North-South Trade and Economic Growth

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Abstract: This paper develops a dynamic general equilibrium model of North-South trade and economic growth. Both innovation and imitation rates are endogenously determined as well as the degree of wage inequality between Northern and Southern workers. Northern firms devote resources to innovative R&D to discover higher quality products and Southern firms devote resources to imitative R&D to copy state-of-the-art quality Northern products. The steady-state equilibrium and welfare implications of three aspects of globalization are studied: increases in the size of the South (e.g., countries like China joining the world trading system), stronger intellectual property protection (e.g., the TRIPs agreement that was part of the Uruguay Round) and lower trade costs.

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1 Introduction

From 1949 to 1978, China's communist regime prohibited private enterprise and largely sealed the country off from international trade. But then in 1978, Chinese policy took a surprising turn. Declaring that "to grow rich is glorious", the communist party opened the doors to internal private enterprise and then later to external trade. Because China is such a large country (20 percent of the world population), it's decision to join the world trading system is a topic of considerable public policy interest. On the one hand, there is concern about workers in advanced countries having to compete against millions of Chinese workers that earn low wages. On the other hand, firms in advanced countries benefit from supplying a vast new market and consumers benefit from the low prices of Chinese goods. This paper presents a conceptual framework for thinking about these issues: a dynamic general equilibrium model of North-South trade and economic growth.

Many models of North-South trade and economic growth have already been developed, including Segerstrom, Anant and Dinopoulos (1990), Grossman and Helpman (1991a,b), Lai (1998), Yang and Maskus (2001), and Glass and Saggi (2002).[1] So the question naturally arises: why do we need another model of North-South trade and economic growth? For thinking about issues like China's entry into the world trading system, why not just use a model that has already been developed? Our decision to develop a new analytical framework is based on the following two considerations.

First, all of the above-mentioned North-South trade models have clearly counterfactual implications for economic growth. For example, these model all imply that any increase in the size of the South permanently increases the economic growth rate in the North. Since 1950, the South has increased dramatically in size, both due to population growth and to developing countries like China opening up to international trade. But as Jones (1995a) has pointed out, there has not been any upward trend in the economic growth rates of advanced countries since 1950. Furthermore, the counterfactual growth implications of these models are clearly linked to assumptions about R&D. All of these models imply that the Northern economic growth rate is proportional to the Northern R&D employment level. If Northern R&D employment doubles, the Northern economic growth rate should also double. Since 1950, R&D employment has more than doubled in the US and other advanced countries without generating any upward trend in economic growth rates.

Second, all of the above-mentioned papers focus on the steady-state equilibrium properties of

[1]For a survey of the literature on North-South trade and economic growth, see Chui, Levine, Murshed and Pearlman (2002).

North-South trade models and do not study the welfare implications.[2] But people are interested not only in knowing about the equilibrium implications of changes in the economic environment, they are also interested in knowing about the welfare implications. For example, do consumers in advanced countries benefit from China's decision to join the world trading system?

In this paper, we present a model of North-South trade that avoids both of these drawbacks. To rule out the counterfactual growth implications of earlier North-South trade models, we assume that innovating becomes more difficult as products improve in quality and become more complex. This assumption was first employed by Li (2003) to study economic growth in a closed-economy setting but has not been used before to study North-South trade.[3] The model is suitable for analyzing both the steady-state equilibrium and welfare implications of changes in the economic environment. To illustrate the model's potential, we explore the implications of three aspects of "globalization": increases in the size of the South (e.g., countries like China joining the world trading system), stronger intellectual property protection (e.g., the TRIPs agreement that was part of the Uruguay Round), and lower trade costs.

Focusing on trade costs first, we show that a decrease in trade costs between the North and the South has no effect on either the rate of copying of Northern products or the Northern innovation rate. When trade costs fall, Northern firms earn higher profits from exporting to the South but their profits fall from selling their products in the North because the Northern market becomes more competitive. Overall profits do not change, so lower trade costs do not affect the incentives to either innovate or imitate. However they do lead to a reallocation of resources within both regions since firms respond by producing less for the domestic market and exporting more. For firms in the larger market, the first consideration is more important for labor demand and lower trade costs lead to a permanent decrease in the relative wage of workers in the larger region. Turning to the welfare implications, we show that lower trade costs unambiguously benefit consumers in both regions. Even though the relative wage of workers in a region can fall, this effect of lower trade costs is more than offset by the fact that consumers face lower prices for both domestically produced and imported products.

Turning next to the effects of increasing the initial size of the South, we show that this leads to

[2]One exception is Helpman (1993), who analyzes the welfare implications of intellectual property protection in a setting with exogenous and costless imitation.

[3]Other closed-economy R&D-driven endogenous growth models that do not have the counterfactual "scale effect" property include Jones (1995b), Kortum (1997), Young (1998), Dinopoulos and Thompson (1998), Segerstrom (1998), and Howitt (1999). For a survey of this literature, see Dinopoulos and Thompson (1999). Recently, Sener (2006) and Parello (2007) have developed alternative North-South trade models that do not have the scale effect property but these papers do not study the welfare implications of policy changes.

a permanent increase in the rate of copying of Northern products and a temporary increase in the Northern innovation rate. When there are more Southern workers, the faster rate of technology transfer that results means that more production jobs move from the high-wage North to the low-wage South. There is a reallocation of resources within the North away from production employment and towards R&D employment. An increase in the size of the South also leads to a permanent decrease in the relative wage of Northern workers, consistent with the evidence of decreasing global income inequality reported in Jones (1997) and Sala-i-Martin (2002).

When it comes to the welfare implications of an increase in the size of the South, things are more complicated than for lower trade costs because both rates of innovation and imitation are affected. Northern consumers are hurt by the fall in their wage and interest income but on the other hand, they benefit from being able to buy higher quality products at lower prices. The overall effect on long-run Northern consumer welfare of an increase in the size of the South is theoretically ambiguous and is approximately zero for plausible parameter values. In contrast with those who claim that the benefits for advanced countries of China joining the world trading system exceed the costs, we find that the benefits to Northern consumers from a larger South are roughly balanced by the costs. We do find however that Southern consumers unambiguously benefit. Due to an increase in the size of the South, Southern consumers are able to buy higher quality products at lower prices and they also benefit from the decrease in the Northern relative wage.

Finally, we show that stronger intellectual property protection leads to a permanent decrease in the rate of copying of Northern products and a temporary decrease in the Northern innovation rate. Fewer production jobs move to the South and there is a reallocation of resources within the North away from R&D employment. Stronger intellectual property protection also leads to a permanent increase in the relative wage of Northern workers. Northern consumers benefit from the increase in their wage and interest income but on the other hand, they are hurt by the slower rate of technological change. Although the overall effect on the long-run welfare of Northern consumers is theoretically ambiguous, we find that Northern consumers gain for plausible parameter values. In contrast, Southern consumers are unambiguously made worse off by stronger intellectual property protection. They are hurt both by the slower rate of technological change and the increase in the Northern relative wage. Thus, the model points to an inherent conflict between North and South vis-à-vis the TRIPs agreement, since Northern consumers benefit from stronger IPR protection whereas Southern consumers lose.

The rest of the paper is organized as follows: In section 2, the model of North-South trade is presented. Section 3 studies the steady-state equilibrium and welfare properties of the model. In Section 4, the model is solved numerically for plausible parameter values and Section 5 concludes.

2 The Model

2.1 Overview

We present a model of trade between two regions: the North and the South. In both regions, labor is the only factor used to manufacture products and to do R&D. Labor is perfectly mobile across activities with a region but cannot move across regions. Since labor markets are perfectly competitive, there is a single wage rate paid to all Northern workers and a single wage rate paid to all Southern workers. The two regions are distinguished by their R&D capabilities. Workers in the North are capable of conducting innovative R&D whereas workers in the South can only conduct imitative R&D. We focus on the steady-state properties of the model where all innovative activity takes place in the high-wage North and all imitative activity takes place in the low-wage South. Northern firms engage in innovative R&D to increase the quality of existing products while southern firms engage in imitative R&D to copy products produced in the North.[4] The model differs from Grossman and Helpman (1991a) by allowing for trade costs, population growth, CES consumer preferences, productivity differences across regions, and by modeling R&D as in Li (2003).

There is a continuum of industries indexed by $\theta \in [0,1]$. In each industry θ, firms are distinguished by the quality of the products they produce. Higher values of the index j denote higher quality products and j is restricted to taking on integer values. At time $t = 0$, the state-of-the-art quality product in each industry is $j = 0$, that is, some firm in each industry knows how to produce a $j = 0$ quality product and no firm knows how to produce any higher-quality product. To learn how to produce higher-quality products, Northern firms in each industry participate in innovative R&D races. In general, when the state-of-the-art quality product in an industry is j, the next winner of an innovative R&D race becomes the sole producer of a $j+1$ quality product. Thus, over time, products improve as innovations push each industry up its "quality ladder."

[4] Gustafsson and Segerstrom (2007) study the same issues as in this paper but in a setting where innovations are increases in product variety (instead of product quality). They find that the comparative steady-state equilibrium effects derived in this paper continue to hold when economic growth is driven by increases in product variety.

2.2 Households

In both the North and the South, there is a fixed measure of households that provide labor services in exchange for wage payments. Each individual member of a household lives forever and is endowed with one unit of labor, which is inelastically supplied. The size of each household, measured by the number of its members, grows exponentially at a fixed rate $n > 0$, the population growth rate. Normalizing the initial size of each household to unity, the number of household members at time t is given by e^{nt}. Let $L_N(t) = \bar{L}_N e^{nt}$ denote the supply of labor in the North at time t, let $L_S(t) = \bar{L}_S e^{nt}$ denote the corresponding supply of labor in the South and let $L(t) = L_N(t) + L_S(t)$ denote the world supply of labor.[5]

Households in both the North and the South share identical preferences. Each household is modeled as a dynastic family that maximizes discounted lifetime utility

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

where $\rho > n$ is the constant subjective discount rate and

$$u(t) = \left\{ \int_0^1 \left[\sum_j \delta^j d(j, \theta, t) \right]^\alpha d\theta \right\}^{1/\alpha} \tag{2}$$

is the utility per person at time t. Equation (2) is a quality-augmented CES consumption index; $d(j, \theta, t)$ denotes the quantity demanded (or consumed) per person of a j quality product produced in industry θ at time t, parameter $\delta > 1$ determines the size of innovations, and parameter $\alpha \in (0, 1)$ determines the degree of product differentiation. With this formulation, the constant elasticity of substitution between products in different industries is given by $\sigma = \frac{1}{1-\alpha} > 1$. Because δ^j is increasing in j, (2) captures in a simple way the idea that consumers prefer higher quality products.

