Non-Scale Effects of North-South Trade on Economic Growth

Oscar Afonso and Alvaro Aguiar

CEMPRE*, Faculdade de Economia, Universidade do Porto

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Please address correspondence to Alvaro Aguiar (alvaro@fep.up.pt), Faculdade de Economia, Universidade do Porto, Rua Roberto Frias 4200-464 Porto, PORTUGAL; +351225571254 (phone); +351225505050 (fax).

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Abstract

In this model of North and South economies, growth is driven by Schumpeterian R&D and by accumulation of two types of human capital, versatile and specialized. The former is school intensive while the latter is on-the-job-training intensive. Growth is endogenous and independent of scale effects. South's imitation of existing technology is conditional to the distance to the technological frontier. Growth depends on technological advances in the quality of available intermediate goods, regardless of the origin - innovation or imitation -, and not on comparative advantage in the production of final goods.

By allowing immediate international access of the state-of-the-art intermediate goods, trade affects the productive structure in the South, bringing about partial convergence to the Northern structure and prices. Nevertheless, even when the countries have access to the same technology - either through imitation or trade of intermediate goods -, differences in domestic institutions and human capital imply differences in productivity.

In addition, trade induces steady-state effects through the price channel, by which the specific types of human capital influence the direction of technological progress. The consideration of two types of human capital also allows the study of wage inequality effects of trade, as well as the derivation of a Schumpeterian dynamic equivalent to the static Stolper-Samuelson factor price equalization result.

Keywords: North-South; International trade; R&D; Human capital; Scale effects; Economic growth.

JEL classification: F43, O31, O47, J24.

1. Introduction

This paper analyses the economic growth effects of North-South trade in intermediate goods that embody technological progress. By North and South we mean two countries that differ in levels of productivity, stocks of human capital and R&D capacity.

The North is more productive than the South due to domestic institutions, is endowed with a higher initial level of the more productive human capital, and its R&D activities result in innovations that improve the quality of products - Schumpeterian R&D, as formalized by Aghion and Howitt (1992). The South has a marginal cost advantage in the production of goods, and also conducts R&D, but its best results are imitations of the North's innovations - as in Grossman and Helpman (1991, chaps. 11 and 12).

These differences are assumed to have historical roots that are reflected in current institutional characteristics. Our main concern is not to explain these differences, but rather to take them as given at time zero and analyze the subsequent path of both economies under international trade.

We aim at improving our understanding of the dynamic mechanisms that underlie the process of North-South technological transmission, following the line previously explored by Barro and Sala-i-Martin (1997), but with a substantive difference. It does not make much sense to think of international transfer of knowledge, or imitation, without the vehicle of international trade. Hence, we want to understand more clearly how international trade of goods alone (*ie* without international mobility of production factors) affects the structure and the dynamics of technological transfer, thereby influencing the levels and growth rates of the economies.

In order to pursue this objective, we first characterize (in a stylized model form) the domestic North and South economies, in such a way that the productivity, human capital and R&D differences become apparent and central to the subsequent analysis.

In addition to Schumpeterian R&D, we consider that economic growth is also driven by endogenous accumulation of two types of human capital, versatile and specialized. We think of the former as being school intensive while the latter is on-the-job-training intensive. The importance of considering both modes of human capital formation has been suggested by Lucas (1993) in order to improve his own Lucas

(1988) model. Moreover, in the context of international trade it is useful to consider factor endowments, factor price movements and income inequality effects.

Since we want to focus on technological transfer through trade of intermediate goods, it seems reasonable to consider that the South is not too backward relative to the North. The degree of backwardness is included by making the South's imitation of existing technology conditional to the distance to the technological frontier, in the sense that there is a threshold distance beyond which the cost of imitation is higher than the cost of re-inventing older product qualities.

An important feature of the stylized North and South economies is that growth is independent of scale effects. Apart from the endogenous growth debate on the subject - e.g., Jones (1995a, b), Dinopoulos and Thompson (1998), and Howitt (1999) -, we regard such independence as mainly instrumental to the isolation of the technology transfer effects of international trade. In other words, we aim at understanding the ways in which international trade affects technological transfers in contexts where market size effects are not important.

Once the economies are characterized, we analyze the effects of international trade in intermediate goods. This is the relevant trade, since we want to underline the dynamic growth effects of trade operating through the intermediate goods - where R&D is directly applied -, while the effects of trade in final goods are limited to the somewhat more traditional (in international trade theory) static level effects.

Keeping with the tradition of growth and international trade analyses, we are able to discuss steady-state results in factor prices. These results may shed some light on issues that have been raised and discussed in the context of globalization debates, as is the case of potential effects of international trade on wage and international inequality.

After these introductory remarks, the paper proceeds to characterize the North and South economies in section 2. Then, in section 3, international trade in intermediate goods is introduced and its level and steady-state growth effects derived. Section 4 concludes the paper with a tentative assessment of the current state of this research.

2. Modeling the domestic economy

We characterize the North economy and, in the process, highlight the differences to the South.

The economy is composed of two sectors: producers of final goods and producers of intermediate goods (IGs). R&D activities are directly connected to the IGs sector, where competitive monopolists use the innovative blueprints as inputs - as in Romer (1990).

Final goods technology

Final goods - Y, continuously indexed by $n \in [0, 1]$ - are produced in perfect competition. Following the Schumpeterian set-up[1] complemented with the recent contribution of Acemoglu and Zilibotti (2001), we consider that each final good can be producible by two technologies, versatile and specialized. The versatile technology uses versatile human capital - VH - complemented with a continuum of versatile-specific intermediate goods indexed by $j \in [0, J^{VH}]$. The specialized technology's inputs are specialized human capital - SH - complemented with a continuum of specialized-specific intermediate goods indexed by $j \in [0, J^{SH}]$. In production function form at time t,

$$\begin{aligned} Y_n(t) = A \Bigg\{ & \left[\int_0^{J^{VH}} \left(\sum_{k=0}^{k(j,t|VH)} q^k \, x_n\,(k,j,t|VH) \right)^{1-\alpha} dj \right] \left[n\, vh\, VH_n(t) \right]^{\alpha} + \\ & + \left[\int_0^{J^{SH}} \left(\sum_{k=0}^{k(j,t|SH)} q^k \, x_n\,(k,j,t|SH) \right)^{1-\alpha} dj \right] \left[(1-n)\, sh\, SH_n\,(t) \right]^{\alpha} \Bigg\}. \end{aligned} \tag{1}$$

The first and third expressions within square brackets sum up the contributions of the two types of IGs to production, while the second and fourth represent the role of the specific human capital inputs. Parameter $\alpha \in]0, 1[$ is the human capital share in production. The term A is a positive exogenous variable representing the level of productivity, dependent on the country's domestic institutions (*ie* non-international trade related), namely property rights, tax laws and government services. We consider $A_{South} < A_{North}$ as the only North-South difference in the parameters of the production function of final goods.

