Education, Innovation, and Imitation in the Quality-Ladder Model of North-South Product Cycles

Manfred Stadler[a)]

February 2007

Abstract

We develop a dynamic general-equilibrium model of North-South trade to analyze the dynamics of international product cycles. Northern firms devote human capital to innovative activities in order to discover higher quality consumer products while firms in the South devote human capital to imitative activities in order to copy these state-of-the-art quality products. Both innovation and imitation rates as well as the degree of wage inequality between Northern and Southern workers are endogenously determined. It is shown that the industry innovation rates decisively depend on education and human-capital accumulation. Globalization in terms of an expansion in the size of the South temporarily raises the innovation rate and leads to a permanent higher imitation rate, shorter product cycles, and less wage inequality. A stronger protection of intellectual property rights produces the opposite effect and thus serves to mitigate the globalization effects.

Keywords: Education, Innovation, North-South product cycles, Globalization, Intellectual property rights

JEL Classification: F4, O2, O3

[a)] University of Tübingen, Department of Economics, Mohlstraße 36, D-72074 Tübingen, Germany. E-mail: manfred.stadler@uni-tuebingen.de

1 Introduction

The continuing process of globalization includes rather different aspects of integration of various markets into the world economy which cannot all be formalized within a single model. Often, globalization is modeled as a reduction in trade barriers between developed countries or as an international movement of resources with focus either on labor migration or on formation of multinationals. The present paper deals with a particular form of globalization which predominantly exerts influence on North-South trade: the integration of developing countries into the world trading system. In detail the paper is concerned with the effects of this aspect of globalization on the dynamics of North-South product cycles. It will be shown that developing Southern countries joining the world trading system induce a temporary increase in the innovation rate, a permanent increase in the imitation rate and, therefore, shorter North-South product cycles. The long-run innovation rate, however, does not depend on the absolute or relative size of the South but instead on education and human-capital accumulation.

The observation that innovative goods are manufactured in a developed country (the North) until production is relocated to a less developed country (the South), was the basis for Vernon's (1966) famous product-cycle theory of international trade. As he claimed, innovative goods are developed and produced in the North until the underlying production techniques have been standardized. At this point the production of goods shifts to the less developed South where the wage rate is lower. A product's life comes to its end when it is replaced by a new and superior product again developed in the North. At that time the next product cycle begins. In this conception, the transfer of technology from the North into the South is governed by innovative firms which might establish an offshore production facility via direct foreign investment or might license the technology to a Southern producer. As several empirical studies have pointed out, this view of technological diffusion properly describes the dynamics in the consumer electronics industry and the office machinery industry in the early 1960s. However, more recently the rapid advances in the technological capabilities of engineers in the newly industrialized countries have made imitation an even more important channel for international technology transfer. In the personal computer industry, for instance, the product cycles have been characterized not only by increasing offshore production by the multinational firms which originally developed the computers, but more so by the introduction of clones by competitors in less developed countries. The clones themselves, however, each time have been replaced by superior computers and laptops developed by Northern firms again.

Krugman (1979) was the first to formalize North-South trade in this spirit, albeit with an exogenously given rate of innovation in the North and an exogenously given rate of technology transfer to the South. Therefore, his model is concerned with the effects of innovation and imitation, but not with their causes. Models with endogenous innovation by profit-maximizing firms in the North have been presented by Segerstrom, Anant, Dinopoulos (1990), Helpman (1993), and Lai (1998). However, since technology transfer is assumed to be costless in these models, they are not able to account for endogenous imitation by profit-maximizing firms in the South. Grossman, Helpman (1991a) specified a model of interrelated innovation and imitation processes by profit-maximizing firms in the North and in the South which, however, cannot capture a sequence of product cycles in a particular industry since innovative activities are directed only to variety expansion via the creation of new industries. In a complementary article, Grossman, Helpman (1991b) constructed a corresponding model with quality improvement instead of variety expansion. This basic model generates stochastic North-South production cycles as an outgrowth of ongoing innovation and imitation processes within the same industries. Both versions of the Grossman-Helpman approach share a common feature which typically characterizes the endogenous innovation-based growth models of the first generation: the scale effect.

In the mid nineties, Jones (1995) presented an influential empirical study in which he could not find support for the scale effect as predicted by these models. In response to this “Jones critique”, a new class of semi-endogenous growth models has emerged. As a distinguishing feature, these models remove the scale effect but instead imply that per-capita growth depends proportionally on population growth. Recently, Dinopoulos, Segerstrom (2006) presented an intriguing extension of the Grossman, Helpman (1991b) model of North-South product cycles which belongs to this semi-endogenous type of innovation-based growth models. Consequently, the single driving force of the innovation process is a positive population growth in the world economy, which is not only assumed to be constant over time, but also to be exogenously given and identical in the North and the South. This increase in the population of workers is compensated by an increase in R&D difficulty such that the model generates a steady-state equilibrium. We argue that this balanced population-growth property is rather unrealistic. The population growth rates in the Northern and Southern countries differ to a large extent and decline over time, taking zero or even negative values in some Northern countries. The balanced population-growth property is also theoretically fragile. It can be shown within the Dinopoulos-Segerstrom (2006) model that a zero population-growth rate inevitably induces a steady-state equilibrium without dynamics: there are no innovative and imitative R&D activities, no product cycles, and finally no growth.