For each household, the discounted utility maximization problem can be solved in three steps. The first step is to solve the within-industry static optimization problem

$$\max_{d(\cdot)} \sum_j \delta^j d(j, \theta, t) \text{ subject to } \sum_j p(j, \theta, t) d(j, \theta, t) = c(\theta, t)$$

[5] We have assumed a common population growth rate in the two regions simply because the model does not have a steady-state equilibrium if the population growth rates differ. By studying the steady-state effects of a one-time increase in the relative size of the South, this paper sheds some light on the changes that take place over time when population growth is faster in the South.

where θ and t are fixed, $p(j, \theta, t)$ is the price of the j quality product produced in industry θ at time t, and $c(\theta, t)$ is the individual consumer's expenditure in industry θ at time t. The solution to this problem is to only buy the product with the lowest quality-adjusted price $p_j(\theta)/\delta^j$. When two products have the same quality-adjusted price so consumers are indifferent, we restrict attention to equilibria where consumers only buy the higher quality product.

The second step is to solve the across-industry static optimization problem

$$\max_{d(\cdot)} \int_0^1 \left[\delta^{j(\theta,t)} d(\theta, t)\right]^{(\sigma-1)/\sigma} d\theta \text{ subject to } \int_0^1 p(\theta, t) d(\theta, t)\, d\theta = c(t)$$

where t is fixed, $d(\theta, t)$ is the individual's quantity demanded of the product with the lowest quality-adjusted price in industry θ at time t, $j(\theta, t)$ is the quality index of the product with the lowest quality-adjusted price in industry θ at time t, $p(\theta, t)$ is the price of this product, and $c(t)$ is the consumer's expenditure at time t. Solving this optimal control problem yields the individual consumer's demand function

$$d(\theta, t) = \frac{q(\theta, t) p(\theta, t)^{-\sigma} c(t)}{\int_0^1 q(\theta, t) p(\theta, t)^{1-\sigma} d\theta} \tag{3}$$

for the product in industry θ at time t with the lowest quality adjusted price, where $q(\theta, t) = \delta^{(\sigma-1)j(\theta,t)}$ is an alternative measure of product quality. The quantity demanded for all other products is zero.

The third step is to solve the dynamic optimization problem by maximizing discounted utility (1) given (2), (3), and the intertemporal budget constraint $\dot{A}(t) = w(t) + r(t)A(t) - c(t) - nA(t)$, where $A(t)$ is the individual's assets at time t, $w(t)$ is the individual's wage rate at time t, and $r(t)$ is the market interest rate at time t. The solution to this optimal control problem yields the well-known differential equation

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

Individual consumer expenditure c grows over time if and only if the market interest rate r exceeds the subjective discount rate ρ.

Let w_N and w_S denote the equilibrium wage rates in the North and South, respectively. Likewise, let c_N and c_S denote the representative consumer's expenditure in the North and South, respectively. We treat the Southern wage as the numeraire price ($w_S = 1$), that is, we measure all prices relative to the price of Southern labor. Furthermore, we solve the model for a steady-state equilibrium where w_N, w_S, c_N and c_S are all constant over time. Then (4) implies that the steady-state market interest rate is also constant over time and given by $r(t) = \rho$.

2.3 Product Markets

In each industry, firms compete in prices and maximize profits. Production is characterized by constant returns to scale. For each Southern firm that knows to produce a product, one unit of labor produces one unit of output For each Northern firm that knows how to produce a product, one unit of labor produces $h > 1$ units of output. The parameter h is intended to capture differences in worker productivity due to Northern workers having higher levels of human capital than Southern workers ("h" for human capital). Thus, each firm in the North has a constant marginal cost equal to w_N/h and each firm in the South has a constant marginal cost equal to w_S. There are also trade costs separating the two regions that take the "iceberg" form: $\tau \geq 1$ units of a product must be produced and exported in order to have one unit arriving at destination.

In each industry, production jumps from the North to the South when a Southern firm copies a Northern firm's product and production jumps from the South to the North when a Northern firm develops a higher quality version of the Southern firm's product. From each region where production takes place, products are exported to the other region. Production only fully shifts from the North to the South when a Southern firm imitates if the marginal cost of serving the Northern market is greater for the Northern firm than its Southern imitator: $w_N/h > \tau w_S$. Furthermore, production only fully shifts from the South to the North when a Northern firm innovates if the effective marginal cost of serving the Southern market is lower for the Northern innovator than the Southern firm whose product has been improved upon: $w_S > \tau w_N/(h\delta)$. We solve the model for a steady-state equilibrium where both inequalities hold, that is, the North-South wage ratio $w \equiv w_N/w_S$ satisfies $\delta h/\tau > w > \tau h$.

At each point in time, a firm can choose to shut down its manufacturing facilities and once it has done so, this decision can only be reversed by incurring a positive entry cost. Furthermore, each firm that fails to attract any consumers (has zero sales) incurs a positive cost of maintaining its unused manufacturing facilities, in addition to the constant marginal cost of production mentioned above. Thus firms that are not able to attract any consumers (because of the low relative quality of their products) choose to shut down their manufacturing facilities in equilibrium and do not play any role in determining market prices, as in Segerstrom (2007). If production is currently in the South and a Northern firm innovates, the Southern firm immediately shuts down. Likewise, if production is currently in the North and a Southern firm imitates, the Northern firm immediately shuts down.

In the presence of trade costs, Northern consumers face different prices than Southern consumers and we need to take this into account. Let the Northern quality-adjusted price index be defined by $P_N(t) \equiv \left[\int_{m_N} q(\theta,t)p_N(\theta,t)^{1-\sigma}d\theta + \int_{m_S} q(\theta,t)p_S^*(\theta,t)^{1-\sigma}d\theta\right]^{1/(1-\sigma)}$ and let the Southern price index be defined by $P_S(t) \equiv \left[\int_{m_N} q(\theta,t)p_N^*(\theta,t)^{1-\sigma}d\theta + \int_{m_S} q(\theta,t)p_S(\theta,t)^{1-\sigma}d\theta\right]^{1/(1-\sigma)}$, where stars denote exports, subscripts denote production location, m_N is the set of industries with Northern production and m_S is the set of industries with Southern production. Using (3), the Northern consumer's demand for a domestically produced good is

$$d_N(\theta,t) = \frac{q(\theta,t)p_N(\theta,t)^{-\sigma}c_N}{P_N(t)^{1-\sigma}}, \tag{5}$$

the Northern consumer's demand for an imported good (exported by the South) is

$$d_S^*(\theta,t) = \frac{q(\theta,t)p_S^*(\theta,t)^{-\sigma}c_N}{P_N(t)^{1-\sigma}}, \tag{6}$$

the Southern consumer's demand for a domestically produced good is

$$d_S(\theta,t) = \frac{q(\theta,t)p_S(\theta,t)^{-\sigma}c_S}{P_S(t)^{1-\sigma}} \tag{7}$$

and the Southern consumer's demand for an imported good (exported by the North) is

$$d_N^*(\theta,t) = \frac{q(\theta,t)p_N^*(\theta,t)^{-\sigma}c_S}{P_S(t)^{1-\sigma}}. \tag{8}$$

Consider now the profit-maximization decision of a Northern quality leader in industry θ at time t. Omitting the arguments of functions, export profits are given by $\pi_N^* = (p_N^* - w_N\tau h^{-1})d_N^* L_S$. The firm supplies $d_N^* L_S$ units to Southern consumers but has to produce $\tau d_N^* L_S$ units and pay its workers w_N/h for each unit produced. Maximizing π_N^* with respect to p_N^* yields the profit-maximizing export price $p_N^* = \frac{\tau w_N}{\alpha h}$, which is the standard monopoly markup of price over marginal cost. Domestic profits are given by $\pi_N^d = (p_N - w_N h^{-1})d_N L_N$. Maximizing π_N with respect to p_N^d yields the profit-maximizing domestic price $p_N = \frac{w_N}{\alpha h}$. Taking into account both domestic and export profits, the total profit flow $\pi_N = \pi_N^d + \pi_N^*$ of a Northern quality leader is

$$\pi_N(\theta,t) = \frac{w_N q(\theta,t)Y_N(t)}{h(\sigma-1)Q(t)} \tag{9}$$

where $Y_N(t) \equiv d_N(\theta,t)L_N(t) + \tau d_N^*(\theta,t)L_S(t) = p_N^{-\sigma}Q(t)\left\{\frac{c_N L_N(t)}{P_N(t)^{1-\sigma}} + \frac{\tau^{1-\sigma}c_S L_S(t)}{P_S(t)^{1-\sigma}}\right\}$ is the world demand for the average quality Northern product (when $q(\theta,t) = Q(t)$).

Similar considerations apply to the calculation of Southern profits. For a Southern quality leader, export profits are given by $\pi_S^* = (p_S^* - w_S\tau)d_S^* L_N$. The firm supplies $d_S^* L_N$ units to Northern consumers but has to produce $\tau d_S^* L_N$ units and pays its workers the Southern wage rate w_S for each unit produced. Maximizing π_S^* with respect to p_S^* yields the profit-maximizing export price $p_S^* = \frac{\tau w_S}{\alpha}$. Domestic profits are given by $\pi_S^d = (p_S - w_S)d_S L_S$. Maximizing π_S^d with respect to p_S yields the profit-maximizing domestic price $p_S = \frac{w_S}{\alpha}$. Taking into account both domestic and export profits, the total profit flow $\pi_S = \pi_S^d + \pi_S^*$ of a Southern quality leader is

$$\pi_S(\theta,t) = \frac{w_S q(\theta,t)Y_S(t)}{(\sigma-1)Q(t)} \tag{10}$$

where $Y_S(t) \equiv \tau d_S^*(\theta,t)L_N(t) + d_S(\theta,t)L_S(t) = p_S^{-\sigma}Q(t)\left\{\frac{\tau^{1-\sigma}c_N L_N(t)}{P_N(t)^{1-\sigma}} + \frac{c_S L_S(t)}{P_S(t)^{1-\sigma}}\right\}$ is the world demand for the average quality Southern product (when $q(\theta,t) = Q(t)$).

Equations (9) and (10) have similar properties. In both the North and the South, profits are increasing in product quality $q(\theta,t)$, Northern consumer expenditure $c_N L_N(t)$ and Southern consumer expenditure $c_S L_S(t)$. Since $\tau^{1-\sigma}$ decreases as τ increases, higher trade costs cut into the profits that firms earn from exporting. For Northern firms, higher trade costs cut into the profits that they earn from selling to Southern consumers and for Southern firms, higher trade costs cut into the profits that they earn from selling to Northern consumers.