The human capital terms include the quantities employed in the production of the n[th] final good - VH_n and SH_n - and two types of corrective factors accounting for differential productivities. An absolute productivity advantage of versatile over specialized human capital is accounted for by the joint parameters vh and sh, assuming

$vh \geq sh \geq 1$, *ie* assuming a technological bias in favor of the versatile technology.[2] A relative productivity advantage of either type of human capital is captured by the terms n and $(1-n)$. The use of these adjustment terms transforms the final goods index n in a relevant ordering index: it means that versatile human capital is relatively more productive in producing final goods indexed by larger ns, and *vice-versa*. Since $n \in [0, 1]$, there is a threshold final good N, endogenously determined, where the switch from one technology to the other becomes advantageous, as will become clear below.

Each of the two intermediate goods terms includes an adjustment for quality that reflects a stylized technological change process of the quality ladder type. The size of each quality upgrade obtained with each successful research is denoted by q, an exogenously determined constant >1. The rungs of the quality ladder are indexed by k, with higher ks denoting higher quality. At time 0, the highest quality good in each IGs industry has a quality index $k=0$. At time t the highest quality good produced by industry j has a quality index $k(j, t\,|\,.)$. The quantity $x_n(k, j, t\,|\,.)$ of the quality rung k of the intermediate good j is used, together with its human capital complement, to produce $Y_n(t)$. Hence, for example,

$$\sum_{k=0}^{k(j,t|VH)} q^k \; x_n\,(k, j, t|VH\,), \tag{2}$$

is the quality–adjusted total amount of the versatile-specific intermediate good j, and $(1-\alpha)$ is its share in the final good production.

Because of profit maximizing limit pricing by the monopolists producers of IGs, only the highest quality available of each intermediate good is actually used, so that the quality-adjusted amount (2) becomes

$$q^{k(j,t|VH)} \, x_n\,(j, t|VH\,). \tag{2'}$$

Taking that into account, the zero profit equilibrium of the (constant returns to scale perfectly competitive) producers of final goods yields the demand for each intermediate good (highest quality only) by the representative producer of n[th] final good,

$$x_n(j,t|VH) = n\; vh\, VH_n(t) \left[\frac{p_n(t)\, A(1-\alpha)}{p(j,t|VH)} \right]^{1/\alpha} q^{k(j,t|VH)[(1-\alpha)/\alpha]}; \tag{3a}$$

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[1] As amply divulged by the textbooks of Barro and Sala-i-Martin (1995) and Aghion and Howitt (1998).
[2] We could think of versatile *vs* specialized as modern *vs* traditional technologies.

$$x_n(j,t|SH) = (1-n)\, sh\, SH_n(t)\left[\frac{p_n(t)\, A(1-\alpha)}{p(j,t|SH)}\right]^{1/\alpha} q^{k(j,t|SH)[(1-\alpha)/\alpha]}. \qquad (3b)$$

where $p_n(t)$ is the price of final good n, $p(j,t|.)$ is the price of intermediate good j, and the numeraire is the composite final good. All prices are given for the perfectly competitive producers of final goods.

Plugging (3a) and (3b) into the production function (1), and using only the highest quality of each intermediate good, the supply of final good n is

$$Y_n(t) = A^{1/\alpha}\left[p_n(t)(1-\alpha)\right]^{\frac{1-\alpha}{\alpha}}\Big[p(j,t|\,VH)^{\frac{\alpha}{1-\alpha}}\, n\, vh\, VH_n(t)\, Q^{J^{VH}}(t)\; + \; + p(j,t|\,SH)^{\frac{\alpha}{1-\alpha}}\, n\, sh\, SH_n(t)\, Q^{J^{SH}}(t)\Big], \qquad (4)$$

where

$$Q^{J^{VH}} = \int_0^{J^{VH}} q^{k(j,t|VH)[(1-\alpha)/\alpha]}\, dj \text{ and } Q^{J^{SH}} = \int_0^{J^{SH}} q^{k(j,t|SH)[(1-\alpha)/\alpha]}\, dj, \qquad (5)$$

are the aggregate domestic quality indexes, measuring domestic technological knowledge. The ratio $Q^{J^{VH}}/Q^{J^{SH}}$ is the relative productivity of the versatile technology, which is an appropriate measure of the versatile–specialized technological bias. Equation (4) clearly shows how growth of final production is driven by growth of technological knowledge and by human capital accumulation.

The prices' numeraire - the composite final good - is obtained by integration over the final goods:

$$Y(t) = \int_0^1 p_n(t)\, Y_n(t)\, dn = exp\left[\int_0^1 ln\, Y_n(t)\, dn\right]. \qquad (6)$$

Intermediate goods technology

Since, by assumption, the production of intermediate goods and R&D is financed by the resources saved after consumption of the composite final good, the simplest hypothesis is to consider that the production function of IGs is identical to the composite final good specified by (6) and (1).[3] Given this convenient simplification, the marginal cost - *MC* - of producing an intermediate good equals the *MC* of producing the composite final good, which, due to perfect competition in the final goods sector, equals the price of the composite final good (numeraire); in short, $MC = 1$. Thus, the MC of producing an intermediate good is independent of its quality level and is identical across all domestic industries.

The manufacture of an intermediate good requires a start–up cost of research in a new design. This investment in a blueprint can only be recovered if profits in each date are positive for a certain period in the future. This is guaranteed by domestically enforced patents, which protect the leader firm's domestic monopoly of that quality good, while at the same time disseminating acquired knowledge to other domestic firms. Under these assumptions, knowledge of how to make a good is public (non–rival and non–excludable) within a country.

Since the last innovator in each industry is the only firm legally allowed to produce the highest quality intermediate good, it will use pricing to wipe out sales of lower quality IGs in its industry. Leader firms in all IGs can choose a price ε - arbitrarily small - less than the limit price $p = q\,MC$. This limit price reflects the fact that the leader in each IGs industry is q times more efficient that the closest follower. Since the lowest price the producer of the second best good can charge (without having negative profits) is MC, the leader firm can successfully capture the entire market for this good by selling at any price slightly below $q\,MC$ - see, for example, Grossman and Helpman (1991, chap. 4).

Maximization of profits, given demand (3a) or (3b), yields the mark-up price equation

$$p(j,t\,|\,.) = \frac{1}{1-\alpha}\,. \tag{7}$$

This is a constant mark-up price, which, together with the $MC=1$ condition explained above and the limit price definition, implies that the price of all IGs is the same - p -, equal to the mark-up price and to the size of each quality improvement - q.

Equilibrium for given technological knowledge and human capitals

It is convenient to derive now the domestic equilibrium of the economy, for given technological knowledge - Q^{JVH} and Q^{JSH} defined by (5) - and stocks of versatile and

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[3] Or, equivalently, that the composite final good is the input in the production of each intermediate good - as in Barro e Sala-i-Martin (1997), for example.

specialized human capital. Then, the endogenous determination of human capital accumulation and R&D activities close the model of the domestic economy.

An important feature of the equilibrium is that only one technology, versatile or specialized - *ie* one combination of IGs of a certain type and the respective human capital - is used to produce a particular final good. The derivation of this result follows, with the due differences, Acemoglu and Zilibotti (2001).