We do not share this pessimistic view on technological progress in the future. Instead, we develop a general-equilibrium model of North-South trade based on the quality-ladders framework which does not rely on such a population-growth property. We avoid this assumption by considering the skill acquisition of workers in order to replace exogenous population growth by endogenous human capital accumulation. In his pioneering contribution, Lucas (1988) has emphasized human capital accumulation by education as a decisive source of endogenous growth. In their empirical studies, Hanushek, Kimko (2000) and Barro (2001) have found that especially the quality, but also the quantity of schooling are positively related to subsequent economic growth. Parello (2004) has been the first to capture the role of human capital in the context of North-South product cycles. But until now, no attempts have been made to integrate the continuing process of human-capital accumulation, as suggested by Lucas (1988), into the class of endogenous models of North-South product cycles without scale effect. The present paper aims to make a first step into this direction. The idea is to extend the Dinopoulos-Segerstrom (2006) model by integrating an education sector in which endogenous accumulation of human capital takes place. Our model implies that education is the driving force that prevents the world economy from reaching a steady state without technological dynamics when the population growth rate declines.

The rest of the paper is organized as follows. In Section 2, the dynamic general-equilibrium model of North-South product cycles is presented. In Section 3, the steady-state equilibrium effects of an increase in the size of the South and of a stronger protection of intellectual property rights are derived. Finally, Section 4 concludes.

2 The Model

According to the innovative model of Dinopoulos, Segerstrom (2006), we consider a world economy consisting of two world regions, the Open North and the Open South, indexed by $\iota \in \{N, S\}$.[1] The Open North consists of the developed countries, whereas the Open South consists of those developing countries which have already joined the world trading system. To keep the analysis tractable, we assume that the countries in both regions have adopted free trade policies without restriction. Additional countries in the Closed South region are assumed not to interact with the rest of the world. This enables us to neglect the Closed South as long as its countries have (or want) to wait for joining the world trading system. Globalization can then be interpreted as an expansion in the size of the Open South. As usual in the literature, we will refer to the Open North as the North and to the Open South as the South.

2.1 Education and Spending Behavior of Households

In both, the North and the South, there is a fixed measure of households which live forever and inelastically supply human-capital services in exchange for wage payments. They share identical preferences and maximize their discounted utility

$$U = \int_0^\infty e^{-\rho t} \ln D_t \, dt, \tag{1}$$

where ρ is the constant subjective discount rate and

$$D_t = \left[\int_0^1 q_{jt}^{1-\alpha} x_{jt}^{\alpha} dj \right]^{1/\alpha}, \quad 0 < \alpha < 1, \tag{2}$$

is a quality-augmented Dixit-Stiglitz consumption index which measures instantaneous utility at time t. It reflects the households' preferences for quantity x_{jt} and quality q_{jt} of the demanded goods available in a continuum of industries indexed by $j \in [0, 1]$. According to these preferences, the elasticity of substitution between any two products across industries is given by $1/(1 - \alpha)$.

[1] The variables and parameters with no country index are common to both countries.

For each household, the discounted utility maximization problem can be solved in two steps. The first step is to solve the across-industry static optimization problem. Maximizing the consumption index (2) subject to the budget constraint

$$E_t = \int_0^1 p_{jt} x_{jt} dj \ ,$$

where E_t is the household's expenditure, and p_{jt} is the price of product j, yields the static demand function

$$x_{jt} = \frac{q_{jt} p_{jt}^{-\frac{1}{1-\alpha}} E}{\int_0^1 q_{jt} p_{jt}^{-\frac{\alpha}{1-\alpha}} dj} \tag{3}$$

for product j at time t. Using this demand function, the consumption index (2) can be written as

$$D_t = E_t / p_t^D \ ; \quad p_t^D \equiv \left[\int_0^1 q_{jt} p_{jt}^{-\frac{\alpha}{1-\alpha}} dj \right]^{-\frac{1-\alpha}{\alpha}} \ . \tag{4}$$

The second step is to solve the dynamic optimization problem by maximizing discounted utility. Households supply human-capital services to production, R&D, and education. By devoting H_t^E units to education, they can raise their human capital according to the Uzawa-Lucas technology

$$\dot{H}_t = \kappa H_t^E - \delta H_t \ , \tag{5}$$

where $\kappa > \delta + \rho$ reflects the efficiency of the education system and δ is the constant depreciation rate of human capital. The dynamic budget constraint is given by

$$\dot{A}_t = r_t A_t + w_t (H_t - H_t^E) - E_t \ , \tag{6}$$

where A_t is the value of asset holdings, r_t is the nominal interest rate and w_t is the nominal wage rate. Thus, each household maximizes its discounted utility (1), given (4), subject to the accumulation function (5) and the dynamic budget constraint (6).