2.4 Innovation and Imitation

Labor is the only factor of production used by firms that engage in either innovative or imitative R&D activities. When a Northern firm i in industry θ at time t hires ℓ_i workers to do innovative R&D, this firm is successful in discovering the next higher-quality product with instantaneous probability (or Poisson arrival rate)

$$I_i = \frac{\ell_i}{\gamma q(\theta,t)} \tag{11}$$

where $\gamma > 0$ is a Northern R&D productivity parameter. As in Li (2003), the presence of the term $q(\theta,t)$ in (11) captures the idea that as products improve in quality and become more complex, innovating becomes more difficult.[6]

[6] Evidence that innovating is becoming more difficult is provided by data on patenting. Kortum (1993, 1997) documents a decreasing patent-per-researcher ratio in a large set of countries. Looking at industry data, Kortum

Firms in the South can do imitative R&D to copy products developed in the North. When a Southern firm j in industry θ at time t hires ℓ_j workers to do imitative R&D, this firm is successful in discovering how to produce the state-of-the-art quality product in industry θ with instantaneous probability (or Poisson arrival rate)

$$C_j = \frac{\ell_j}{\beta q(\theta, t)}, \tag{12}$$

where $\beta > 0$ is a Southern R&D productivity parameter. A higher value β can be interpreted as stricter enforcement of intellectual property rights. The presence of the term $q(\theta, t)$ in (12) captures the idea that as products improve in quality and become more complex, imitating also becomes more difficult.[7]

The returns to both innovative and imitative R&D are assumed to be independently distributed across firms, industries, and over time. Consequently, the instantaneous probability that some Northern firm innovates in an industry is given by $I = \sum_i I_i$ and the instantaneous probability that some Southern firm imitates in an industry is given by $C = \sum_j C_j$.

The equilibrium pattern of innovation and imitation is illustrated in Figure 1. Northern firms do innovative R&D in all industries and Southern firms do imitative R&D in the measure m_N of industries where production is currently in the North. No imitative R&D occurs in the measure m_S of industries where production is currently in the South because it is not profitable to imitate in these industries. If a Southern firm were successful in copying a product produced by a Southern quality leader, Bertrand price competition would drive profits of both firms down to zero. Northern firms do not copy the products of other Northern firms for the same reason.

We solve the model for a steady-state equilibrium where the innovation and imitation rate (I and C) do not vary across industries or over time. Since m_N is constant over time in a steady-state equilibrium, the flow into the m_N-industry state must equal the flow out of the m_N-industry state, that is, $m_N C = m_S I$. Using $m_N + m_S = 1$, it follows immediately that

$$m_N = \frac{I}{I+C} \qquad \text{and} \qquad m_S = \frac{C}{I+C}. \tag{13}$$

The measure of industries with Northern quality leaders m_N is an increasing function of the rate

(1993) finds that the patenting per unit of real R&D ratio has declined in all 20 industries for which data could be obtained. Also, Jones (2007) finds evidence of an increasing knowledge burden over time that leads researchers to choose narrower expertise and to compensate for their reduced individual capacities by working in larger teams.

[7]Mansfield, Schwartz and Wagner (1981) have found that imitation costs are substantial, of the order of 65 percent of innovation costs. They also found that patents rarely hinder imitation but typically make it more expensive, which is consistent with our interpretation of β.

of innovation I and a decreasing function of the rate of imitation C. The converse is true for the measure of industries with Southern quality leaders m_S.

2.5 R&D Optimization

We assume that all firms maximize expected discounted profits and that there is free entry into innovative R&D races in the North. Since all Northern firms have access to the same linear innovative R&D technology (11), Northern quality leaders (the incumbents) do not engage in R&D activities. Instead all innovative R&D in the North is done by other firms (the challengers) and the identity of the quality leader in an industry changes every time innovation occurs. Northern quality leaders have less to gain by innovating since they are already earning monopoly profits and with challengers entering innovative R&D races until their expected discounted profits equal zero, it is not profitable for Northern quality leaders to do any innovative R&D.[8]

Consider now the incentives that a Northern challenger firm i has to engage in innovative R&D in industry θ at time t. The expected benefit from engaging in innovative R&D is $v_I(\theta, t)I_i dt$, where $v_I(\theta, t)$ is the expected discounted profits or reward for innovating and $I_i dt$ is firm i's probability of innovating during the infinitesimal time interval dt. The expected cost of engaging in innovative R&D is equal to $w_N \ell_i dt$, where ℓ_i is firm i's innovative R&D employment. Equation (11) implies that the expected cost can be rewritten as $w_N I_i \gamma q(\theta, t)dt$. Thus, since expected benefit equals expected cost in a steady-state equilibrium with free entry into innovative R&D races, it follows that

$$v_I(\theta, t) = w_N \gamma q(\theta, t) \tag{14}$$

As the quality of products increases over time, innovating becomes more difficult and the reward for innovating must correspondingly increase to induce innovative effort by Northern firms.

We assume that there is also free entry into all imitative R&D races in the South. Consider the incentives that a Southern firm j has to engage in imitative R&D in industry θ at time t (where there is a Northern quality leader). The expected benefit from engaging in imitative R&D is $v_C(\theta, t)C_j dt$, where $v_C(\theta, t)$ is the expected discounted profits or reward for imitating and $C_j dt$ is firm j's probability of imitating during the infinitesimal time interval dt. The expected cost of engaging in imitative R&D is equal to $w_S \ell_j dt$, where ℓ_j is firm j's imitative R&D employment.

[8] The property that only industry followers engage in innovative R&D is a common property of R&D-driven endogenous growth models. One can avoid this outcome and obtain that industry leaders invest in innovative R&D by assuming that industry leaders have some R&D cost advantages, as in Aghion et al (2001) and Segerstrom (2007).

Equation (12) implies that the expected cost can be rewritten as $w_S C_j \beta q(\theta, t)dt$. Thus, since expected benefit equals expected cost in a steady-state equilibrium with free entry into imitative R&D races, it follows that

$$v_C(\theta, t) = w_S \beta q(\theta, t). \tag{15}$$

As the quality of products increases over time, copying also becomes more difficult and the reward for copying must correspondingly increase to induce imitative effort by Southern firms.

We assume that there is a stock market that channels consumer savings to Northern and Southern firms that engage in R&D and helps households to diversify the risk of holding stocks issued by these firms. We can calculate directly the rewards for innovating and imitating by solving for the stock market values of Northern and Southern quality leaders.

Since there is a continuum of industries and the returns to engaging in R&D races are independently distributed across firms and industries, each investor can completely diversify away risk by holding a diversified portfolio of stocks. Thus, the return from holding the stock of a Northern quality leader must be the same as the return from an equal-sized investment in a riskless bond and we obtain the following no-arbitrage condition:

$$\frac{\pi_N(\theta, t)}{v_I(\theta, t)} + \frac{\dot{v}_I(\theta, t)}{v_I(\theta, t)} - I - C = \rho.$$

This equation states that the dividend rate from the stock of a Northern quality leader $\frac{\pi_N}{v_I}$ plus the capital gains rate $\frac{\dot{v}_I}{v_I}$ minus the instantaneous probabilities of experiencing total capital losses due to further innovation I and imitation C equals the market interest rate ρ. Since the quality level $q(\theta, t)$ is constant during an innovative R&D race and only jumps up when the race ends (innovation occurs), it follows that $v_I(\theta, t)$ is constant during an innovative R&D race and $\frac{\dot{v}_I}{v_I} = 0$. Thus, for the steady-state equilibrium reward for innovating is

$$v_I(\theta, t) = \frac{\pi_N(\theta, t)}{\rho + I + C}. \tag{16}$$

The profits earned by each Northern quality leader π_N are appropriately discounted using the market interest rate ρ, the instantaneous probability I of being driven out of business by Northern firms which develop higher quality products and the instantaneous probability C of being driven out of business by Southern firms which copy the Northern firm's product (and have lower wage costs).

The stock market value of a Southern quality leader can be similarly calculated. The corresponding no-arbitrage condition is

$$\frac{\pi_S(\theta,t)}{v_C(\theta,t)} + \frac{\dot{v}_C(\theta,t)}{v_C(\theta,t)} - I = \rho.$$

Setting $\dot{v}_C = 0$ and solving for the steady-state equilibrium reward for imitating yields

$$v_C(\theta,t) = \frac{\pi_S(\theta,t)}{\rho + I}. \tag{17}$$

The profits earned by each Southern quality leader π_S are appropriately discounted using the market interest rate ρ and the instantaneous probability I of being driven out of business by Northern firms which develop higher quality products. A Southern quality leader does not have to worry about its product being copied by another Southern firm since there is no reward for copying already copied products (if copying resulted in two Southern quality leaders in an industry, then under Bertrand price competition, the market price would fall down to marginal cost and both profits and the reward for copying would equal zero).

Let $Q(t) \equiv \int_0^1 q(\theta,t)\,d\theta$ denote the average quality level across industries at time t and let $x_N(t) \equiv Q(t)/L_N(t)$ denote average quality relative to the size of the North. We solve for a steady-state equilibrium where x_N is constant over time. As product quality improves over time and $Q(t)$ increases, innovating becomes more difficult. On the other hand, as the North increases in size over time and $L_N(t)$ increases, there are more resources that can be devoted to innovating. Thus x_N is a natural measure of "relative R&D difficulty": R&D difficulty relative to the size of the Northern economy.[9]

We are now ready to state an innovative R&D condition that must be satisfied if Northern firms are making profit-maximizing innovative R&D choices. Equations (9), (14) and (16) together imply that

$$\frac{\frac{Y_N(t)}{h(\sigma-1)Q(t)}}{\rho + I + C} = \gamma. \tag{18}$$

Equation (18) has a natural economic interpretation. The left-hand side is related to the benefit (expected discounted profits) from innovating and the right-hand side is related to the cost of

[9]In Segerstrom (1998) and Li (2003), it is shown in a closed-economy setting that, regardless of initial conditions, relative R&D difficulty necessarily converges to a constant value over time. Steger (2003) calibrates the Segerstrom (1998) model and studies the speed of convergence to the steady-state. In this paper, we focus on the steady-state properties of the model and do not try to characterize the transition path leading to the steady-state.

innovating. The benefit from innovating increases when c_N or c_S increase (individual consumers buy more), when $L_N(t)$ or $L_S(t)$ increase (there are more consumers to sell to), when ρ decreases (future profits are discounted less), and when I or C decrease (the Northern quality leader is less threatened by further innovation or imitation). The cost of innovating increases when γ increases (innovating becomes more difficult).