The pattern of comparative advantage embedded in the production function (1) through the adjustment terms n and $1-n$ makes VH relatively more productive in high indexes final goods. Together with profit maximization, this pattern implies the existence of a threshold final good $N \in [0,1]$ such that only specialized technology is used to produce final goods indexed by $n \leq N$, and only versatile technology is used to produce goods with $n > N$, *ie* in production function (1),

$$\begin{aligned} VH_n &= x_n(.\,|\,VH) = 0, \quad \forall\, 0 \leq n \leq N \\ SH_n &= x_n(.\,|\,SH) = 0, \quad \forall\, N < n \leq 1 \end{aligned} . \tag{8}$$

The determination of N follows from equilibrium in the factors markets, by equalizing the marginal value product of each type of human capital across the relevant final goods industries - $n \leq N$ for SH and $n > N$ for VH. The resulting N, as a function of the currently given variables, is

$$N(t) = \left\{ 1 + \left[\frac{Q^{J^{VH}}(t)}{Q^{J^{SH}}(t)} \frac{vh\, VH(t\,|\,w)}{sh\, SH(t\,|\,w)} \right]^{\frac{1}{2}} \right\}^{-1}, \tag{9}$$

where the index w in the human capital inputs identifies, at each moment in time, the VH and SH actually employed in the production of goods, as opposed to VH and SH in formation (at school or on-the-job-training, as will be apparent below).

It is useful to relate N to prices, as well. This is achieved by taking into account that in the threshold industry $n=N$ both a firm that uses specialized technology and a firm that uses versatile technology should breakeven. This turns out to yield, at each moment in time, the following ratio of index prices of goods produced with versatile and specialized technologies:

$$\frac{p^{VH}}{p^{SH}} = \left[\frac{N}{1-N} \right]^{\alpha}, \tag{10}$$

where prices are, at each period t, conveniently indexed as

$$p_n = \begin{cases} p^{SH}(1-n)^{-\alpha}, & \forall\, 0 \le n \le N \\ p^{VH} n^{-\alpha}, & \forall\, N < n \le 1 \end{cases}. \tag{11}$$

Equation (9) shows that either if the technology is highly versatile-biased - that is, high $Q^{J^{VH}}/Q^{J^{SH}}$ - or if there is a large relative supply of *VH*, the fraction of industries using the versatile technology is large and so *N* is small. In terms of prices, small *N* implies that the relative price of versatile technology goods is also low and, conversely, the relative price of specialized technology goods is high, as equation (10) shows. In this situation, the demand for specialized-specific IGs is high - equations (3a,b), increasing the demand for specialized-specific new designs and inducing R&D activities aimed at improving specialized-specific technologies. In sum, the structure of the stock of human capital influences the direction of R&D through the final goods price channel - there are stronger incentives to develop technologies when the final goods produced by these technologies command higher prices.[4]

The equilibrium aggregate output at each time *t* - the composite final good from equation (6) - is expressible as a function of the currently given aggregate domestic quality indexes and human capitals,

$$Y(t) = exp\,(-1)\, A^{1/\alpha}(1-\alpha)^{2\frac{1-\alpha}{\alpha}} \left\{ \left[Q^{J^{SH}}(t)\, sh\, SH(t \mid w)\right]^{\frac{1}{2}} + \left[Q^{J^{VH}}(t)\, vh\, VH(t \mid w)\right]^{\frac{1}{2}} \right\}^{2}. \tag{12}$$

Consumers and human capital accumulation

In order to account for human capital accumulation and employment, we turn now to the individuals in the economy. Population growth is zero and there are many heterogeneous consumers, each of them deciding on the allocation of time and income. Time is divided between attending the education system to accumulate human capital, and working to earn an amount denominated in composite final output, proportional to his human capital. Income is partly spent directly on the consumption of the composite final good, and partly lent in return for future interest.

Heterogeneity is present in two related individuals' characteristics. One is ability level - *a* - uniformly distributed over a range [*0, 1*] and specific to each individual. And the other is the type of human capital - *VH* and *SH*. For simplicity, we consider an

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[4] This price channel shows up in various papers by Acemoglu (*eg* 2002), although always dominated by the market size effect, which, in our case, is removed - see below section 3, Equilibrium R&D.

exogenous threshold ability $\overline{a}$ such that individuals with high ability - $a > \overline{a}$ - accumulate the versatile type (more productive, recall), while low ability individuals - $a \leq \overline{a}$ - are only able to accumulate the specialized type. Thus, each individual is indexed by *a*, which implicitly also defines the type of his human capital.

The infinite horizon lifetime utility of an individual with ability *a* is the integral of a discounted CIES utility function,

$$U(a) = \int_0^{\infty} \left[\frac{c(a,t)^{1-\theta} - 1}{1-\theta} \right] exp(-\rho t)\, dt \,. \tag{13}$$

where $c(a,t)$ is the amount of consumption of the composite final good of the individual with ability *a*, at time *t*; $\rho > 0$ is the discount rate; and $\theta > 0$ is the inverse of the intertemporal elasticity of substitution.

The individual *a* budget constraint, at each *t*, equalizes income earned to consumption plus savings. Savings are the accumulation of assets, *i.e.* lending takes the form of ownership of the profitable firms, which are the ones that produce intermediate goods in monopolistic competition.[5] Denominating these assets by *K* and its return by *r*, the budget constraint, expressed as savings = income + consumption, is

$$\dot{K}(a,t) = r(t) K(a,t) + \left[1 - u_S(a,t) - u_T(a,t)\right] w^m(t)\, m(a,t) - c(a,t)\,. \tag{14}$$

where:

$m = \begin{cases} SH & if\ a \leq \overline{a} \\ VH & if\ a \leq \overline{a} \end{cases}$; $w^m(t)$ is the wage per unit of human capital type *m* at time *t*; $u_S(a,t)$ and $u_T(a,t)$ are the fractions of time *t* that individual *a* spends accumulating human capital at school and on-the-job-training (OJT), respectively. Thus, $[1 - u_S(a,t) - u_T(a,t)]$ is the fraction of time *t* that individual *a* spends at work. Due to arbitrage in the domestic assets markets, the interest rate in (14) depends neither on ability nor on the type of human capital, only on time.

In the education system, individuals accumulate human capital of the type *VH* or *SH*, using as inputs school and OJT in any desired combination. School and OJT, in turn, are proportional to the fraction of time allocated to each and to the amount of the individual's human capital.[6] We consider the following CES, constant returns, accumulation function of type *m* human capital:

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[5] The value of these firms, in turn, corresponds to the value of patents in use, as explained below.
[6] This extends Lucas' (1988) schooling model to both schooling and OJT.

$$\dot{m}(a,t) = \left\{ \varphi^m \left[\chi_S u_S(a,t) m(a,t) \right]^{\phi} + (1-\varphi^m) \left[\chi_T u_T(a,t) m(a,t) \right]^{\phi} \right\}^{1/\phi} - \delta^m m(a,t) \,, \quad (15)$$

where δ^m is the depreciation rate of the *m* type human capital; the expressions within square brackets are the factors *school*(a,t) and *OJT*(a,t) denoting, respectively, schooling activities and OJT of an individual with ability *a*, at time *t*; χ_S and χ_T are efficiency parameters measuring the intensity of schooling and OJT activities; and $\varphi^m \in [0,1]$ is the distribution parameter, which determines the relative importance of the two factors in human capital accumulation.[7]

We assume $\varphi^{VH} > \varphi^{SH}$, such that *VH* is relatively school intensive and *SH* is relatively OJT intensive,[8] and $\chi_S \geq \chi_T$, such that productivity in OJT is not higher than in schooling. As to the relationship between the two factors in the accumulation of human capital, the CES formulation (15) allows schooling and OJT to be either complements or substitutes, depending on the value of the substitution parameter - complements if $\phi < 0$ and substitutes if $0 < \phi \leq 1$.

