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ABSTRACT

Trade-induced Technical Bias And Wage Inequalities: A Theory Of Defensive Innovations*

This Paper considers a dynamic North–South model of international trade and innovations in which firms can endogenously bias the direction of technological change. We show that, when there is a differential degree of protection of property rights between the two regions, innovating firms face a trade-off between de-localization in the South and more secure property rights in the North. For a certain range of products, the optimal response to this trade-off is the emergence of endogenous technological bias towards skilled labour technologies. We discuss the implications of this trade-induced technological bias on the dynamics of international trade and relative wages in the two regions. For some configurations of parameters, the model is able to generate, along the transition path, an increase in wage inequalities in both regions and skill upgrading of southern production compatible with small changes in import penetration rates in North.

JEL Classification: D33, F12, O33
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NON-TECHNICAL SUMMARY

Since the 1980s, wage inequality between low and highly educated workers has widened dramatically in the US. While part of the answer to these events has to do with a slowdown of the supply of highly educated workers in the 1980's, the most popular explanation lies with a demand shift toward educated workers. Two main reasons have been suggested to explain such a demand shift. The first explanation argues that the growing international trade integration observed during the same period between advanced economies and low-wage countries, has shifted, through standard Hecksher-Ohlinian effects, in high-wage economies the labour demand away from low-skill workers. The second holds that technological change has been biased towards high education

An important line of attack of the trade hypothesis proponents is the fact that empirical measures may produce understatements of the real impact of trade on wage inequalities because of the intrinsic difficulty of disentangling empirically pure trade effects from pure technical effects. In particular, it is suggested that, by measuring technical effects as unexplained residuals of other variables, most studies tend to ignore the potential contribution of trade to technical progress itself. This idea of trade-induced technical change is exemplified by what Adrian Wood describes as 'defensive innovation'; namely that technical change could be biased towards skilled labour as an endogenous reaction of developed country firms to trade with low-wage countries.

The purpose of this Paper is to provide a general equilibrium model to consider this issue theoretically. We start with a North–South Schumpeterian model of trade and growth. Goods can be produced with skilled and unskilled labour. We consider that the ratio of skilled to unskilled labour for each good can be endogenously chosen by firms whenever a cost-reducing innovation is made through research. Hence, at each point in time, all goods can be ranked according to their factor intensity. To highlight the effect of *trade-induced technical change* in the most transparent way, we adopt a 'technology bias' specification such that, everything else being equal, it is always more profitable for a firm to adopt a neutral technical change rather than a biased technical change. Under such a specification, we show that in autarky, no biased technical change occurs in equilibrium.

We then consider trade between a southern region (the South) and a northern region (the North): the two regions differ fundamentally in two dimensions. First, because of strong enough factor endowment differences, the two regions face different factor prices. Second, they also display a crucial institutional asymmetry in terms of protection of property rights. More precisely, we consider that the southern region has less secure social institutions in terms of protection of property rights (because of more political instability, corruption, various risks, reputation or transport costs, less secure intellectual property rights). In such a context, whenever an innovation appears, the choice of factor bias can clearly affect the choice of location of production. Indeed there may be a trade-off between adoption of a neutral innovation with production located according to standard comparative advantage and, on the other hand, adoption of an innovation technically biased toward skilled workers with production located in the northern region enjoying more secure property rights. For a certain range of products, we show that the optimal outcome of this trade-off is the emergence of endogenous technological bias in the North towards skilled labour technologies.

Intuitively, trade allows cost-minimizing firms to produce in different regions according to their comparative advantage. Low-skill intensive goods are produced in the South and high-skill intensive goods are produced in the North. Consider then, at a given point in time, a good produced in The South (namely with a low enough skill intensity technology) and suppose that there is a cost-reducing innovation falling on that particular good. A firm adopting such an innovation has the opportunity to choose the direction of technical change on the good. A neutral technical change direction implies that the factor intensity of the sector does not change. Therefore, production associated to that sector is still optimally located in The South with low labour wages. Given our specification of technical bias, a technical change biased towards skilled labour reduces the incremental cost reduction but also upgrades the skill intensity of the sector. This then makes it more likely to have cost-minimizing production located in the North, with more secure property rights and a smaller threat of future imitation. Clearly, if the good has a skill intensity close enough to the specialization frontier between the two regions, then the gains of 'bringing back' production of this good into the 'more secure' northern location, through endogenous skill-biased technical change, more than compensate for the benefits of adopting a neutral innovation and producing in The South with low wages. Hence, for a whole range of products in South, close enough to the specialization frontier, biased technical change will occur naturally in equilibrium.