Likewise, we can state an imitative R&D condition that must be satisfied if Southern firms are making profit-maximizing imitative R&D choices. Equations (10), (15) and (17) together imply that

$$\frac{\frac{Y_S(t)}{(\sigma-1)Q(t)}}{\rho + I} = \beta. \tag{19}$$

Equation (19) also has a natural economic interpretation. The left-hand side is related to the benefit (expected discounted profits) from imitating and the right-hand side is related to the cost of imitating. The benefit from imitating increases when c_N or c_S increases (individual consumers buy more), when $L_N(t)$ or $L_S(t)$ increase (there are more consumers to sell to), when ρ decreases (future profits are discounted less), and when I decrease (the Southern quality leader is less threatened by further innovation). The cost of imitating increases when β increases (imitating becomes more difficult).

2.6 Quality Dynamics and Semi-Endogenous Growth

By definition, the average quality of products at time t is

$$Q(t) = \int_0^1 q(\theta, t)\, d\theta = \int_0^1 \lambda^{j(\theta,t)}\, d\theta$$

where $\lambda = \delta^{\sigma-1} > 1$. We can calculate how $Q(t)$ evolves over time in a steady-state equilibrium. Since $j(\theta, t)$ jumps up to $j(\theta, t) + 1$ when innovation occurs in industry θ, and the innovation rate I is constant across industries and over time, we obtain that the time derivative of $Q(t)$ is

$$\dot{Q}(t) = \int_0^1 \left[\lambda^{j(\theta,t)+1} - \lambda^{j(\theta,t)}\right] I\, d\theta = (\lambda - 1) I Q(t).$$

The growth rate of average product quality $\frac{\dot{Q}}{Q}$ is proportional to the innovation rate I in each industry. It follows that the measure of relative R&D difficulty $x_N = Q(t)/L_N(t)$ can only be constant over time if $\frac{\dot{Q}}{Q} = (\lambda - 1)I = n$, from which it follows that the steady-state innovation rate is

$$I = \frac{n}{\lambda - 1}. \tag{20}$$

Thus, the steady-state innovation rate depends only on the population growth rate n and the R&D difficulty parameter λ, as in Segerstrom (1998). In a steady-state equilibrium, individual researchers are becoming less productive and firms compensate for this by increasing the number of employed researchers over time. This compensation is only feasible for firms in general if there is positive population growth, so positive population growth is needed to sustain technological change in the long run.

Because the steady-state innovation rate I does not depend on the level of trade costs (τ), intellectual property protection (β) or other policy choices, this type of model is commonly referred to as a *semi-endogenous* (as opposed to *fully-endogenous*) growth model.[10] The following reasons have influenced our decision to use the semi-endogenous growth approach in the present paper.

First, the empirical relevance of both classes of models has been questioned recently. On the one hand, as Jones (2005) points out, per-capita GDP growth in the United States economy has been remarkably stable over time despite many policy-related changes that one might think would promote long-run growth (i.e., post-war trade liberalization, increases in the years of education, liberalization in financial markets, stronger protection of intellectual property rights, etc). This evidence represents a challenge for fully-endogenous growth models that routinely generate long-run growth effects that are rather large. For example, Impullitti (2006) calibrates a fully-endogenous growth model to fit the post-1950 experience of the US economy and finds that the increase in competition in the market for innovations since 1950 should have led to a 35 percent increase in the US long-run growth rate. In fact, there has been no upward trend in US growth rates since 1950. On the other hand, Ha and Howitt (2006) using cointegration techniques argue that long-run trends in US R&D investment and total factor productivity are more supportive of fully-endogenous growth theory.

Second, semi-endogenous growth theory offers an analytically tractable framework which allows us to address the dynamic effects of a variety of policies and provide useful insights without having to worry about complex interactions generated by changes in the long-run rate of innovation. Thus we are able to analyze the effects of trade costs and perform welfare analysis that would not be

[10] Jones (1995b), Kortum (1997), Segerstrom (1998) and Li (2003) among others have constructed scale-invariant *semi-endogenous* growth models whereas Peretto (1996), Young (1998), Dinopoulos and Thompson (1998), Howitt (1999) and Segerstrom (2000) among others have developed a variety of scale-invariant fully-endogenous growth models.

analytically feasible in the context of fully-endogenous growth models.

Returning to quality dynamics, the average quality of products $Q(t)$ can be broken up into two parts

$$Q(t) = \int_0^1 q(\theta, t)\, d\theta = Q_N(t) + Q_S(t) = \int_{m_N} q(\theta, t)\, d\theta + \int_{m_S} q(\theta, t)\, d\theta,$$

where Q_N denotes the aggregate quality of Northern products and Q_S denotes the aggregate quality of Southern products. We can calculate how Q_N and Q_S evolve over time in a steady-state equilibrium. Referring back to Figure 1, the time derivative of Q_S is

$$\dot{Q}_S = \int_{m_N} \lambda^{j(\theta,t)} C\, d\theta - \int_{m_S} \lambda^{j(\theta,t)} I\, d\theta = CQ_N - IQ_S$$

and the time derivative of Q_N is

$$\begin{aligned} \dot{Q}_N &= \int_{m_S} \lambda^{j(\theta,t)+1} I\, d\theta - \int_{m_N} \lambda^{j(\theta,t)} C\, d\theta + \int_{m_N} \left[\lambda^{j(\theta,t)+1} - \lambda^{j(\theta,t)}\right] I\, d\theta \\ &= I\lambda Q_S - CQ_N + (\lambda - 1) IQ_N. \end{aligned}$$

It follows that the growth rates of Q_N and Q_S are constant over time only if they are identical. Solving

$$\frac{\dot{Q}_S}{Q_S} = C\frac{Q_N}{Q_S} - I = \frac{\dot{Q}_N}{Q_N} = I\lambda\frac{Q_S}{Q_N} - C + (\lambda - 1)I$$

yields $C\frac{Q_N+Q_S}{Q_S} = \lambda I \frac{Q_S+Q_N}{Q_N}$, which simplifies to $\frac{Q_S}{Q_N} = \frac{C}{\lambda I}$. It follows that

$$Q_N(t) = \frac{\lambda I}{\lambda I + C} Q(t) \qquad \text{and} \qquad Q_S(t) = \frac{C}{\lambda I + C} Q(t). \tag{21}$$

Combining (13) with (21) yields $\frac{Q_N(t)}{m_N} = \frac{\lambda Q_S(t)}{m_S}$. The average quality of products produced in the North $\frac{Q_N(t)}{m_N}$ is somewhat higher than the average quality of products produced in the South $\frac{Q_S(t)}{m_S}$ since shifts in production from the South to the North are always associated with increases in product quality (innovation).

2.7 Labor Markets

We assume that workers can move freely and instantaneously across firms and activities in each region. Consequently, at each instant in time full employment of labor prevails in each region and wages adjust instantaneously to equalize labor demand and supply.

Full employment of labor in the North holds at time t when the supply of labor $L_N(t)$ equals the demand for labor in manufacturing plus the demand for labor in R&D. In industry θ with a Northern industry leader, manufacturing employment is $[d_N(\theta,t)L_N(t) + \tau d_N^*(\theta,t)L_S(t)]/h$. Thus, the total demand for manufacturing labor in the North is $\int_{m_N} [d_N(\theta,t)L_N(t) + \tau d_N^*(\theta,t)L_S(t)]\, h^{-1} d\theta$. Likewise, Northern R&D employment in industry θ is $\sum_i \ell_i = \gamma I q(\theta,t)$ and total Northern R&D employment is $\int_0^1 \gamma I q(\theta,t) d\theta = \gamma I Q(t)$. Substituting using (5), (8) and (21) yields the Northern full employment condition

$$L_N(t) = \frac{\lambda I}{\lambda I + C}\left[\frac{Y_N(t)}{h}\right] + \gamma I Q(t). \tag{22}$$

The two terms on the right-hand-side of (22) are the Northern employment levels in production and R&D activities, respectively. The Northern production employment level increases when $c_N L_N(t)$ or $c_S L_S(t)$ increase (aggregate consumer expenditure is higher in the North or South), or $\lambda I/(\lambda I + C)$ increases (more products are produced in the North). The Northern R&D employment level increases when I increases (there is a higher innovation rate) or $Q(t)$ increases (innovating becomes more difficult).

Similar calculations apply for the Southern labor market. Full employment of labor in the South holds at time t when the supply of labor $L_S(t)$ equals the demand for labor in manufacturing plus the demand for labor in R&D. In industry θ with a Southern industry leader, manufacturing employment is $d_S(\theta,t)L_S(t) + \tau d_S^*(\theta,t)L_N(t)$. Thus, the total demand for manufacturing labor in the South is $\int_{m_S} [d_S(\theta,t)L_S(t) + \tau d_S^*(\theta,t)L_N(t)]\, d\theta$. Likewise, Southern R&D employment in industry θ is $\sum_i \ell_i = \beta C q(\theta,t)$ and total Southern R&D employment is $\int_{m_N} \beta C q(\theta,t) d\theta = \beta C Q_N(t)$. Substituting using (6), (7) and (21) yields the Southern full employment condition

$$L_S(t) = \frac{C}{\lambda I + C} Y_S(t) + \frac{\lambda I}{\lambda I + C}\beta C Q(t). \tag{23}$$

The two terms on the right-hand-side of (23) are the employment levels of Southern labor in production and R&D activities, respectively. The Southern production employment level increases when $c_N L_N(t)$ or $c_S L_S(t)$ increase (aggregate consumer expenditure is higher in the North or South), or $C/(\lambda I + C)$ increases (there are more products produced in the South). The Southern R&D employment share increases when C increases (there is a higher rate of copying), $\lambda I/(\lambda I + C)$ increases (there are more Northern products to copy) or $Q(t)$ increases (imitating becomes more difficult).

The Northern full employment and R&D conditions can be combined to yield a single steady-state condition describing the North. Solving (18) for $Y_N(t)$, substituting into (22) and then dividing both sides by $L_N(t)$ yields

$$1 = \gamma x_N \left[(\sigma - 1)(\rho + I + C) \frac{\lambda I}{\lambda I + C} + I \right], \tag{24}$$

which we will call the *Northern steady-state condition.* It is a Northern full employment condition that takes into account the implications of profit-maximizing R&D behavior by Northern firms.

Similarly for the South, solving (19) for $Y_S(t)$, substituting into (23) and then dividing both sides by $L_S(t)$ yields

$$1 = \beta \frac{x_N \bar{L}_N}{\bar{L}_S} \left[(\sigma - 1)(\rho + I) \frac{C}{\lambda I + C} + C \frac{\lambda I}{\lambda I + C} \right] \tag{25}$$

which we will call the *Southern steady-state condition.* It is a Southern full employment condition that takes into account the implications of profit-maximizing R&D behavior by Southern firms.