The current-value Hamiltonian of this optimal-control problem is given by

$$\mathscr{H} = \ln E_t - \ln p_t^D + \psi_1 [r_t A_t + w_t (H_t - H_t^E) - E_t] + \psi_2 [\kappa H_t^E - \delta H_t] \ ,$$

where ψ_1 and ψ_2 are the costate variables of A_t and H_t. The necessary first-order conditions are given by

$$\mathscr{H}_E = 1/E_t - \psi_1 = 0, \tag{7}$$

$$\mathscr{H}_A = \psi_1 r_t = \psi_1 \rho - \dot{\psi}_1, \tag{8}$$

$$\mathscr{H}_{H^E} = -\psi_1 w_t + \psi_2 \kappa = 0, \tag{9}$$

$$\mathscr{H}_H = \psi_1 w_t - \psi_2 \delta = \psi_2 \rho - \dot{\psi}_2. \tag{10}$$

Conditions (7) and (8) yield the well-known differential equation

$$\dot{E}_t/E_t = r_t - \rho \; .$$

The optimal time path of consumer expenditures applies not only to a representative Northern or Southern household but also to the aggregate world economy. At this aggregation level, it proves convenient to impose the normalization $E_t = p_t^D D_t = 1$ which implies that the nominal interest rate r_t equals the subjective discount rate ρ. Using this identity, we further derive from (8), (9), and (10) the differential equation

$$\dot{w}_t/w_t = -(\kappa - \delta - \rho) \; . \tag{11}$$

The larger the discount and depreciation rates and the lower the efficiency of education, the larger is the growth rate of nominal wages required to induce households to continuously invest resources in the accumulation of their human capital. The steady-state growth rate of human capital is therefore given by

$$\dot{H}_t/H_t = \kappa - \delta - \rho \; , \tag{12}$$

so that (5) implies

$$H_t^E/H_t = 1 - \rho/\kappa \; . \tag{13}$$

The share of human capital devoted to education is constant over time and merely depends on the growth rate of human capital and on the discount rate.

2.2 The Product Markets

In each industry, the product's quality grades are arrayed along the rungs of a quality ladder which is assumed to be equal across industries. Each new generation of products provides a quality λ times higher than the previous quality level, where the upgrading factor $\lambda > 1$ is assumed to be exogenously given and constant over time. Thus the quality of the top-of-the-line product in industry j at time t is given by

$$q_{jt} = \lambda^{m_{jt}},$$

where m_{jt} is the number of sequential upgrading innovations in industry j until time t. Northern firms can enter an industry by introducing the next higher quality product while Southern firms can enter this industry by imitating its state-of-the-art-quality product.

Labor markets are perfectly competitive in both world regions. The production of all existing consumer goods is characterized by constant returns to scale. In each industry, one unit of human capital produces one unit of output independent of its quality level or regional location. Thus, each firm in the North has a constant marginal cost equal to w_t^N and each firm in the South has a constant marginal cost equal to w_t^S.

A Northern firm which realizes an innovation in industry j becomes the only firm disposing of the technology to manufacture the highest-quality product in this industry. Its flow of profits is given by

$$\pi_{jt}^N = (p_{jt} - w_t^N)x_{jt} \ ,$$

where the industry demand functions x_{jt} are given in (3). The price-setting behavior of the leading firm depends on the underlying market structure which in turn is determined by the basic technological conditions in the industry and the region in which the closest competitor resides. To simplify the analysis, we assume according to Dinopoulos, Segerstrom (2006) that following each innovation, the previous incumbent immediately exits the industry. Then all Northern quality leaders are able to charge the unconstrained monopoly price[2]

$$p_t^N = (1/\alpha) w_t^N \tag{14}$$

which yields the flow of profits

$$\pi_{jt}^N = (1/\alpha - 1) w_t^N q_{jt} (p_t^N)^{-\frac{1}{1-\alpha}} (p_t^D)^{\frac{\alpha}{1-\alpha}} \tag{15}$$

from selling to both Northern and Southern consumers.

A Southern firm that succeeds in copying the quality of a top-of-the-line product manufactured by a Northern firm has a cost advantage over the Northern competitors if $w^N > w^S$, which will prove to generally hold in the steady-state equilibrium. It is therefore able to undercut the price of the previous Northern producer and attract all the consumers such that its flow of profits amounts to

$$\pi_{jt}^S = (p_{jt} - w_t^S) x_{jt} \ .$$

Since the previous Northern incumbent immediately exits the industry, by assumption all Southern imitators can charge the unconstrained monopoly price[3]

$$p_t^S = (1/\alpha) w_t^S \tag{16}$$

and earn the flow of profits

$$\pi_{jt}^S = (1/\alpha - 1) w_t^S q_{jt} (p_t^S)^{-\frac{1}{1-\alpha}} (p_t^D)^{\frac{\alpha}{1-\alpha}} . \tag{17}$$

We now turn to the dynamics of technological progress in the North and of technology transfer into the South.