We investigate then the implications of this *'trade-induced'* technological bias on the dynamics of international trade and the evolution of relative wages. Interestingly, two effects are at work. First, there is the static impact effect of the *trade-induced technical bias* described above. This bias, being applied to the sector close to the specialization frontier, will increase (or reduce), at a given point in time, the number of low-skill intensive (or high-skill intensive) goods produced in the North (or the South). This effect shifts up (or down) the relative labour demand for unskilled workers in the North (or the South), thereby increasing (or reducing) wages in the North (or in the South) and reducing wage inequalities in both regions. Paradoxically, although Wood was right in arguing on the possibility of *trade-induced technical bias*, this effect suggests that he would be wrong in arguing that this is a justification of an increase in wage inequality. The story however does not stop here. Indeed, a second countervailing dynamic effect comes into play. The change in factor prices associated *trade-induced technical bias* makes in turn production location in the South more attractive, displacing forward the specialization frontier between the South and the North and thereby upgrading the average skill intensity of goods produced in the South and the North. This dynamic skill upgrading of technologies then, by an inverse argument, shifts down (or up) relative unskilled labour demand in the North (or in the South) and therefore tends to increase wages inequalities in both regions.

The process of *trade-induced technical bias* and dynamic skill upgrading proceeds as long as the world economy has not reached a stationary situation. We show that the process of *trade-induced technical bias* and dynamic skill upgrading converges to a stationary situation in which there is no trade-induced biased technical change. Still, because of the transition, wage inequalities in the long run will be different from wage inequalities at the beginning of the process. With the help of simple numerical simulations, we discuss conditions under which such wage inequalities have increased. We show in particular that our theory is able to generate a pattern of increasing inequalities in the North and the South consistent with very low variations of the South's Import Penetration. This reproduces important stylized facts which, acccording to Krugman, are at the heart of the Trade and Inequalities Puzzle. We see however that the transition path is sensitive to initial conditions and elasticity parameters. This suggests that the *trade-induced technical bias* idea, while theoretically possible, merits further serious empirical investigation before being taken for granted.

1. Introduction

Since the 1980s, wage inequality[1] between low and highly educated workers has widened dramatically in the US. While part of the answer to these events has to do with a slowdown of the supply of of highly educated workers in the 80's, the most popular explanation lies with a demand shift toward educated workers. Two main reasons have been suggested to explain such a demand shift. The first explanation argues that the growing international trade integration observed during the same period between advanced economies and low wage countries, has shifted, through standard Hecksher-Ohlinian effects, in high wage economies the labor demand away from low skill workers. The second holds that technological change has been biased towards high education workers[2].

An important line of attack of the trade hypothesis proponents is the fact that most empirical measures may produce understatements of the real impact of trade on wage inequalities because of the intrinsic difficulty to disentangle empirically pure trade effects from pure technical effects (Wood (1994), Leamer (1994)). In particular, it is suggested that, by measuring technical effects as unexplained residuals of other variables, most studies tend to ignore the potential contribution of trade to technical progress itself. This idea of *trade induced technical change* is exemplified by what Adrian Wood describes as "defen-

[1]For instance, the wage gap between college education and high school education has increased by about 20 % (Borjas and Ramey (1994). A similar trend, though less important, has also been observed in other industrial european economies. In addition, employment of unskilled workers has declined in favor of skilled workers and, in several continental european countries, increased unemployment for the less skilled has been widely observed (OECD 1993, Bloom and Brender 1993).