The Northern and Southern steady-state conditions are illustrated in Figure 2 and are labeled "North" and "South," respectively. The Northern steady-state condition is upward-sloping in (x_N, C) space with a positive x_N intercept, while the Southern steady-state condition is downward-sloping in (x_N, C) space with no intercepts.[11] These two curves have a unique intersection at point A and thus the steady-state equilibrium values of x_N and C are uniquely determined. In Figure 2, the vertical axis measures the rate of technology transfer from the North to the South since any increase in the rate of copying C is associated with faster technology transfer. For the horizontal axis, it is useful to think of it as measuring the rate of technological change in the North although this is not exactly true. Movements to the right on the horizontal axis are associated with temporary increases in the Northern innovation rate I and permanent increases in the relative size of the Northern R&D sector.

Why is the Northern steady-state condition upward-sloping? When the rate of copying C increases, there are two steady-state effects in the North. First, a faster rate of copying means that more industries move to the South and this contributes to reducing production employment in the North ($m_N = \frac{I}{I+C}$ decreases). Second, when Northern industry leaders are exposed to a faster rate of copying, they must earn higher profit flows while in business for Northern firms to break even on their R&D investments [in (18), an increase in C must be matched by a corresponding increase in

[11] To determine the slope of the Northern steady-state condition, we use the result that $I = \frac{n}{\lambda - 1}$ and the assumption $\rho > n$ to obtain $\frac{\partial}{\partial C} \left[\frac{\rho + I + C}{\lambda I + C} \right] = \frac{n - \rho}{(\lambda I + C)^2} < 0$. To determine the slope of the Southern steady-state condition, we use the fact that $\frac{\partial}{\partial C} \left[\frac{C}{\lambda I + C} \right] = \frac{\lambda I}{(\lambda I + C)^2} > 0$.

c_N and/or c_S, holding all other variables fixed]. Northern industry leaders earn higher profit flows when consumers buy more of their products and these higher sales are associated with increased production employment in individual Northern industries. Given our assumption that $\rho > n$ (the real interest rate is higher that the population growth rate), the first effect unambiguously dominates, so aggregate Northern production employment falls when the rate of copying goes up. To maintain full employment of Northern labor, the fall in Northern production employment must be matched by a correspond increase in Northern R&D employment. This implies that x_N must increase (R&D becomes relatively more difficult) since only then are more workers needed in the Northern R&D sector to maintain the steady-state innovation rate $I = \frac{n}{\lambda - 1}$. Thus, to satisfy both Northern profit-maximization and full employment conditions, any increase in the rate of copying C (which reduces Northern production employment) must be matched by an increase in relative R&D difficulty x_N (which raises Northern R&D employment).

The intuition behind the downward slope of the Southern steady-state condition is similar: When the rate of copying C decreases, there are two steady-state effects in the South. First, a slower rate of copying C means that more industries move to the North and this contributes to lowering production employment in the South ($m_S = \frac{C}{I+C}$ decreases). Second, a slower rate of copying C directly contributes to lowering R&D employment in the South ($m_N C = \frac{IC}{I+C}$ decreases). Of course, both Southern production and R&D employment cannot simultaneously decrease because there is a given supply of labor in the South at any point in time. To maintain full employment of Southern labor, a decrease in the rate of copying C must be matched by an increase in relative R&D difficulty x_N so more Southern R&D labor is needed to maintain any given imitation rate. From (19), we can also see that an increase in x_N is associated with an increase in c_N and/or c_S (holding all other variables fixed) and hence, with an increase in Southern production employment. When R&D is relatively more difficult, Southern industry leaders must earn higher profit flows while in business to break even on their R&D investments. Thus, to satisfy both Southern profit-maximization and full employment conditions, any decrease in the rate of copying C (which reduces both Southern production and R&D employment) must be matched by an increase in relative R&D difficulty x_N (which raises both Southern production and R&D employment).

2.8 The Market Value of Firms

Let V_N denote the total market value of all Northern firms at time $t = 0$ and let V_S denote the total market value of all Southern firms at time $t = 0$. To solve the model, we need to determine what these market values are in steady-state equilibrium.

First, consider how the price indexes evolve over time. Using (21), we obtain that $P_N(t)^{1-\sigma} = \int_{m_N} q(\theta,t)(p_N)^{1-\sigma}d\theta + \int_{m_S} q(\theta,t)(p_S^*)^{1-\sigma}d\theta = (\frac{w_N}{\alpha h})^{1-\sigma}\frac{\lambda I}{\lambda I+C}Q(t) + (\frac{\tau w_S}{\alpha})^{1-\sigma}\frac{C}{\lambda I+C}Q(t)$. Thus the Northern price index $P_N(t)$ decreases over time with product quality $Q(t)$ and $P_N(t)^{1-\sigma}/Q(t)$ is constant over time. The same holds for the Southern price index: $P_S(t)^{1-\sigma} = (\frac{\tau w_N}{\alpha h})^{1-\sigma}\frac{\lambda I}{\lambda I+C}Q(t) + (\frac{w_S}{\alpha})^{1-\sigma}\frac{C}{\lambda I+C}Q(t)$ decreases over time with product quality $Q(t)$ and $P_S(t)^{1-\sigma}/Q(t)$ is constant over time. Next consider the profit flows earned by a typical Northern firm. During the lifetime of the firm, $q(\theta,t)$ is constant, $p_N = \frac{w_N}{\alpha h}$ is constant since w_N is constant, $P_N(t)^{1-\sigma}/Q(t)$ and $P_S(t)^{1-\sigma}/Q(t)$ are constants, and $\frac{\dot{Q}(t)}{Q(t)} = (\lambda-1)I = n$, so $L_N(t)/P_N(t)^{1-\sigma}$ and $L_S(t)/P_S(t)^{1-\sigma}$ are also constants over time. It immediately follows from (9) that the firm's profit flow $\pi_N(\theta,t)$ is constant over time. Consequently, the market value of a Northern firm $\frac{\pi_N(\theta,t)}{\rho+I+C}$ does not change over the course of the firm's lifetime and $\frac{\pi_N(\theta,t)}{\rho+I+C} = w_N\gamma q(\theta,t)$ holds not just at the time of innovation but during the entire lifetime of a Northern firm. Using this information, $V_N = \int_{m_N} w_N\gamma q(\theta,0)\,d\theta = w_N\gamma Q_N(0)$. Substituting using (21) and $Q(0) = x_N\bar{L}_N$, we obtain that the market value of all Northern firms at $t=0$ is

$$V_N = w_N\gamma\frac{\lambda I}{\lambda I+C}x_N\bar{L}_N. \tag{26}$$

Using similar reasoning, (10), (15) and (17) imply that the market value of all Southern firms at $t=0$ is

$$V_S = w_S\beta\frac{C}{\lambda I+C}x_N\bar{L}_N. \tag{27}$$

Other things being equal, the market value of firms in a region is higher when workers earn higher wages and when innovating is relatively more difficult. This is because profit flows are proportional to wages and increasing in product quality [see (9) and (10)].

For future reference, the price indexes at $t=0$ satisfy

$$P_N(0)^{1-\sigma} = \left[\left(\frac{w_N}{\alpha h}\right)^{1-\sigma}\frac{\lambda I}{\lambda I+C} + \left(\frac{\tau w_S}{\alpha}\right)^{1-\sigma}\frac{C}{\lambda I+C}\right]x_N\bar{L}_N. \tag{28}$$

$$P_S(0)^{1-\sigma} = \left[\left(\frac{\tau w_N}{\alpha h}\right)^{1-\sigma}\frac{\lambda I}{\lambda I+C} + \left(\frac{w_S}{\alpha}\right)^{1-\sigma}\frac{C}{\lambda I+C}\right]x_N\bar{L}_N. \tag{29}$$

2.9 Consumer Expenditures

Having determined the market value of firms, we are in a position to solve for consumer expenditures. Let $A_N(t)$ and $A_S(t)$ denote the financial assets of the representative Northern consumer and Southern consumer, respectively. Consistent with the Feldstein and Horioka (1980) finding that domestic savings finance domestic investments, we assume that Northern consumers own the Northern firms and Southern consumers own the Southern firms, that is, $A_N(t) = V_N(t)/L_N(t)$ and $A_S(t) = V_S(t)/L_S(t)$. Now, the intertemporal budget constraint of the representative Northern consumer $\dot{A}_N(t) = w_N + \rho A_N(t) - c_N - nA_N(t)$ can be rewritten as $\frac{\dot{A}_N(t)}{A_N(t)} = \frac{w_N - c_N}{A_N(t)} + \rho - n$. Since the growth rate of $A_N(t)$ must be constant over time in any steady-state equilibrium, the intertemporal budget constraint implies that A_N must be constant over time. Using (26), we obtain

$$c_N = w_N \left[1 + (\rho - n)\gamma \frac{\lambda I}{\lambda I + C} x_N \right]. \tag{30}$$

The representative Northern consumer's expenditure c_N is wage income w_N plus interest income on financial assets appropriately adjusted to take into account the splitting of financial assets that results from population growth. Using similar reasoning and (27), we obtain that the representative Southern consumer's expenditure is

$$c_S = w_S \left[1 + (\rho - n)\beta \frac{C}{\lambda I + C} x_N \frac{\bar{L}_N}{\bar{L}_S} \right]. \tag{31}$$

2.10 The Relative Wage

To solve for the relative wage w, it is useful to first define the relative expenditure of the two regions

$$\phi_N \equiv \frac{c_N \bar{L}_N}{c_S \bar{L}_S} = w \left[\frac{\bar{L}_N + (\rho - n)\gamma \frac{\lambda I}{\lambda I + C} x_N \bar{L}_N}{\bar{L}_S + (\rho - n)\beta \frac{C}{\lambda I + C} x_N \bar{L}_N} \right] \tag{32}$$