Each consumer solves an optimal control problem of maximization of lifetime utility (13) subject to the constraints on the accumulation of assets (14) and human capital (15). The controls are c, u_S and u_T, and the state variables are K and *VH* or *SH*. The solution for the consumption path, which turns out to be independent of the ability and type of human capital, is the Euler equation

$$\frac{\dot{c}(t)}{c(t)} = \frac{1}{\theta}\left[r(t) - \rho \right]. \quad (16)$$

As for the time-allocation part of the problem, the optimal ratio is independent of time and individual ability, but dependent on the type of human capital,

$$\frac{u_T(t|m)}{u_S(t|m)} = \left[\frac{(1-\varphi^m)\ \chi_T^{\phi}}{\varphi^m\ \chi_S^{\phi}} \right]^{\frac{1}{1-\phi}}. \quad (17)$$

When schooling and OJT are substitutes, the optimal time-allocation ratio is positively related to the intensity ratio, and vice-versa in the case of complements. It makes sense - if schooling and OJT are complements in (15), then an increase in the

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[7] $\varphi^m = 1$ yields the human capital accumulation function *à la* Lucas (1988); and when $\varphi^m = 0$, the increase in the stock of human capital is only due to OJT.

[8] This is in line with Grossman and Shapiro's (1982) suggestion that school provides general human capital, more versatile or adaptable to changing environments, while OJT is more specific.

time allocated to the factor with higher intensity requires a greater increase in the time allocated to the lower intensity factor.

The optimal time-allocation ratios can also be expressed in terms of the given wages' dynamics, yielding supply of effort functions for each type of human capital. The optimal time-allocation ratio is such that

$$\frac{\dot{w}^m(t)}{w^m(t)} = r(t) + \delta^m - \varphi^{m^{1/\phi}} \chi_S \left[1 + \frac{u_T(m)}{u_S(m)}\right]^{\frac{1-\phi}{\phi}} \tag{18}$$

Probabilities of successful R&D

In addition to human capital, R&D drives economic growth. A more detailed description of the technology of R&D activities is thus in order, closing the characterization of the North and South domestic economies.

R&D activities in the North result in innovative designs for the manufacture of intermediate goods, which increase their quality. The designs are domestically patented and the leader firm in each IGs industry - the one that produces according to the latest patent - uses limit pricing to assure monopoly. The value of the leading-edge patent depends on the profit-yields accruing at each period t to the monopolist, and on the duration of the monopoly power. The duration, in turn, depends on the probability of a new innovation, which creatively destroys the current leading-edge design - in the lines of the Schumpeterian models introduced by Segerstrom *et al.* (1990) and Aghion and Howitt (1992). The probability of a successful innovation is, thus, at the heart of R&D. Let I index the Northern innovator, and $pb_I(k, j, t|m)$ denote the instantaneous probability at time t - a Poisson arrival rate - of successful innovation in the next higher quality $[k(j,t|m)+1]$ in IGs industry j, which complements human capital type m.

$$pb_I(k, j, t|m) = rs_I(k, j, t|m)\, lr_I(k, j, t|m)\, lm_I(t|m)\, cp_I(k, j, t|m), \tag{19}$$

where

(i) rs_I is the flow of domestic final good resources devoted to domestic R&D;

(ii) $lr_I(k, j, t|m) = \beta_I q^{k(j,t|m)}$ represents learning by R&D, as the positive learning effect of accumulated public knowledge from past successful research - see Grossman and Helpman (1991, chap. 12).

(iii) $lm_I(t|m) = m(t|w)^{-\xi_I}, \xi_I > 0,$ is the adverse effect of market size, capturing the idea that the difficulty of introducing new quality IGs and replace old ones is proportional to the size of the market measured by the respective human capital employed. That is, for reasons of simplicity, we reflect in R&D the costs of scale increasing, due to coordination among agents, processing of ideas, informational, organisational, marketing and transportation costs, as reported by works such as Becker and Murphy (1992), Alesina and Spolaore (1997), Dinopoulos and Segerstrom (1999) and Dinopoulos and Thompson (1999).[9]

(iv) $cp_I(k,j,t|m) = \zeta_I^{-1} q^{-\alpha^{-1}k(j,t|m)}, \zeta_I > 0,$ is the adverse effect - cost of complexity - caused by the increasing complexity of quality improvements.[10]

The South mimics the R&D process of the North, but not necessarily at the edge of technological progress. That is, South's R&D activities result either in imitation of current best qualities or in re-invention of lower rung qualities. Let us focus on the former case. Indexing the imitator by *P*, and denoting the probability of successful imitation by $pb_P(k,j,t|m)$ - the instantaneous probability of successful imitation of the current higher quality $[k(j,t|m)]$ in IGs industry *j*,

$$pb_P(k,j,t|m) = rs_P(k,j,t|m)\, lr_P(k,j,t|m)\, lm_P(t|m)\, cp_P(k,j,t|m)\, bp_P(k,j,t|m), \quad (20)$$

where

(i) rs_P is the flow of domestic final good resources devoted to domestic R&D;

(ii) $lr_P(k,j,t|m) = \beta_P q^{k_P(j,t|m)}, 0 < \beta_P < \beta_I, k_P \le k$;

(iii) $lm_P(t|m) = m(t|w)^{-\xi_P}, \xi_P > 0,$ is the adverse effect of market size;

(iv) $cp_P(k,j,t|m) = \zeta_P^{-1} q^{-\alpha^{-1}k(j,t|m)}, \zeta_I > \zeta_P > 0,$ *ie* we assume that the complexity cost of imitation is lower than the innovation's - as argued by Mansfield *et al.* (1981) and Teece (1977);

(v) $bp_P(k,j,t|m) = \exp[DP(j,t|m) + IT(j,t|m)]\exp(\sigma g(.))$, with $\sigma = 0$ in autarky and > 0 otherwise, is a catching-up term, specific to the imitator, that sums up positive effects of imitation capacity and backwardness.

The first exponential of the catching-up term in (iii) captures two important determinants of imitation capacity, domestic policies promoting R&D[11] - index number

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[9] Dinopoulos and Thompson (1999), in particular, provided micro foundations for this effect in a model of growth through variety accumulation.

[10] This complexity cost is modelled in such a way that, together with the positive learning effect (ii), exactly offsets the positive influence of the quality rung on the profits of each leader IGs firm - calculated below in (28); this is the technical reason for the presence of the production function parameter α in the expression - see also Barro and Sala-i-Martin (1995, chap. 7).

[11] See Aghion *et al.* (2000 and 2001).

DP - and openness to international trade[12] and other trade policies[13] - index number $IT = 0$ in autarky and > 0 otherwise.