2.3 Innovation and Imitation

The quality of the consumer goods can be upgraded by a sequence of innovations, each building upon its predecessors. To produce a higher quality product, a blueprint

[2] An alternative justification for this price-setting behavior is to assume drastic innovations, i.e. $\lambda^{(1/\alpha-1)} w^S > (1/\alpha) w^N$.

[3] Alternatively, the condition $w^N > (1/\alpha) w^S$ is sufficient to generate this price-setting behavior.

is needed which is developed by innovative Northern firms in a separate R&D sector. The lure of temporary monopoly rents drives potential entrants to engage in risky R&D projects in order to search for the blueprint of a higher quality product. R&D competition takes the form of stochastic innovation races between Northern firms. Any quality innovation opens up the opportunity for all Northern firms to search for the next vertical innovation in this industry. This implies an external spillover effect of technological knowledge since even laggard firms can equally participate in each innovation race without having climbed all of the rungs of the quality ladder themselves. Each Northern firm i may target its research efforts at any of the whole continuum of state-of-the-art products, i.e. it may engage in any industry $j \in [0, 1]$. If it undertakes R&D at intensity h_{ijt} for a time interval of length dt, it will succeed in taking the next step up the quality ladder for the targeted product j with probability $h_{ijt}dt$. This implies that the number of realized innovations in each industry follows a Poisson process with the arrival rate h_{ijt} which is specified as

$$h_{ijt} = \frac{H_{ijt}}{\mu q_{jt}} \,, \tag{18}$$

where $\mu > 0$ is a measure of the technological difficulty in realizing a quality innovation and is closely related to the degree of protection of intellectual property rights. The arrival rate of quality innovations is assumed to depend proportionally on the amount of human capital H_{ijt} devoted to innovative activities. The presence of the term q_{jt} reflects a negative externality of industry-specific innovation successes in the past by indicating that the realization of a further quality innovation becomes more difficult as technology evolves.

Firms in the South are assumed to undertake only imitative activities targeted to copy the quality of the top-of-the-line products which are actually produced in the North. Corresponding to the innovation races, this competition is assumed to take the form stochastic imitation races between Southern firms. Each Southern firm i may target its research efforts at any of the state-of-the-art products currently manufactured in the North. If it undertakes imitative activities at intensity k_{ijt} for a time interval of length dt, it will succeed in copying the targeted product with probability $k_{ijt}dt$. This implies that the number of realized imitations in each industry follows a Poisson process with the arrival rate k_{ijt} which is specified as

$$k_{ijt} = \frac{H_{ijt}}{\nu q_{jt}} \,, \tag{19}$$

where $\nu > 0$ is a measure of the technological difficulty in realizing an imitation and is closely related to the extend of protection of intellectual property rights. The arrival rate of imitations is assumed to depend proportionally on the amount of human capital H_{ijt} devoted to imitative activities. The presence of the term q_{jt} again reflects a negative externality of industry-specific innovation successes in the past.

The returns to both innovative and imitative activities are assumed to be independently distributed across firms, industries, and over time. Consequently, the instantaneous probability that a Northern firm innovates in an industry is given by $h_{jt} = \sum_i h_{ijt}$ and the instantaneous probability that a Southern firm imitates in an industry is given by $k_{jt} = \sum_i k_{ijt}$.

At each point in time, a measure n^N of industries have Northern incumbents and a measure n^S of industries have Southern incumbents whereby $n^N + n^S = 1$. Northern firms undertake innovative activities in all industries while Southern firms undertake imitative activities only in the n^N industries where production is currently in the North. Due to Bertrand competition, imitations in the n^S industries would not be profitable. If a Southern firm was successful in imitating the top-of-the-line quality of a product currently produced by a Southern firm, price competition would drive the profits of both firms down to zero. However, if a Southern firm is successful in imitating the quality of a product of a Northern quality leader, production shifts to the South because the unit cost of production is lower there. As soon as a Northern firm is successful in a quality innovation of a product which is currently manufactured in the South, production shifts back to the North. Thus, products in all industries experience cycles as Vernon (1966) has argued. The products are initially discovered in developed countries and exported to developing countries. As the technologies become more standardized, production shifts to developing countries and the products are exported back to developed countries.

We solve the model for a steady-state equilibrium where the innovation and imitation rates do not vary across industries or over time, i.e. $h_{jt} = h \; \forall \; j, t$ and $k_{jt} = k \; \forall \; j, t$. Since n^N is constant over time in a steady-state equilibrium, the flow into the n^N industries must equal the flow out of the n^N industries, i.e. $n^S h = n^N k$, so that

$$n^N = \frac{h}{h+k}; \quad n^S = \frac{k}{h+k} \; . \tag{20}$$

The measure of industries with Northern incumbents is an increasing function of the rate of innovation and a decreasing function of the rate of imitation. The opposite holds for the measure of industries with Southern incumbents.