Note that ϕ_N is a well-defined function of the relative wage $w \equiv \frac{w_N}{w_S}$ only, since everything else in the bracketed expression is determined in steady-state equilibrium. Next, we divide the imitative R&D condition (19) by the innovative R&D condition (18) to obtain

$$\frac{hY_S(t)}{Y_N(t)} = \frac{\beta(\rho + I)}{\gamma(\rho + I + C)}.$$

Now

$$\frac{Y_S(t)}{Y_N(t)} = \frac{p_S^{-\sigma} Q(t) \left\{ \frac{\tau^{1-\sigma} c_N L_N(t)}{P_N(t)^{1-\sigma}} + \frac{c_S L_S(t)}{P_S(t)^{1-\sigma}} \right\}}{p_N^{-\sigma} Q(t) \left\{ \frac{c_N L_N(t)}{P_N(t)^{1-\sigma}} + \frac{\tau^{1-\sigma} c_S L_S(t)}{P_S(t)^{1-\sigma}} \right\}} = \frac{p_S^{-\sigma} \left\{ \frac{\tau^{1-\sigma} \phi_N P_S(t)^{1-\sigma}}{Q_S(t)} + \frac{P_N(t)^{1-\sigma}}{Q_S(t)} \right\}}{p_N^{-\sigma} \left\{ \frac{\phi_N P_S(t)^{1-\sigma}}{Q_S(t)} + \frac{\tau^{1-\sigma} P_N(t)^{1-\sigma}}{Q_S(t)} \right\}}$$

Substituting using $\frac{P_N(t)^{1-\sigma}}{Q_S(t)} = \frac{\lambda I}{C}(p_N)^{1-\sigma} + (p_S^*)^{1-\sigma}$ and $\frac{P_S(t)^{1-\sigma}}{Q_S(t)} = \frac{\lambda I}{C}(p_N^*)^{1-\sigma} + (p_S)^{1-\sigma}$ yields the *steady-state wage equation*

$$\frac{(\tau^{\sigma-1} + \phi_N \tau^{1-\sigma})\frac{\lambda I}{C} + (\frac{w}{h})^{\sigma-1}(1+\phi_N)}{\frac{1+\phi_N}{w}(\frac{w}{h})^{1-\sigma}\frac{\lambda I}{C} + \frac{\tau^{1-\sigma}+\phi_N\tau^{\sigma-1}}{w}} = \frac{\beta(\rho+I)}{\gamma(\rho+I+C)}. \tag{33}$$

Since $\frac{\phi_N}{w}$ does not depend on w and is completely pinned down by previous steady-state equilibrium calculations, the denominator on the LHS of the wage equation (33) is decreasing in w and the numerator is increasing in w. Hence, the LHS of the wage equation is increasing in w. Furthermore, the LHS converges to zero as w converges to zero and the LHS converges to infinity as w converges to infinity. Thus, the wage equation (33) determines w.

The model's steady-state equilibrium is determined by the Northern condition (24), the Southern condition (25) and the wage condition (33). These equations uniquely determine steady-state equilibrium values of x_N, C and w. To verify that we really have found a steady-state equilibrium, we always need to check that w lies in the wage interval $\frac{\delta h}{\tau} > w > \tau h$.

2.11 Steady-State Utility Paths

We turn now to solving for the steady-state utility paths of representative consumers in the North and South, respectively. For the typical Northern consumer, (2) implies that utility at time t is $u_N(t) = \left\{\int_{m_N} q(\theta,t)^{1-\alpha} d_N(\theta,t)^{\alpha}\, d\theta + \int_{m_S} q(\theta,t)^{1-\alpha} d_S^*(\theta,t)^{\alpha}\, d\theta\right\}^{1/\alpha}$. Substituting using (5) and (6) yields

$$u_N(t) = \frac{c_N}{P_N(t)} \tag{34}$$

and the corresponding calculations for the typical Southern consumer yields

$$u_S(t) = \frac{c_S}{P_S(t)} \tag{35}$$

In both the North and the South, consumer expenditure is constant over time and consumer utility grows over time entirely because of growth in the quality $Q(t)$ of products [for example, $(1-\sigma)\frac{\dot{P}_N(t)}{P_N(t)} = \frac{\dot{Q}(t)}{Q(t)}$]. Because $x_N = \frac{Q(t)}{L_N(t)}$ is constant in steady-state equilibrium and the growth rate of Q is n, there is a common steady-state rate of economic growth g given by

$$g \equiv \frac{\dot{u}_N(t)}{u_N(t)} = \frac{\dot{u}_S(t)}{u_S(t)} = \frac{1}{\sigma-1}\frac{\dot{Q}(t)}{Q(t)} = \frac{n}{\sigma-1}. \tag{36}$$

Equations (34) and (35) will prove useful for studying the long-run welfare effects of policy changes. Taking as given that the economy always converges over time to its steady-state equilibrium, whenever there is a change in the economic environment (for example, trade costs fall), this leads to convergence to a new steady-state equilibrium. Since the old and the new steady-state equilibrium paths involve the same rate of economic growth, we just have to compare utility levels at time $t = 0$ in the old and new steady-states to determine whether the change makes consumers better off in the long run. If $u_N(0)$ is higher in the steady-state equilibrium with lower trade costs, this means that eventually the typical Northern consumer will be happier on the new equilibrium path with lower trade costs than on the old equilibrium path with higher trade costs.

This completes the description of the model's steady-state equilibrium.

3 Steady-State Properties

In this section, we study the steady-state equilibrium and welfare properties of the model. To illustrate the model's potential, we study the implications of three aspects of "globalization": increases in the size of the South (e.g., countries like China joining the world trading system), stronger intellectual property protection (e.g., the TRIPs agreement that was part of the Uruguay Round) and lower trade costs (e.g., improvements in transportation technology or reductions in trade barriers). An increase in the size of the South is capturing by increasing $\bar{L}_S$, the size of the South at time $t = 0$. As in Glass and Saggi (2002), stronger intellectual property protection is captured by increasing the parameter β that governs how hard it is for Southern firms to copy ideas developed in the North. Lower trade costs are captured by decreasing τ.

3.1 General Results

First, an increase in the size of the South $\bar{L}_S$ has no effect on the Northern steady-state condition (24) but implies that x_N increases for given C in (25). Thus the Southern steady-state condition shifts to the right in (x_N, C) space and as illustrated in Figure 3, the increase in $\bar{L}_S$ leads to higher values of both x_N and C. Second, an increase in β has no effect on the Northern steady-state condition (24) but implies that x_N decreases for given C in (25). Thus the Southern steady-state condition shifts to the left in (x_N, C) space and increasing β leads to lower values of both x_N and C. Finally, a decrease in τ has no effect on the Northern steady-state condition (24) and no effect on the Southern steady-state condition (25). Thus, decreasing τ has no effect on either x_N or C.

The measure of relative R&D difficulty $x_N = \frac{Q(t)}{L_N(t)}$ can only permanently increase if the average quality of products $Q(t)$ temporarily grows at a faster than usual rate. This means that a permanent increase in x_N is associated with a temporary increase in the Northern innovation rate I.

We have established

Theorem 1 *(i) A permanent increase in the size of the South ($\bar{L}_S \uparrow$) leads to a permanent increase in the rate of copying of Northern products ($C \uparrow$) and a temporary increase in the Northern innovation rate ($x_N \uparrow$). (ii) A permanent increase in intellectual property protection ($\beta \uparrow$) leads to a permanent decrease in the rate of copying of Northern products ($C \downarrow$) and a temporary decrease in the Northern innovation rate ($x_N \downarrow$). (iii) A permanent decrease in trade costs ($\tau \downarrow$) leads to no change in the rate of copying of Northern products (C constant) and no change in the Northern innovation rate (x_N constant).*

An increase in the size of the South naturally leads to more copying of Northern products and the faster rate of technology transfer means that production (and jobs) move from the high wage North to the low wage South. With production jobs moving to the South, more Northern workers become available for employment in the Northern R&D sector and the Northern wage must adjust to make it attractive for Northern firms to expand their R&D activities. In the short-run, an increase in the size of the South causes the industry-level innovation rate I to jump up and technological change to accelerate, but the industry-level innovation rate gradually falls back to the original steady-state level $I = n/(\lambda - 1)$ as R&D becomes relatively more difficult. In the long run, an increase in the size of the South does not change the innovation rate but increases relative R&D difficulty x_N and the fraction of Northern labor employed in R&D activities.

A increase in intellectual property protection naturally leads to less copying of Northern products. What is perhaps surprising is that it also slows technological change. The reason why is that the lower rate of copying has important implications for the Northern labor market. It directly increases the demand for Northern production workers (because fewer production jobs get transferred to the South) and since Northern workers were fully employed to begin with, there are no additional Northern workers to hire. Thus, the Northern wage must increase enough so that the increase in demand for Northern production workers is completely offset by a decrease in demand for Northern R&D workers. In negotiations about the protection of intellectual property rights at the World Trade Organization (WTO), developing countries have been arguing that stronger intellectual property rights protection would simply generate substantial rents for Northern innovators at the expense of Southern consumers and would not stimulate faster technological change (see Maskus, 2000). Theorem 1 provides support for this position taken by developing countries.

The result in Theorem 1 that is perhaps the most surprising is that lower trade costs between the North and the South have no effect on the rate of technology transfer or rate of innovation. The reason is that when trade costs fall, Northern firms make higher profits from exporting to the South but their profits fall from selling their products locally in the North because the Northern market becomes more competitive. Given the assumption of CES consumer preferences, these two opposing effects exactly cancel. Thus, lower trade costs do not change either the profits earned from innovating or the profits earned from imitating and there is no change in either C or x_N.

While it is straightforward to obtain general results about how policy changes affect C and x_N, the same is not true for what happens to the relative wage w and consumer welfare. The reason is that the wage condition (33) is quite complicated. But there is a special case where further analytical results can be obtained, namely, when trade is costless ($\tau = 1$). In this case, the wage condition (33) simplifies considerably to

$$\frac{w}{h^{\alpha}} = \left[\frac{\beta(\rho + I)}{\gamma(\rho + I + C)}\right]^{1-\alpha}. \tag{37}$$

In the rest of this section, we fully solve the model analytically assuming costless trade since these calculations are particularly illuminating about how the model works. Then we solve the model numerically in Section 4 for the main case of interest: when there are positive trade costs ($\tau > 1$).

3.2 The Costless Trade Special Case

First consider the steady-state equilibrium effects of policy changes on the relative wage w. Since an increase in $\bar{L}_S$ raises C, (37) implies that w falls. In contrast, since an increase in β lowers C, (37) implies that w rises. We have established

Theorem 2 *When there is costless trade, a permanent increase in the size of the South ($\bar{L}_S \uparrow$) leads to a permanent decrease in the Northern relative wage ($w \equiv \frac{w_N}{w_S} \downarrow$), while a permanent increase in intellectual property protection ($\beta \uparrow$) leads to a permanent increase in the Northern relative wage ($w \equiv \frac{w_N}{w_S} \uparrow$).*

The intuition behind these steady-state effects is as follows: An increase in the size of the South $\bar{L}_S$ leads to a faster rate of copying C of Northern products by Southern firms. Consequently, with more production jobs moving from the high-wage North to the low-wage South, to restore full employment of labor in the North, the Northern relative wage w must fall enough so that the loss of Northern production employment is fully offset by an increase in Northern R&D employment. For stronger intellectual property protection, we just run this intuition in the opposite direction. An increase in the intellectual property protection β leads to a slower rate of copying C of Northern products by Southern firms. Consequently, fewer production jobs move from the high-wage North to the low-wage South, increasing the demand for Northern labor. The Northern relative wage w must rise enough so that the gain in Northern production employment is fully offset by a loss in Northern R&D employment.

