds the skill intensity of PRAs, then globalization causes Home's long-run growth to fall and Foreign's long-run growth to rise. Of course, one could readily introduce factor intensity reversals and obtain the same changes in the growth rate of both countries as they move from autarky to the integrated world equilibrium.
18. Feenstra (2004, Chapter 2) offers an excellent critical overview of various empirical tests for the standard static Heckscher-Ohlin model.