There is free entry into the innovation races in the North and into the imitation races in the South. Since all Northern firms have access to the same linear R&D technology, Northern incumbents do not engage in innovative activities devoted to improvements of their own products. They have nothing to gain by innovating since they are already earning a monopolistic flow profit. Thus all innovative activities in the North are undertaken by Northern challengers and the identity of the quality leader in an industry changes each time an innovation occurs.

2.4 The Stock Market

The expected discounted profits of a Northern challenger winning an innovation race is the stock market value V_{jt}^N. To participate in an innovation race Northern firms have to employ human capital in their research labs. A challenger who devotes H_{ijt} units of human capital to R&D at a cost of $w_t^N H_{ijt}$ for a time interval of length dt attains the stock market value V_{jt}^N with probability $(H_{ijt}/(\mu q_{jt}))dt$. He can finance this R&D venture by issuing equity claims which pay nothing in the case that the research effort fails but entitle the claimants to the income stream π_{jt}^N if the effort succeeds. Free entry into each innovation race implies

$$V_{jt}^N = \mu w_t^N q_{jt} \; . \tag{21}$$

As the quality q_{jt} increases over time, innovating becomes more difficult and the reward of innovations must correspondingly increase to induce innovative activities by Northern challengers. Since there is a continuum of industries and the returns from engaging in innovation 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 obain the no-arbitrage condition

$$r_t = \pi_{jt}^N / V_{jt}^N + \dot{V}_{jt}^N / V_{jt}^N - h - k \; . \tag{22}$$

Substituting (15) and (21) into (22), taking the time derivative of V_{jt}^N, and using $r_t = \rho$ yields

$$h + k + \kappa - \delta = (1/\alpha - 1)\mu^{-1}(p_t^N)^{-\frac{1}{1-\alpha}}(p_t^D)^{\frac{\alpha}{1-\alpha}} \ . \tag{23}$$

The expected discounted profits of a Southern firm winning an imitation race is the stock market value V_{jt}^S. To participate in an imitation race Southern firms have to employ skilled labor in their research labs. A firm which devotes H_{ijt} units of human capital to imitative activities at a cost of $w_t^S H_{ijt}$ for a time interval of length dt attains the value V_{jt}^S with probability $(H_{ijt}/(\nu q_{jt}))dt$. Similar to Northern challengers, it can finance the R&D venture by issuing equity claims that pay nothing if the research effort fails but entitle the claimants to the income stream π_{jt}^S in case of successful effort. Free entry into each imitation race implies

$$V_{jt}^S = \nu w^S q_{jt} \ . \tag{24}$$

The return from holding the stock of a Southern incumbent must be the same as the return from an equal-sized investment in a riskless bond. The corresponding no-arbitrage condition is

$$r_t = \pi_{jt}^S / V_{jt}^S + \dot{V}_{jt}^S / V_{jt}^S - h \ . \tag{25}$$

A Southern incumbent does not have to worry about its product being copied by another Southern firm since there is no reward for copying already copied products under Bertrand competition. Substituting (17) and (24) into (25), taking the time derivative of V_{jt}^S, and using $r_t = \rho$ yields

$$h + \kappa - \delta = (1/\alpha - 1)\nu^{-1}(p_t^S)^{-\frac{1}{1-\alpha}}(p_t^D)^{\frac{\alpha}{1-\alpha}} \ . \tag{26}$$

To solve for the relative product price in the North, we devide (26) by (23) to obtain

$$\frac{p^N}{p^S} = \left(\frac{\nu(h + \kappa - \delta)}{\mu(h + k + \kappa - \delta)}\right)^{\frac{1}{1-\alpha}} \ .$$

Using the price-setting equations (14) and (16) we obtain for the relative wage rate in the North

$$\frac{w^N}{w^S} = \frac{p^N}{p^S} = \left(\frac{\nu(h + \kappa - \delta)}{\mu(h + k + \kappa - \delta)}\right)^{\frac{1}{1-\alpha}} \tag{27}$$

which is an increasing function of the rate of innovation and a decreasing function of the rate of imitation.

2.5 The Dynamics of Innovation and Quality Growth

The average quality of the top-of-the-line consumer products at time t is given by

$$Q_t = \int_0^1 q_{jt} dj = \int_0^1 \lambda^{m_{jt}} dj \ .$$

Since the number of realized quality innovations in industry j jumps up from m_{jt} to $m_{jt}+1$ whenever a further innovation occurs, and the innovation rate h is constant across industries and over time, the time derivative of the average quality is

$$\dot{Q}_t = \int_0^1 (\lambda^{m_{jt}+1} - \lambda^{m_{jt}}) h dj = (\lambda - 1) h Q_t \ .$$

The growth rate of the average product quality is therefore proportional to the innovation rate. As will be seen, in a steady-state equilibrium the ratio Q_t/H_t^N has to be constant over time. Therefore, (12) implies that $\dot{Q}_t/Q_t = (\lambda - 1)h = \kappa - \delta - \rho$, from which follows

$$h = \frac{\kappa - \delta - \rho}{\lambda - 1} \ . \tag{28}$$

Thus, in sharp contrast to the predecessor models, the steady-state innovation rate does neither depend on the exogenously given labor force as in Grossman, Helpman (1991b) nor on the exogenously given population growth rate as in Dinopoulos, Segerstrom (2006), but on the endogenously determined growth rate of the workers' human capital. The realization of innovations becomes more difficult as technology evolves but researchers compensate for this by increasing their skills due to better education.