Solving for the steady-state equilibrium effect of lower trade costs τ on the Northern relative wage w involves more work. Since a change in τ has no effect on I, C and x_N, the LHS of the wage equation (33) can be viewed as a function of just τ and w. Let $g(\tau, w)$ denote this function. We proceed by totally differentiating the wage equation (33) with respect to w and τ and then using the implicit function theorem. Evaluating the derivatives at $\tau = 1$ and using the fact that $g(1, w) = w^\sigma$, this yields

$$\left.\frac{\partial g(\tau, w)}{\partial \tau}\right|_{\tau=1} = \frac{(\sigma-1)(1-\phi_N)}{1+\phi_N} w^\sigma, \qquad \left.\frac{\partial g(\tau, w)}{\partial w}\right|_{\tau=1} = \sigma w^{\sigma-1},$$

and

$$\left.\frac{dw}{d\tau}\right|_{\tau=1} = -\frac{\left.\frac{\partial g(\tau,w)}{\partial \tau}\right|_{\tau=1}}{\left.\frac{\partial g(\tau,w)}{\partial w}\right|_{\tau=1}} = \frac{(\sigma-1)(\phi_N-1)w}{\sigma(1+\phi_N)}. \tag{38}$$

Increasing trade costs τ on the margin starting from costless trade increases the relative wage w if $\phi_N > 1$ and decreases the relative wage w if $\phi_N < 1$. The condition $\phi_N > 1$ means that aggregate Northern consumer expenditure is larger that aggregate Southern consumer expenditure ($\bar{L}_N c_N > \bar{L}_S c_S$), or the Northern market is larger than the Southern market (in terms of purchasing power). We are mainly interesting in the result going in the reverse direction, which can be stated as:

Theorem 3 *In the neighborhood of costless trade, a permanent decrease in the trade costs ($\tau \downarrow$) leads to a permanent decrease in the Northern relative wage ($w \equiv \frac{w_N}{w_S} \downarrow$) if the Northern market is larger than the Southern market ($\phi_N > 1$), and has the opposite effect on the Northern relative wage ($w \equiv \frac{w_N}{w_S} \uparrow$) if the Northern market is smaller than the Southern market ($\phi_N < 1$).*

When trade costs τ decrease on the margin, there is no effect on the innovation rate I, the copying rate C or relative R&D difficulty x_N. Referring back to (24) and (25), the relative size of the Northern R&D sector $\gamma x_N I$ does not change and the relative size of the Southern R&D sector $\beta \frac{x_N \bar{L}_N}{\bar{L}_S} C \frac{\lambda I}{\lambda I + C}$ does not change either. But the reduction in trade costs does lead to a reallocation of resources in both the North and the South. Firms respond by exporting more, employing more workers to produce goods for the export market and employ fewer workers to produce goods for the domestic market. Lower trade costs mean that firms face stiffer competition in their domestic markets since the prices charged by other firms fall. For firms in the larger market, this stiffer domestic competition is more important in lowering labor demand than the increase in exporting is in raising labor demand. Thus lower trade costs tend to depress the relative wage of workers in the larger market.

Consider next the welfare implications of lower trade costs. A change in τ has no steady-state effect on I, C or x_N. Hence, an immediate jump to the new steady-state equilibrium is feasible and the long run welfare effects of a change in τ are also the short run welfare effects. Equation (34) together with (28) and (30) imply that a change in τ only increases $u_N(0)$ if it leads to an increase in w/τ. Likewise, (35) together with (29) and (31) imply that a change in τ only increases $u_S(0)$ if it leads to a decrease in $w\tau$. Using (38), we can differentiate both of these terms with respect to τ. This yields

$$\left.\frac{d\,[w/\tau]}{d\tau}\right|_{\tau=1} = \frac{(\sigma-1)(\phi_N-1)w}{\sigma(1+\phi_N)} - w < 0$$

and

$$\left.\frac{d\,[w\tau]}{d\tau}\right|_{\tau=1} = \frac{(\sigma-1)(\phi_N-1)w}{\sigma(1+\phi_N)} + w > 0,$$

taking into account that $\phi_N > 0$. Thus, regardless of the value of ϕ_N, an increase in trade costs τ makes the typical Northern consumer worse off and makes the typical Southern consumer worse off. We are mainly interesting in the result going in the reverse direction, which can be stated as:

Theorem 4 *In the neighborhood of costless trade, a permanent decrease in the trade costs ($\tau \downarrow$) makes the typical Northern consumer better off ($u_N(0) \uparrow$), and makes the typical Southern consumer better off ($u_S(0) \uparrow$).*

Theorem 4 is surprising in light of the ambiguous effect of lower trade costs on the Northern relative wage. Even though lower trade costs τ can either increase or decrease the w depending on the value of ϕ_N (Theorem 3), the proof of Theorem 4 shows that this wage effect is always dominated by the effect on prices. Lower trade costs lead to lower prices for goods in both the North and the South. Consumers benefit from lower prices and these price benefits always dominate the possibly negative effects of lower trade costs on their wages.

When it comes to the welfare implications of an increase in the size of the South $\bar{L}_S$, things are more complicated because an increase in the size of the South $\bar{L}_S$ has the steady-state effects of increasing C and x_N, as well as decreasing w_N. From the Northern condition (24), an increase in $\bar{L}_S$ causes $\frac{x_N}{\lambda I+C}$ to unambiguously fall. It follows from (30) that an increase in $\bar{L}_S$ lowers Northern consumer expenditure c_N because both the consumer's wage income and interest income fall. It also follows from (28) that an increase in $\bar{L}_S$ lowers the Northern price index $P_N(0)$ because both the average quality of products increases ($x_N \uparrow$) and the average price level becomes more favorable for consumers $[(w_N/h)^{1-\sigma}\frac{\lambda I}{\lambda I+C} + (\tau w_S)^{1-\sigma}\frac{C}{\lambda I+C} \uparrow]$. The overall effect on Northern consumer welfare $u_N(0) = c_N/P_N(0)$ is ambiguous. From the Southern condition (25), an increase in $\bar{L}_S$ has no effect on $\frac{C}{\lambda I+C}\frac{x_N \bar{L}_N}{\bar{L}_S}$. It follows immediately from (31) that an increase in $\bar{L}_S$ has no effect on Southern consumer expenditure c_S. Now the Southern price index $P_S(0)$ is the same as the Northern price index $P_N(0)$ since we are assuming costless trade and hence, an increase in $\bar{L}_S$ lower the Southern price index $P_S(0)$ for the same reasons as in the North. The overall effect on Southern consumer welfare $u_S(0) = c_S/P_S(0)$ is unambiguously positive. To summarize, we have established

Theorem 5 *When there is costless trade, a permanent increase in the size of the South ($\bar{L}_S \uparrow$) has an ambiguous effect on the long run welfare of the typical Northern consumer but unambiguously makes the typical Southern consumer better off in the long run ($u_S(0) \uparrow$).*

An increase in the size of the South $\bar{L}_S$ results in a faster steady-state rate of copying C of Northern products. This stimulates technological change in the North but also depresses the wages of Northern workers. The overall effect on Northern welfare in the long run is ambiguous. On the one hand, Northern consumers are hurt by the fall in their wage and interest income but on the other hand, they benefit from being able to buy higher quality products at lower prices. For Southern consumers, the long-run welfare effects of an increase in the size of the South are unambiguously positive. Southern consumers are able to buy higher quality products at lower prices and there is no change in their wage or interest income.

Finally, consider the welfare implications of an increase in intellectual property protection. Things are complicated in this case as well because an increase in β has the steady-state effects of decreasing C and x_N, as well as increasing w. From the Northern condition (24), an increase in

β raises $\frac{x_N}{\lambda I+C}$ unambiguously. It follows from (30) that an increase in β raises Northern consumer expenditure c_N because both the consumer's wage income and interest income rise. It also follows from (28) that an increase in β raises the Northern price index $P_N(0)$ because both the average quality of products decrease ($x_N \downarrow$) and the average price level becomes less favorable for consumers ($(w_N/h)^{1-\sigma}\frac{\lambda I}{\lambda I+C} + (\tau w_S)^{1-\sigma}\frac{C}{\lambda I+C} \downarrow$). The overall effect on Northern consumer welfare $u_N(0) = c_N/P_N(0)$ is ambiguous. From the Southern condition (25), an increase in β has no effect on $\beta\frac{C}{\lambda I+C}\frac{x_N\bar{L}_N}{\bar{L}_S}$. It follows immediately from (31) that an increase in β has no effect on Southern consumer expenditure c_S but it does raise the Southern price index $P_S(0)$ for the same reasons as in the North. The overall effect on Southern consumer welfare $u_S(0) = c_S/P_S(0)$ is unambiguously negative. To summarize, we have established

Theorem 6 *When there is costless trade, a permanent increase in intellectual property protection ($\beta \uparrow$) has an ambiguous effect on the long run welfare of the typical Northern consumer but unambiguously makes the typical Southern consumer worse off in the long run ($u_S(0) \downarrow$).*

An increase in intellectual property protection β results in a slower steady-state rate of copying C of Northern products. This slows technological change in the North but also raises the wages of Northern workers. The overall effect on Northern welfare in the long run is ambiguous. On the one hand, Northern consumers benefit from the rise in their wage and interest income but on the other hand, they are hurt by having to buy lower quality products at higher prices. For Southern consumers, the long-run welfare effects of an increase in intellectual property protection are unambiguously negative. Southern consumers end up buying lower quality products at higher prices and there is no change in their wage or interest income.

4 Simulation Analysis

In this section, we use simulation analysis to explore further the properties of the model: first, we show that the model has a steady-state equilibrium for reasonable parameter values; second, we establish the robustness of several results in the presence of moderate (as opposed to infinitesimal) trade costs; and third, we analyze the welfare properties of the model in an attempt to resolve the ambiguities associated with Theorems 5 and 6. The results of the simulation analysis should be interpreted as suggestive rather than conclusive: there is neither physical nor human capital accumulation in the model; all industries are structurally identical and trade costs are not prohibitive for any firms; there is only one factor of production; and copying is the only channel of international technology transfer.