The second exponential term includes the function (similar to Papageorgiou, 2002)

$$g\left(\tilde{m}(t \mid w), \tilde{q}(t \mid m), d\right) = \\ = \begin{cases} 0 & \text{, if } \; 0 < \tilde{q}(.) \leq d \\ \tilde{m}(t \mid w)\left[-\tilde{q}(t \mid m)^2 + (1+d)\,\tilde{q}(t \mid m) - d\right] & \text{, if } \; d < \tilde{q}(.) < 1 \end{cases} \tag{21}$$

where

(i) $\tilde{m}(t \mid w) = m_P(t \mid w) / m_I(t \mid w)$ is the imitator's relative level of employed m type human capital; that is, human capital enhances the imitation capacity - as argued by Nelson and Phelps (1966) and, more recently, Benhabib and Spiegel (1994) and Aghion *et al*. (2000), for example;

(ii) $\tilde{q}(t \mid m) = \dfrac{Q_P^{J^m}}{Q_I^{J^m}}$ is the relative technological level of the imitator's m-specific IGs;[14]

provided that the gap is not big - *ie* if $\tilde{q}$ is above threshold d - the term within square brackets on the right hand side of (21) reflects an advantage of backwardness - as in Barro and Sala-i-Martin (1997).

When the gap is wider - so that $\tilde{q}$ is below threshold d - backwardness is no longer an advantage. In this case, we assume that re-invention of past innovations becomes more profitable than imitation.

3. Equilibrium with international trade in intermediate goods

Once the countries' structure characterized, we proceed now to consider international trade of intermediate goods. In this context, the South has access to the same technology as the North, either by imitation of the latest innovations, or by importing state-of-the art intermediate goods. This improvement in the level of technological available to the South is a static benefit of international trade, with immediate effects on the levels of productivity and prices of goods and factors. The

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[12] See, for example Coe and Helpman (1995) and Coe *et al.* (1997).

[13] Namely international integration - see Grossman and Helpman (1991, chap. 11).

[14] The ratio $\tilde{q}$ is a relative average across m-specific IGs, since J^m is the same in both countries and the Qs - defined in (5) - are aggregate indexes.

dynamics - growth effect - involves the South as well as the North, due to interaction (feedback) between the countries.

In balanced trade without international mobility of the other factors of production and assets, in order to import some IGs, the South has to be able to export other. Due to marginal cost advantages, the IGs of which top-qualities are imitated become South's exports. This implies that the re-inventor South is out of this trade regime, unless trade is extended to final goods.

Worldwide limit pricing

We must distinguish now between the composite final good of the North, which is the international numeraire given by (6), and the Southern one, which we assume produced at a lower marginal cost - MC_P. Since under perfect competition prices equal marginal costs, South's final goods aggregation is

$$Y_P(t) = MC_P \exp\left[\int_0^1 \ln Y_{nP}(t)dn\right], \tag{22}$$

where $0 < MC_P < MC_I = 1$ (recall the intermediate goods technology, section 2 above).

Due to the simplification in technology explained in section 2, this marginal cost advantage carries out to the production of intermediate goods. This influences worldwide optimizing limit pricing by the relevant competitive monopolists. The three possible sequences of successful R&D outcomes and their limit pricing consequences at time t, given quality k at time $t\text{-}dt$, are depicted in table 1.

Table 1. Limit pricing of the *m*-specific intermediate good *j*

t-dt	*t*	$p(t)$
North produces and exports quality k	North innovates, produces and exports quality $k+1$	$p(j\,|\,m,I,I)=\dfrac{1}{1-\alpha}$
North produces and exports quality k	South imitates, produces and exports quality k	$p(j\,|\,m,P,I)=1$
South produces and exports quality k	North innovates, produces and exports quality $k+1$	$p(j\,|\,m,I,P)=\dfrac{MC_P}{1-\alpha}$

The first mark-up is the one derived above in (7) and is the highest - the Northern entrant (I) competes with a Northern incumbent (I), at the same marginal cost (= 1) but better quality. The second one is smaller - the Southern entrant (P), with lower marginal cost, competes in the same quality rung with a Northern incumbent (I). Compared with the first, the third mark-up is again smaller, but due to a different reason - the Northern entrant improves quality as in the first case, but competes with an incumbent with lower marginal cost.

Level effects

The static effect of international trade influencing the South is apparent in the equilibrium threshold final good

$$N_P(t)=\left\{1+\left[\frac{Q_I^{J^{VH}}(t)}{Q_I^{J^{SH}}(t)}\frac{vh\,VH_P\left(t|\,w\right)}{sh\,SH_P\left(t|\,w\right)}\right]^{\frac{1}{2}}\right\}^{-1}. \tag{23}$$

By allowing international access to the state-of-the-art intermediate goods, international trade affects the final goods' productive structure in the South - through the ratio $Q_I^{J^{VH}}/Q_I^{J^{SH}}$ - bringing about convergence to the Northern structure and prices - which depend on *N*, equation (10). Since the technological gap is always favourable to the North in either specific knowledge - *ie* $Q_I^{J^m}>Q_P^{J^m}$ -,[15] the South enjoys an immediate absolute and relative to the North benefit in terms of aggregate product and factor prices - w^m. That is apparent in (12) above, provided that both (i) the instantaneous jumps in the allocation of time between employment and human capital accumulation, and (ii) the changes in mark-ups, are of second order. In fact, both the level of the composite final good, and the marginal productivities of *VH* and *SH* increase with Q^{J^m}.

Let us suppose that the regime of international trade changes in time $t = 0$ from autarky to free trade of intermediate goods. Also, assume that the technological gap is relatively higher in the versatile-specific knowledge, and that initial endowments of human capital are such that the North is relatively *VH* abundant, *ie*

$$\frac{Q_I^{J^{VH}}(0)}{Q_I^{J^{SH}}(0)}>\frac{Q_P^{J^{VH}}(0)}{Q_P^{J^{SH}}(0)}\quad\text{and}\quad\frac{VH_I(0)}{SH_I(0)}>\frac{VH_P(0)}{SH_P(0)}. \tag{24}$$

These assumptions imply that (the subscript *aut* denotes autarkic regime)

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[15] From the definition of the probabilities (19) and (20), the South always lags behind, be it as imitator or re-inventor.

$$N_P > N_I; \quad N_{P,aut}(0) > N_P(0); \quad \text{and } N_{P,aut}(0) - N_{I,aut}(0) > N_P(0) - N_I(0) > 0\,, \tag{25}$$

ie, the North always produces more final goods with versatile technology than the South, although the direction of the immediate level effect is towards convergence in the structure of final goods' production.

In spite of the absolute and relative to the North benefit from the static effect of trade to Southern individuals holding either type of human capital, convergence brings about an immediate increase in inequality within the South. The shift in the demand for *VH* is more pronounced, due to complementarity between IGs and human capital together with the versatile-specific bias in technological knowledge - first inequality in (24).