The average quality of all products can be decomposed to $Q_t = Q_t^N + Q_t^S$, where

$$Q_t^N = \int_{n^N} q_{jt} dj = \int_{n^N} \lambda^{m_{jt}} dj \tag{29}$$

is the aggregate quality of the Northern products and

$$Q_t^S = \int_{n^S} q_{jt} dj = \int_{n^S} \lambda^{m_{jt}} dj \tag{30}$$

is the aggregate quality of the Southern products. The time derivative of Q_t^N is

$$\dot{Q}_t^N = \int_{n^N} (\lambda^{m_{jt}+1} - \lambda^{m_{jt}})\, h\, dj \ + \int_{n^S} \lambda^{m_{jt}+1}\, h\, dj \ - \int_{n^N} \lambda^{m_{jt}}\, k\, dj$$

$$= (\lambda - 1)hQ_t^N + \lambda h Q_t^S - kQ_t^N$$

and the time derivative of Q_t^S is

$$\dot{Q}_t^S = \int_{n^N} \lambda^{m_{jt}} k\, dj \; - \; \int_{n^S} \lambda^{m_{jt}}\, h\, dj$$
$$= kQ_t^N - hQ_t^S .$$

Obviously, the growth rates of Q_t^N and Q_t^S are constant over time only if they are equal. It follows from $\dot{Q}_t^N / Q_t^N = \dot{Q}_t^S / Q_t^S$ that $Q_t^N / Q_t^S = \lambda h / k$ and, by definition,

$$Q_t^N = \frac{\lambda h}{\lambda h + k}\, Q_t; \quad Q_t^S = \frac{k}{\lambda h + k}\, Q_t \; . \tag{31}$$

Using (20), this implies

$$\frac{Q^N(t)}{n^N} = \frac{\lambda(h+k)}{\lambda h + k}\, Q_t \quad > \quad \frac{Q_t^S}{n^S} = \frac{h+k}{\lambda h + k}\, Q(t) \; ,$$

guaranteeing that the average quality of products manufactured in the North is generally higher than the average quality of products manufactured in the South.

2.6 The Markets for Human Capital

It is assumed that workers can move freely across firms and sectors within each region but not across the regions. Wages adjust instantaneously to equalize human capital supply and demand in the North and in the South. According to (13), in both regions a constant share $1 - \rho/\kappa$ of human capital is devoted to education. The remaining amount of human capital is devoted to production and to R&D. In the North, the aggregate demand for human capital in the production sector is

$$\int_{n^N} x_{jt} dj = Q_t^N (p_t^N)^{-\frac{1}{1-\alpha}} (p_t^D)^{\frac{\alpha}{1-\alpha}} \; ,$$

whereas the aggregate demand for human capital in the research sector amounts to

$$\int_0^1 \mu h q_{jt} dj = \mu h Q_t \; .$$

Thus, full employment of Northern workers implies that

$$H_t^N = (1 - \rho/\kappa) H_t^N + Q_t^N (p_t^N)^{-1/(1-\alpha)} (p_t^D)^{\alpha/(1-\alpha)} + \mu Q_t h \; . \tag{32}$$

Similar calculations apply for the Southern market for human capital. The aggregate demand for human capital in the production sector is given by

$$\int_{n^S} x_{jt} dj = Q_t^S (p_t^S)^{-\frac{1}{1-\alpha}} (p_t^D)^{\frac{\alpha}{1-\alpha}} \; ,$$

the aggregate demand for human capital in the research sector is

$$\int_{n^N} \nu k q_{jt} dj = \nu k Q_t^N \; .$$

Thus, full employment of Southern workers implies that

$$H_t^S = (1 - \rho/\kappa) H_t^S + Q_t^S (p_t^S)^{-1/(1-\alpha)} (p_t^D)^{\alpha/(1-\alpha)} + \; \nu Q_t^N k \; . \tag{33}$$

The equation system (23), (26), (31), (32), and (33) are sufficient to solve the model for a steady-state equilibrium.

3 The Steady-State Equilibrium

We now solve the model for a steady-state equilibrium where all endogenous variables are growing at constant rates over time. Substituting (23) and (31) into (32) yields the Northern steady-state condition

$$\rho/\kappa = \mu \frac{Q_t}{H_t^N} \left[\frac{\alpha}{1-\alpha} \frac{(h + k + \kappa - \delta)\lambda h}{\lambda h + k} + h \right] \tag{34}$$

whereas substituting (26) and (31) into (33) yields the Southern steady-state condition

$$\rho/\kappa = \nu \frac{Q_t}{H_t^S} \left[\frac{\alpha}{1-\alpha} \frac{(h + \kappa - \delta)k}{\lambda h + k} + \frac{\lambda h k}{\lambda h + k} \right] \; . \tag{35}$$