In the computer simulations, we used the following benchmark parameter values: $\rho = 0.07$, $n = 0.014$, $\bar{L}_N = 1$, $\bar{L}_S = 2$, $\sigma = 1.5$, $\tau = 1.15$, $\delta = 1.7$, $h = 1.67$, $\gamma = 1$ and $\beta = 3.5$. The subjective discount rate ρ was set at 0.07 to reflect a real interest rate of 7 percent, consistent with the average real return on the US stock market over the past century as calculated by Mehra and Prescott (1985). The population growth rate $n = 0.014$ equals the annual rate of world population growth between 1991 and 2000 according to the World Bank (2003). The values of initial Northern and Southern labor endowments are set at $\bar{L}_N = 1$ and $\bar{L}_S = 2$; this implies a ratio of Southern to Northern population $\bar{L}_S/\bar{L}_N = 2$ which matches the ratio of the working age population in middle-income countries to that in high-income countries (World Bank, 2003). The value of the elasticity of substitution $\sigma = 1.5$ was chosen to be roughly consistent with an economic growth rate of 2.3 percent using (36). This was the average US growth rate over the period 1951-2000 (Impulliti, 2006). The level of trade costs varies substantially across industries and can even be prohibitively high for many industries (Anderson and Wincoop, 2004). Since we assume that all industries are symmetric and engage in product cycle trade, we set $\tau = 1.15$, which means that there are 15 percent trade costs. The innovation size parameter $\delta = 1.7$ implies that $\lambda = \delta^{\sigma-1} = 1.3$ which means that each innovation is associated with a 30 percent improvement in quality. Finally, the labor productivity parameters $h = 1.67$, $\gamma = 1$ and $\beta = 3.5$ were chosen to satisfy $\gamma < \beta$ and with the purpose of generating a reasonable Northern relative wage which satisfies the model's constraints. The above parameters imply that the Northern relative wage is $w_N = 2.17$, which is within the interval defined by the product-cycle feasibility constraint $\tau h = 1.92 < w_N < \delta h/\tau = 2.46$. The US-Mexico GDP per worker ratio is 2.17 according to Jones (2002).[12]

The results from the computer simulations are reported in Tables 1, 2 and 3. In each table, the first column shows endogenous variables that we solved for and the third column shows the results for the benchmark parameter values. Table 1 shows how the values of endogenous variables change when $\bar{L}_S$ increases from 1.8 to 2.2 (the South increases in size), Table 2 shows the changes when β increases from 3.25 to 3.75 (stronger IPR protection) and Table 3 shows the changes when τ decreases from 1.20 to 1.05 (lower trade costs). There are several conclusions that we draw from studying these tables.

[12] The benchmark parameter values also imply that the expected time interval between innovations is a typical industry ($1/I = 21.7$ years) is approximately the same as the expected time duration before a new product is copied ($1/C = 20.8$ years).

First, the results confirm Theorem 1: an increase in the size of the South increases the steady-state values of relative R&D difficulty (x_N rises from 10.77 to 11.03) and the imitation rate (C rises from 0.040 to .055); whereas stronger IPR protection has the opposite effects (x_N falls from 11.00 to 10.82, C falls from .054 to .043); and lower trade costs have no effect on x_N or C.

Second, the various steady-state equilibrium effects that we derived assuming costless trade continue to hold in the presence of moderate trade costs ($\tau = 1.15$). Consistent with Theorem 2, an increase in the size of the South leads to a permanent decline in the Northern relative wage (w_N falls from 2.24 to 2.09), whereas stronger IPR protection leads to an increase in the Northern relative wage (w_N rises from 2.01 to 2.32). And consistent with Theorem 3, lower trade costs lead to a small increase in the Northern relative wage (w_N rises from 2.1711 to 2.1720), given that the Southern market is slightly larger when it comes to aggregate consumer expenditure ($\phi_N = .987 < 1$).

Third, the various unambiguous welfare effects that we derived assuming costless trade also continue to hold in the presence of moderate trade costs. Consistent with Theorem 4, lower trade costs lead to increases in both Northern consumer utility ($u_N(0)$ rises from 91.95 to 97.82) and Southern consumer utility ($u_S(0)$ rises from 46.19 to 49.43). Consistent with Theorem 5, an increase in the size of the South makes the typical Southern consumer better off ($u_S(0)$ rises from 44.52 to 49.90) and consistent with Theorem 6, an increase in IPR protection makes the typical Southern consumer worse off ($u_S(0)$ falls from 50.45 to 44.33).

Finally, for the theoretically ambiguous welfare effects in Theorems 5 and 6, we find that stronger IPR protection makes the typical Northern consumer better off ($u_N(0)$ rises from 91.34 to 95.67) whereas increasing the size of the South has an approximately zero effect on Northern consumer welfare ($u_N(0)$ rises slightly from 93.74 to 93.76 and then falls to 93.39). Thus, the simulation analysis suggests that Northern consumers neither gain nor lose much from developing countries like China joining the world trading system. The benefits for Northern consumers from an increase in the size of the South are roughly balanced by the costs. But there is an inherent conflict between North and South vis-à-vis the TRIPs agreement, since Northern consumers benefit from stronger IPR protection whereas Southern consumers lose.

5 Conclusions

This paper develops a dynamic general-equilibrium model of North-South trade and economic growth. Both innovation and imitation rates are endogenously determined as well as the degree of wage inequality between Northern and Southern workers. Northern firms devote resources to innovative R&D to discover higher quality products and Southern firms devote resources to imitative R&D to copy state-of-the-art quality Northern products. The model does not have the counterfactual growth implications of earlier North-South trade models and can be used to study the long-run welfare implications of changes in the economic environment. We use the model to study the equilibrium and welfare implications of three aspects of globalization: increases in the size of the South (i.e., countries like China joining the world trading system), stronger intellectual property protection (i.e., the TRIPs agreement that was part of the Uruguay Round) and lower trade costs.

Because the theoretical framework developed in this paper is quite tractable, it could prove useful for analyzing other issues. We have already explored one extension: Dinopoulos and Segerstrom (2007) study how the model's implications change when technology transfer takes place within multinational firms. Another interesting extension that has yet to be explored is to allow for two factors of production (low and high-skilled labor). Using such a model, one could study how different aspects of globalization affect wage inequality within regions. The effects of Northern and/or Southern tariffs, technology transfer by means of licensing agreements, and international labor migration could also be studied using this framework. These are all possible directions for further research.

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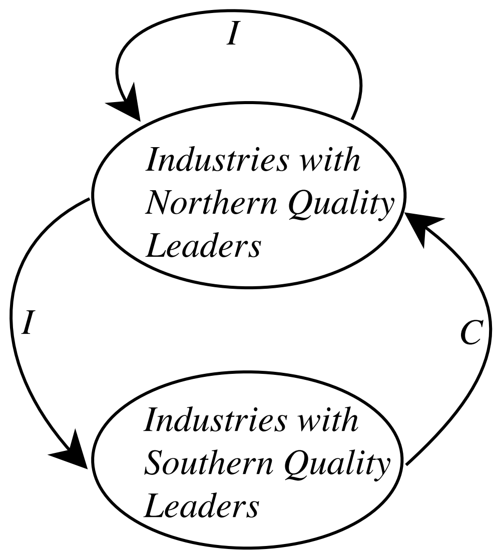

Figure 1: The pattern of innovation and imitation

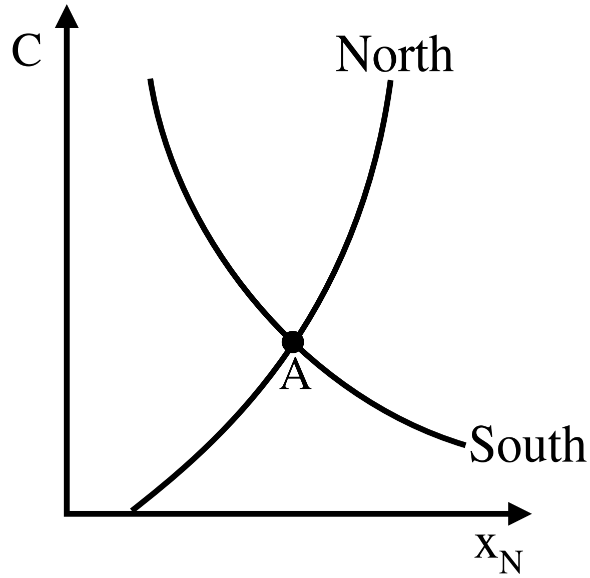

Figure 2: The steady-state equilibrium

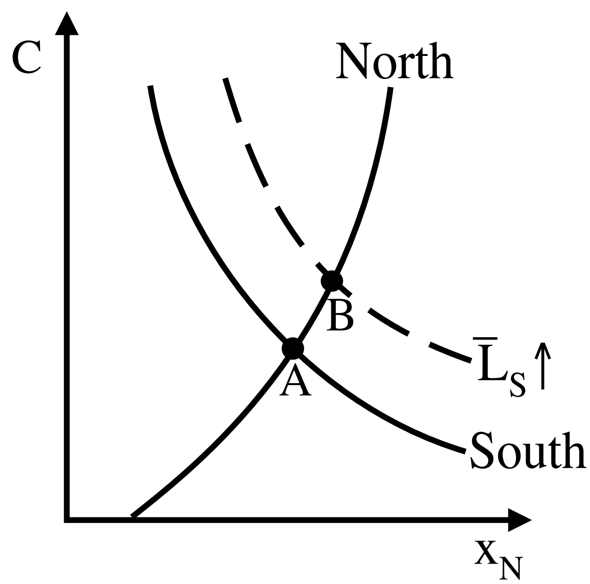

Figure 3: The steady-state effects of increasing the size of the South

Table 1: Larger South ($\bar{L}_S \uparrow$)

$\bar{L}_S$	1.8	2.0	2.2
w_N	2.24	2.17	2.09
x_N	10.77	10.90	11.03
C	.040	.048	.055
$u_N(0)$	93.74	93.76	93.39
$u_S(0)$	44.52	47.19	49.90

Table 2: Stronger IPR Protection ($\beta \uparrow$)

β	3.25	3.50	3.75
w_N	2.01	2.17	2.32
x_N	11.00	10.90	10.82
C	.054	.048	.043
$u_N(0)$	91.34	93.76	95.67
$u_S(0)$	50.45	47.19	44.33

Table 3: Lower Trade Costs ($\tau \downarrow$)

τ	1.20	1.15	1.05
w_N	2.1711	2.1715	2.1720
x_N	10.90	10.90	10.90
C	.048	.048	.048
$u_N(0)$	91.95	93.76	97.82
$u_S(0)$	46.19	47.19	49.43