Equilibrium R&D

Given the functional forms (19) and (20) of the probabilities of success in R&D, which depend on the resources - composite final goods - allocated to it, free-entry equilibrium is defined by the equality between expected revenue and resources spent. Taking, for example, the case of imitation, such equality takes the form

$$pb_P(k, j, t \mid m)\, V_P(k, j, t \mid m) \;=\; rs_P(k, j, t \mid m)\,, \tag{26}$$

where $V_P(k, j, t \mid m)$ is the expected current value of the flow of profits to the monopolist producer of intermediate good j, or, in other words, the market value of the patent.[16]

This expected flow of profits depends on the amount in each period, on the interest rate, and on the expected duration of the flow, which is the expected duration of the imitator's technological leadership. Such duration depends on the probability of a successful innovation in the North, which is the potential challenger, as shown in the third case in table 1.[17] The expression for V_P is

$$V_P(k, j, t \mid m) = \frac{\Pi_P(k, j, t \mid m)}{r_P(t) + pb_I(k, j, t \mid m)}\,. \tag{27}$$

The amount of profits - Π_P -, at time t, for a j IGs monopolist using an imitation of quality k depends on the marginal cost, the mark-up, and the world demand for intermediate good j by the final goods producers. Its expression, for a versatile-specific j and recalling that P,I indexes the second sequence in table 1, is

[16] Still in other words, V is the value of the monopolist firm, owned by domestic consumers.

$$\Pi(k,j,t\,|\,VH,P,I) = vh(1-\alpha)^{\alpha^{-1}}\, q^{(1-\alpha)\alpha^{-1}k(j,t|VH)}\left(1-MC_P\right)$$
$$\left[VH_P(t\,|\,w)\left(A_P p_p^{VH}(t)\right)^{\alpha^{-1}} + VH_I(t\,|\,w)\left(A_I p_I^{VH}(t)\right)^{\alpha^{-1}}\right]. \tag{28}$$

Plugging (28) into (27), and then (27) and (20), with $\xi_P = 1$, into (26), and solving for pb_I, the equilibrium probability of a successful innovation in a versatile-specific intermediate good - given the interest rate, the human capitals and the final goods' price indexes - is

$$pb_I(t\,|\,VH) =$$
$$= \frac{\beta_P}{\zeta_P}\exp\left[DP(t\,|\,VH) + IT(t\,|\,VH)\right]\exp\left[\sigma g\left(\widetilde{VH}(t\,|\,w), \widetilde{q}(t\,|\,VH), d\right)\right]\widetilde{q}(t\,|\,VH)$$
$$vh(1-\alpha)^{\alpha^{-1}}\left(1-MC_P\right)D - r_P(t) \quad . \tag{29}$$

where

$$D \equiv \left[\frac{VH_P(t\,|\,w)}{VH_P(t\,|\,w)+VH_I(t\,|\,w)}\left(A_P p_p^{VH}(t)\right)^{\alpha^{-1}} + \frac{VH_I(t\,|\,w)}{VH_P(t\,|\,w)+VH_I(t\,|\,w)}\left(A_I p_I^{VH}(t)\right)^{\alpha^{-1}}\right]$$

The equilibrium *m*-specific pb_I turns out to be independent of *j* and *k*. There are two reasons behind this independence. The first and most substantial one is the removal of scale of knowledge effects - the positive influence of the quality rung on profits and on the learning effect is exactly offset by its influence on the complexity cost [see the exponents of q in (28) and in (20)-(ii) and (iv)]. The other is the simplifying assumption that the determinants of imitation capacity, *DP* and *IT* in the catching-up term in (20)-(v), are not specific to each intermediate good.

Additional scale effects could arise through market size, as has been intensely discussed in the R&D endogenous growth literature since Jones' (1995) critique. Due to the technological complementarity in the production function (1), in our model the size of the market for *m*-specific intermediate goods is the employed *m*-type human capital. Then, the scale effect is apparent in the size of the profits (28) - see the human capital terms within square brackets. Since we aim at understanding international trade effects other than market size, the removal of scale is in order. The adverse effect of market size due to the scale-proportional difficulty of introducing new quality intermediate goods - term (iii) in (19) and (20) - is designed to offset the scale effect on profits. With $\xi = 1$, the offsetting is such that the market size influence becomes negligible, as it is apparent in expression *D* in (29).

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[17] In the case of the value of a patented innovation - V_I - the challenge comes from both a new Northern innovation and a Southern imitation - *ie* the first and second cases in table 1.

Since the probability of successful innovation - as a Poisson arrival rate - determines the speed of technological progress, equilibrium can be translated into the path of Northern knowledge, from which free trade in intermediate goods allows the South to benefit as well. The relationship turns out to yield the following expression - where (29) is plugged in - for the equilibrium rate of growth of, for example, *VH*-specific technological knowledge:

$$\frac{\dot{Q}_I^{J^{VH}}(t)}{Q_I^{J^{VH}}(t)} = pb_I(t \mid VH)\left[q^{(1-\alpha)\alpha^{-1}} - 1\right] =$$

$$= \left\{ \frac{\beta_P}{\zeta_P} \exp\left[DP(t \mid VH) + IT(t \mid VH)\right] \exp\left[\sigma g(.)\right] \tilde{q}(t \mid VH) vh (1-\alpha)^{\alpha^{-1}} \left(1 - MC_P\right) D - \right. \quad (30)$$

$$\left. - r_P(t) \right\} \left[q^{(1-\alpha)\alpha^{-1}} - 1\right]$$

It is clear in (30) that there are international trade feedback effects from imitation to innovation. That is, the positive level effect from the innovator to the imitator - the access to the state-of-the-art intermediate goods increases production and thus the resources available to imitation R&D - feeds-back into the innovator, affecting its technological knowledge through creative destruction.

Due to the technological complementarity in the production of final goods, the rate of growth of m-specific technological knowledge - (30) for the South and $m = VH$ - translates into the growth of demand for m-type human capital interrelated with the dynamics of the prices of final goods, such that

$$\frac{\dot{w}_P^m(t)}{w_P^m(t)} = \frac{\dot{p}_P^m(t)}{p_P^m(t)} + \frac{\dot{Q}_I^{J^m}(t)}{Q_I^{J^m}(t)} . \quad (31)$$

Plugging (30) into (31) and equating this m-type human capital demand path to the respective supply by individuals - equation (18) - the equilibrium interest rate in the South is obtained. By Walras law, this is also the interest rate that clears the assets market - savings by individuals equal to the value of the firms. Finally, the general equilibrium instantaneous growth rate of the South economy at time t results from plugging the equilibrium interest rate into the Euler equation (16).

Steady-state growth

Since, by assumption, both countries have: (i) the same technology of production of final goods;[18] (ii) the access - through free trade - to the same state-of-the art intermediate goods, and (iii) the same technology of human capital accumulation; then the steady-state growth rate must be the same as well. This implies, through Euler equation (16), that interest rates are also equalized between countries in steady-state.

As for the sectorial growth rates, we note that the aggregate resources constraint - again in country *P*, for example - is

$$Y_P(t) = C_P(t) + X_P(t) + RS_P(t), \tag{32}$$

where Y_P is total resources, the composite final good; C_P is aggregate consumption; X_P is aggregate intermediate goods; and RS_P is total resources spent in R&D. In other words, the aggregate final good is used for consumption and savings, which in turn are allocated between production of intermediate goods and R&D.