In the steady-state equilibrium, the innovation and imitation rates, h and k, the relative prices and wage rates, p^N/p^S and w^N/w^S, and the ratios Q/H^N and Q/H^S are constant over time. Growth takes the form of an ongoing process of quality improvement. The products in each industry follow stochastic life cycles with rather different histories. A particular product might be manufactured for a while in the North before a Southern firm succeeds in its efforts to imitate the technology. Then production shifts to the South where the product is manufactured until being upgraded again in the North. Alternatively, the product might be improved several times in succession by various Northern firms before it is imitated by a Southern firm. An appropriate measure of the average length of a North-South cycle is $(1/k + 1/h)$. The first term indicates how long, on average, a product will be produced in the North before being imitated by a Southern firm. Analogously, the second term indicates how long, on average, a product will be manufactured by that Southern firm before being upgraded again by a Northern innovator.

The model predicts an evolving distribution of product qualities and producer locations. However, whereas the technological development in any particular industry is both erratic and stochastic, the world economy at the aggregate level experiences a process of quantity and quality growth that is smooth and nonrandom.

4 Globalization and Intellectual Property Rights

The steady-state equilibrium of the model enables us to derive some comparative-static effects of globalization on the dynamics of innovation and imitation. Globalization is modeled as an expansion in the size of the South. Even if less developed, each country joining the world trading system will increase the stock of human capital in the South, H^S. To keep the analysis tractable, we assume that the per-capita human capital of the joining country equals that of the already integrated countries in the South. In order to concentrate on a steady-state equililibrium, we further have to assume that the efficiency of education, measured by the education parameter κ, is equal in the North and the South.[4] However, the effects of a higher human-capital

[4] A smaller efficiency parameter in the South would induce a process of continuously falling behind which is at odds with the empirical evidence with respect to the considered developing countries. A higher efficiency parameter in the South would induce a process of continuously catching up which would contradict the assumption of only Northern firms being able to innovate. Of course, both alternative assumptions are not compatible with a balanced steady-state growth equilibrium.

growth rate in the South can be captured within the model by an increase in the relative stock of human capital H^S/H^N in the South.

To begin with, an increase in the stock of human capital in the South H^S has no effect on the long-run rate of innovation h as determined in (28). However, a comparative-static analysis unambiguously shows that $d(Q/H^N)/dH^S > 0$. Since this ratio can only increase if the average quality of products temporarily grows at a rate faster than the permanent rate, this implies a short-run increase in the innovation rate. While the innovation rate immediately falls back to its long-run level, we can conclude from $dk/dH^S > 0$ that the imitation rate permanently increases. The results are summarized in Proposition 1:

Proposition 1: *Globalization measured by an increase in the stock of human capital in the South raises the innovation rate in the short run, but leads to a permanent increase in the imitation rate so that the average length of the North-South product cycle falls.*

Proof: See the Appendix

The intuition behind this result is obvious. More human capital in the South increases the rate of copying top-of-the-line products currently manufactured by Northern firms. This faster rate of technology transfer implies that production is relocated from the high wage North to the low wage South so that Northern workers are set free for employment in R&D. As can be seen from (27), the Northern relative wage rate falls and gives Northern firms an incentive to expand their innovative activities. The innovation rate jumps up and accelerates technological progress, but workers are partially shifted back into production as innovation becomes more difficult due to the large number of innovation successes. In the long run, globalization increases the fraction of Northern human capital devoted to R&D but the innovation rate remains constant.

Nowadays, the question of the extent of protection of intellectual property rights has become an important topic within the discussion of globalization effects. As can be shown, all the comparative-static effects of an increase in the difficulty parameter ν, which is interpreted as a stronger protection of intellectual property rights, work in the opposite direction as an increase in H^S. The corresponding results are summarized in Proposition 2:

Proposition 2: *Stronger intellectual property protection measured by an increase in the difficulty for Southern firms to realize an imitation success reduces the innovation rate in the short-run, but leads to a permanent decrease in the imitation rate so that the average length of the North-South product cycle rises.*

Proof: See the Appendix

Of course, a stronger protection of intellectual property rights induces Southern firms to devote less human capital to imitative activities. The lower rate of imitation increases the demand for Northern workers. The Northern relative wage rate increases until the additional employment of human capital in production is offset by an equal decrease in the demand for human capital in the Northern R&D labs. The innovation rate temporarily declines. In the long run, however, the innovation rate remains constant, even if a smaller fraction of Northern human capital is devoted to R&D. Proposition 3 summarizes these results:

Proposition 3: *The long-run innovation rate neither depends on the stock of human capital in the South and North nor on the extent of intellectual property rights protection, but positively on the growth rate of human-capital.*

Proof: follows from equation (28)

The influence of human capital accumulation on the long-run growth rate is well-known from closed-economy models of endogenous innovation-based growth without scale effects. Arnold (2002) has clearly pointed out the important role of education and human-capital in the process of innovation and technological change. It is no surprise that this relationship still persists in an open world economy.