Since the composite final good production is constant returns to scale in the inputs *Qs* and human capitals - see above (12) -, then the constant common steady-state growth rate, designated by *gr*, is

$$\frac{\dot{Q}^{J^{VH}}}{Q^{J^{VH}}} + \frac{\dot{VH}(w)}{VH(w)} = \frac{\dot{Q}^{J^{SH}}}{Q^{J^{SH}}} + \frac{\dot{SH}(w)}{SH(w)} = \frac{\dot{Y}}{Y} = \frac{\dot{X}}{X} = \frac{\dot{RS}}{RS} = \frac{\dot{C}}{C} = \frac{\dot{c}}{c} = \theta^{-1}\left(r^{ss} - \rho\right) = gr. \tag{33}$$

Clearly, steady-state endogenous growth is driven by R&D and human capital accumulation. This feature is not, however, specific to the regime of international trade. In order to look at the steady-state effects of international trade we must investigate *gr* further. To this end, we compare the steady-state interest rate

$$\begin{aligned} r^{ss} = q^{(\alpha-1)\alpha^{-1}} \Bigg\{ & \frac{\beta_P}{\zeta_P} \exp\left[DP(VH) + IT(VH)\right] \exp\left[\sigma g(.)\right] \widetilde{q}\left(VH\right) \\ & vh(1-\alpha)^{\alpha^{-1}} \left(1 - MC_P\right) D \left[q^{(1-\alpha)\alpha^{-1}} - 1\right] - \delta^{VH} + \varphi^{VH^{1/\phi}} \chi_S \left[1 + \frac{u_T(VH)}{u_S(VH)}\right]^{\frac{1-\phi}{\phi}} \Bigg\}, \end{aligned} \tag{34}$$

with the one that would prevail under an autarkic steady-state. Taking into account that goods, assets, as well as knowledge do not flow internationally in autarky, only re-invention is possible in the South. In that case the probability of successful imitation (20) collapses into a probability of successful re-invention, where backwardness and trade effects disappear. The increment in the steady-state interest rate, from autarky to trade in intermediate goods and imitation, depends on the difference

$$\exp\left(IT(VH)\right)\exp\left[\sigma g(.)\right]\tilde{q}\left(VH\right)D\left(1-MC_P\right)-(1-\alpha)\left(p_{P,aut}^{VH}A_P\right)^{\alpha^{-1}}\left[(1-\alpha)^{-1}-MC_P\right], \quad (35)$$

where $p_{P,aut}^{VH}$ is the autarkic steady-state index price of the final goods produced with versatile technology, and all other variables are in steady-state under international trade of intermediate goods.

While evaluation of (35) requires solving for transitional dynamics through calibration and simulation - which is beyond the purpose of this paper -, we can, however, emphasize two ways, in addition to the level effects, through which international trade influences, in opposite directions, steady-state growth.

The first is the positive catching-up effect on the probability of successful imitation. Imitation capacity increases with the index of openness - IT - and the advantages of backwardness are only captured in the presence of international trade - $\sigma > 0$. Through the feedback effect described above, the probability of successful innovation, and thus the steady-state growth rate, are also affected - see (29) and (30).

The second - counteracting - channel is the monopolistic competition mark-up. In (35) the Southern monopolist's mark-up under international trade is $\left(1-MC_P\right)$, clearly less than the mark-up in the South under autarky, $\left[(1-\alpha)^{-1}-MC_P\right]$. This loss of profits also happens to the Northern monopolist: the average mark-up between the first and third situations in table 1 above is smaller than $\left[(1-\alpha)^{-1}-1\right]$, which is the mark-up under autarky. The reason is that in autarky successful innovations in the North and re-inventions in the South are protected from each other's international competition. Once engaged in international trade and imitation becomes profitable (provided that the technological threshold d is overcome), profit margins in both North and South are reduced, which disincentives R&D activities.[19]

In addition to the direct international trade effects, expressions (34) and (35) allow further comparative steady-state analysis. Table 2 sums up some qualitative results not directly related to R&D.

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[18] Except for the level of productivity A in (1), which implies differences in the levels but not in the growth rates.

[19] Contrary to previous models in which the reduction of margins is offset by market enlargement - eg Rivera-Batiz and Romer (1991) -, we have removed the scale effect, as explained above.

Table 2. Comparative steady-state analysis

$\frac{\partial gr}{\partial A_I}, \frac{\partial gr}{\partial A_P}$	$\frac{\partial gr}{\partial \varphi^m}$	$\frac{\partial gr}{\partial \phi}$	$\frac{\partial gr}{\partial \chi_S}, \frac{\partial gr}{\partial \chi_T}$
(+)	(+)	(+)	(+)

Both countries' exogenous levels of productivity - A_I and A_P -, affect not only the levels, but the growth rate as well, due of the role of competitive monopoly profits. International trade emphasizes the importance of improvements in domestic institutions, because they turn out to matter not only at home but also abroad.

As to the human capital production parameters - recall (15) -, the second column of table 2 shows that the more intensive is the use - in the production of *VH* and *SH* - of the more productive mode of human capital production - schooling -, the higher is the growth rate. Also, the more substitutes the modes of human capital production are - measured by ϕ -, the higher is the use of the more productive one, thus, again, the higher is the growth rate. Productivity in the human capital sector, then propagated to the economy, is also improvable directly through χ_S and χ_T. In sum, improvements in productivity in the human capital sector reduce its opportunity cost and consequently increase its accumulation, which, in turn, increases *gr*.

Steady-state effects

We come now to the technological implications of steady-state growth in both countries, in terms of relative prices of final goods, technological productivities and wages. Figure 1 compares the autarkic steady-state paths with the ones resulting from a move - at time zero - to free trade of intermediate goods. The figure is arranged in a suitable order to accompany the sequence of analytical steps that follows.

Due to complementarity, the technology threshold and relative prices of final goods are determined by the combination of the two types of technological knowledge with the respective human capital employed - recall (9) and (10). As results from the steady-state relationships in (33), such combination tends to a constant in each country and, consequently, so do *N* and relative prices. Despite the downward level effect in the South at time zero (explained above), differences in factor endowments - as assumed by (24) - dominate the steady-state, such that relative prices of versatile technology final goods are always higher in the South.

Figures 1.1-1.2 also show a consistent drop in the steady-state levels of both N and relative prices, from autarky to trade. In fact, due to differences in endowments, the time zero (under trade) North-South average relative price of versatile technology final goods is higher than in the North alone. Through the price channel - discussed above in section 2 - this induces relative demand for versatile-specific new designs, biasing R&D in that direction more than in autarky, as shown in both scenarios A and B of figure 1.3. Relative to autarky, such steady-state bias increases the worldwide supply of versatile-specific IGs, thereby lowering in both countries the steady-state relative price of the versatile technology final goods and the technological threshold.

Scenarios A and B in figure 1.3 lead to two alternative steady-state paths for the relative productivity of the state-of-the-art versatile technology.[20] While the price effect on the technology bias - just described above - operates in both A and B in the same direction (diminishing the rate of growth of the relative productivity of the specialized technology), in case B the effect is strong enough to revert the bias. This is crucial to the steady-state path of relative wages, as expression (31) and figures 1.4-1.5 show. In fact, with relative prices of final goods constant, the direction of technology bias is the sole determinant of the path of wage inequality. The immediate increase (level effect) in the relative wage of *VH* in the South ends up being reverted in steady-state A, or reinforced in steady-state B, depending on the bias in favor of specialized or versatile technology, respectively. In any case, the steady-state path of wage inequality, in either direction, is always more moderate than in autarky, reflecting the weaker technology bias.

Figures 1.4-1.5 also depict the maintenance of a wage differential between the North and the South. This is to be expected from the conjunction of assumptions of (i) international immobility human capital and (ii) differences in productivity and marginal costs between the countries. But the steady-state rates of growth of wages are equalized between countries, as results from the application of (31) to both types of human capital in steady-state,

$$\left.\frac{\dot{w}_I^m}{w_I^m}\right|^{ss} = \left.\frac{\dot{Q}_I^{J^m}}{Q_I^{J^m}}\right|^{ss} = \left.\frac{\dot{w}_P^m}{w_P^m}\right|^{ss} \Rightarrow \left(\left.\frac{w_P^{VH}}{w_P^{SH}}\right|^{ss}\right)^{\bullet} = \left(\left.\frac{w_I^{VH}}{w_I^{SH}}\right|^{ss}\right)^{\bullet} = \left.\frac{\dot{Q}_I^{J^{VH}}}{Q_I^{J^{VH}}} - \frac{\dot{Q}_I^{J^{SH}}}{Q_I^{J^{SH}}}\right|^{ss}, \tag{36}$$

This can be regarded as a Schumpeterian dynamic equivalent to the static Stolper-Samuelson result. That is, in spite of international immobility of human capital, the steady-state growth of wages is common to both countries because they share the same technological progress embodied in internationally traded intermediate goods.

4. Concluding remarks

This paper emphasized the mechanisms, other than market size, through which international trade brings about North-South transfer of technology. After properly designing the probabilities of successful R&D in order to isolate the scale effect, we have analyzed a level static effect arising from worldwide access to the state-of-the-art intermediate goods, and steady-state effects due to the price channel through which specific types of human capital influence the direction of technological progress. The consideration of two types of human capital in this set-up allowed the study of wage inequality effects of international trade, as well as the derivation of a Schumpeterian dynamic equivalent to the static Stolper-Samuelson factor price equalization result.

Next steps of this research include (i) solving for transitional dynamics through calibration and simulation in order to quantify the differences and transition from autarky to international trade; (ii) discussing the implications to technological diffusion of international intellectual property rights, in addition to the domestic ones already considered; and (iii) introducing a general purpose technology with the possibility of alternative scenarios of international diffusion.

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[20] The path in the South is only shown up to time zero, since its relationship with the dynamics of prices and wages is confined to autarky.

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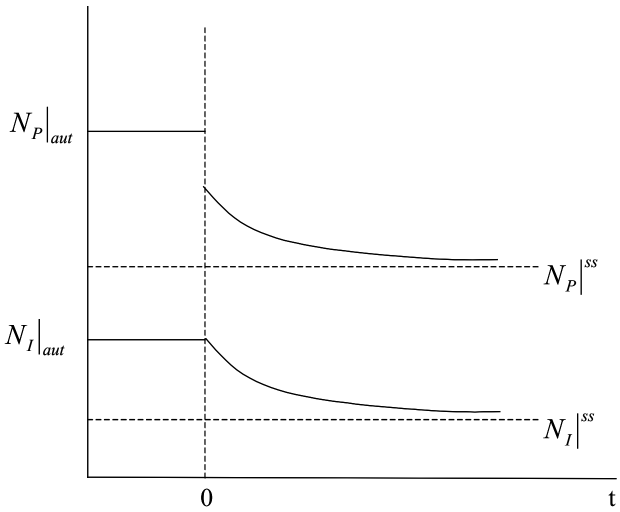
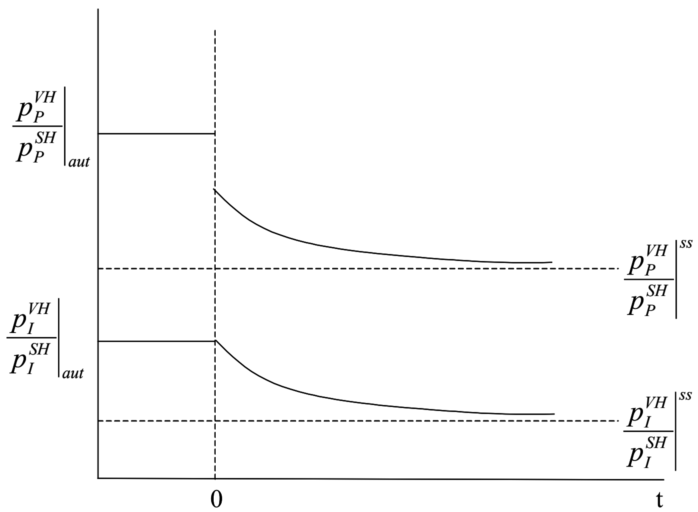
Figure 1. Steady-state under free trade of intermediate goods

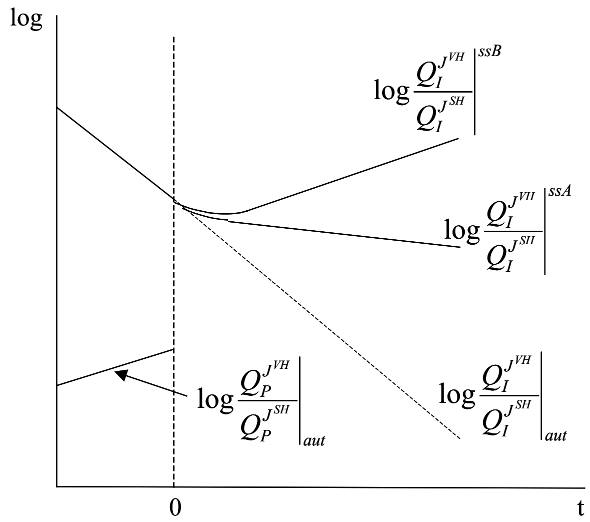
1.1. Technology threshold



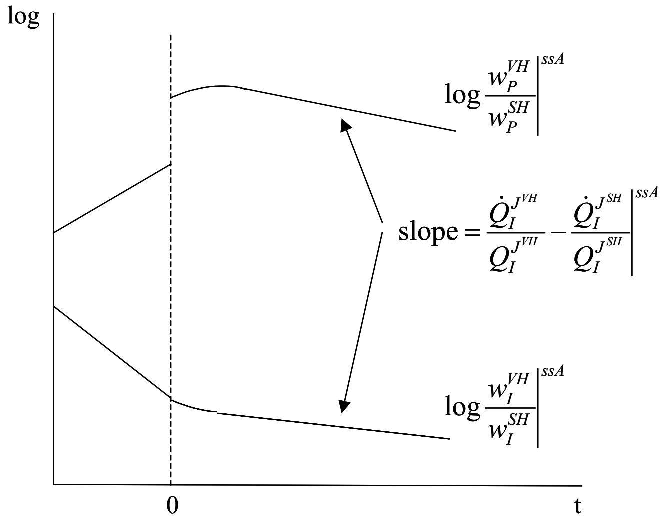
1.2. Relative price of versatile technology final goods



1.3. Relative productivity of the versatile technology



1.4. Relative wage of the versatile human capital Case A – decreasing inequality



1.5. Relative wage of the versatile human capital Case B – increasing inequality