5 Conclusion

We have developed a dynamic general-equilibrium model of North-South trade to analyze the dynamics of innovation, imitation and North-South product cycles. Recent semi-endogenous models of North-South product cycles have accomplished a valuable task by removing the scale effect present in the predecessor models. A disturbing property of these non-scale models is, however, that the innovation and growth rates depend proportionally on population growth. Without doubt, this property is at odds with empirical evidence.

The present paper has offered an alternative interpretation of the role of workers by replacing exogenous population growth by endogenous human capital accumulation. Building on this alternative assumption, we have shown that the innovation rate decisively depends on the parameters characterizing the education system. In accordance with the semi-endogenous models, however, globalization temporarily raises the innovation rate and leads to a permanent higher imitation rate, shorter product cycles, and less wage inequality. A stronger protection of intellectual property rights produces the opposite effects and thus tends to mitigate these globalization effects. This robustness of the globalization effects allows for the conclusion that the TRIPS agreement of the WTO on the trade related aspects of intellectual property rights, which has been signed in 1995, is appropriate to moderate the globalization effects of an entrance of developing countries into the world trading system. It should be noted, however, that this mitigation involves a reduced impact of technology-push that arises each time a new Southern country joins the world trading system.

Appendix

In this appendix, we derive the long-run responses of the imitation rate k and the ratio Q/H^N to changes in the stock of human capital in the South H^S and the extent of intellectual property rights protection ν. The two-equation system (34) and (35) can be solved recursively. First, we substitute Q from (35) into (34) to get

$$\frac{\mu}{H^N}\left[\frac{\alpha}{1-\alpha}\,\frac{(h+k+\kappa-\delta)\lambda h}{\lambda h+k}+h\right]-\frac{\nu}{H^S}\left[\frac{\alpha}{1-\alpha}\,\frac{(h+\kappa-\delta)k}{\lambda h+k}+\frac{\lambda hk}{\lambda h+k}\right]=0\ .$$

Next, we totally differentiate this equation to find

$$dk/dH^S>0;\quad dk/d\nu<0\ .$$

These effects are unambiguous since we can use (28) to obtain

$$\frac{\partial}{\partial k}\left(\frac{h+k+\kappa-\delta}{\lambda h+k}\right)=-\frac{\rho}{(\lambda h+k)^2}<0$$

whereas

$$\frac{\partial}{\partial k}\left(\frac{k}{\lambda h+k}\right)=\frac{\lambda h}{(\lambda h+k)^2}>0.$$

Finally, we totally differentiate (34) and make use of the above comparative statics to obtain

$$d(Q/H^N)/dH^S>0;\quad d(Q/H^N)/d\nu<0\ .$$

References

Arnold, L.G. (2002), On the Effectiveness of Growth-Enhancing Policies in a Model of Growth without Scale Effects. *German Economic Review* 3, 339-346.

Barro, R.J. (2001), Human Capital and Growth. *American Economic Review, P&P,* 91, 12-17.

Barro, R.J., Sala-i-Martin, X. (1997), Technological Diffusion, Convergence, and Growth. *Journal of Economic Growth.* MIT Press, Cambridge, MA.

Chui, M., Levine, P., Murshed, M., Pearlman, J. (2002), North-South Models of Growth and Trade. *Journal of Economic Surveys* 16, 123-165.

Dinopoulos, E., Segerstrom, P. (2006), North-South Trade and Economic Growth. University of Florida. mimeo.

Grossman, G.M., Helpman, E. (1991a), Endogenous Product Cycles. *Economic Journal* 101, 1214-1229.

Grossman, G.M., Helpman, E. (1991b), Quality Ladders and Product Cycles. *Quarterly Journal of Economics* 106, 557-586.

Hanushek, E., Kimko, D.D. (2000), Schooling, Labor-Force Quality, and the Growth of Nations. *American Economic Review* 90, 1184-1208.

Helpman, E. (1993), Innovation, Imitation and Intellectual Property Rights. *Econometrica* 61, 1247-1280.

Jones, C.I. (1995), Time Series Tests of Endogenous Growth Models. *Quarterly Journal of Economics* 110, 495-525.

Krugman, P. (1979), A Model of Innovation, Technology Transfer, and the World Distribution of Income. *Journal of Political Economy* 87, 253-266.

Lai, E. (1998), International Property Rights Protection and the Rate of Product Innovation. *Journal of Development Economics* 55, 133-153.

Lucas, R.E. (1988), On the Mechanics of Economic Development. *Journal of Monetary Economics* 22, 3-42.

Peretto, P. (1998), Technological Change and Population Growth. *Journal of Economic Growth* 3, 283-311.

Romer, P.M. (1990), Endogenous Technological Change. *Journal of Political Economy* 98, 71-102.

Segerstrom, P.S., Anant, T., Dinopoulos, E. (1990), A Schumpeterian Model of the Product Life Cycle. *American Economic Review* 80, 1077-1091.

Vernon, R. (1966), International Investment and International Trade in the Product Cycle. *Quarterly Journal of Economics* 80, 190-207.