[2]The focus on trade and technology and the issue of which aspect is the most relevant, has generated considerable debate among economists. On the one hand, proponents of the technology hypothesis minimize the role of trade as an explanation on the basis of two main arguments. First, despite the fall in the relative wage of unskilled labor, they observe that the high-skilled to low-skilled workers' ratio has increased in almost every manufacturing sector, suggesting skill bias technical change rather than trade effects (Berman, Bound and Griliches (1994)). Second, they argue that output prices have not moved in the direction suggested by Hecksher-Ohlin trade theory, undermining therefore the link from trade to factor prices (Lawrence and Slaughter (93)). Proponents of the trade hypothesis, on the other hand, emphasize the fact that such observations do not necessarily prove that trade has no significant effect per se. Hence for instance, Feenstra and Hanson (1996) and (1999) argue that the increase in the ratios of skilled to unskilled workers within manufacturing sectors may be due as much to intensive outsourcing as to biased technical change. Also, they maintain that more complete price data reestablish significant price movements in agreement with standard trade theory (ie. a continuous decline of relative prices of low-skilled intensive sectors during the period 1979-1990). In a different vein of the trade view proponents, Rodrick (1996) argues that, the main channel through which globalization plays a role is the induced change in elasticity of the labor demand for unskilled workers rather than a pure labor demand shifting effect.

sive innovation", namely that technical change could be biased towards skilled labor as an endogenous reaction of developed country firms to trade with low wage countries[3]. Going along this line of reasoning, Wood then argued that allowance for "defensive innovation" would require something like a doubling of the usual factor content estimates.

Though the argument has aroused much controversy in the empirical literature (see Burtess (1994) for a survey), interestingly, little work has been done to investigate precisely its theoretical consistency. The purpose of this paper is to provide a general equilibrium model to consider theoretically this issue. At first sight, the idea of "defensive innovation" seems to be inconsistent with standard economic theory. Indeed, if labor-saving cost reducing technologies existed, why were they not used already by profit maximizing firms in autarky? Also, if it is cheaper to produce with a given technology in a low wage economy, why not delocalize rather than try to defend location in the high wage economy by some kind of costly "defensive innovation" biased toward skilled labor? As we will see shortly, it is still possible to provide a simple framework to rationalize Adrian Wood's intuition of *trade induced technical change* as a natural outcome of trade integration between a low-wage and a high-wage economy.

In order to do this, we start with a North-South schumpeterian model of trade and growth *à la* Aghion and Howitt (1998) and Grossman and Helpman (1991). Goods can be produced with skilled and unskilled labor. Following however Von Weizsäcker (1962), Drandakis-Phelps (1966), Samuelson (1965) and Newel, Jaffe and Stavins (1999), we consider that the ratio of skilled to unskilled labor for each good can be endogenously chosen by firms whenever a cost reducing innovation is made through research. Hence, at each point of time, all goods can be ranked according to their factor intensity. To highlight the effect of *trade induced technical change* in the most transparent way, we adopt a "technology bias" specification such that, everything else being equal, it is always more profitable for a firm to adopt a neutral technical change rather than a biased technical change. Under such a specification, we show that in autarky, no biased technical change occurs in equilibrium.

[3]Wood's evidence of this phenomenon rests on suggestive case studies and anecdotal evidence. Statistical support for "defensive innovation" is also somehow suggested by findings from Sachs and Shatz (1994) of faster total factor productivity growth during the 1980's in low-intensive manufacturing sectors. See also Lawrence and Slaughter (1993) and Leamer (1994) for similar observations of higher productivity growth in low-skill than in high-skill sectors

We then consider trade between a southern region (South) and a northern region (North): the two regions differ fundamentally in two dimensions. First, because of strong enough factor endowments differences, the two regions face different factor prices. Second, they also display a crucial institutional asymmetry in terms of protection of property rights. More precisely, we consider that the southern region has less secure intellectual property rights than the northern region (Helpman (1993), Lai (1998)). Framing the model in terms of asymmetric protection of intellectual property is in fact inessential to the argument. What matters is the regional asymmetry in terms of protection of property rights[4]. More political instability, corruption or higher costs of outsourcing in South (due to various risks, reputation or transport costs) would be equally sufficient to our argument. In such a context, whenever an innovation appears, the choice of factor bias can clearly affect the choice of location of production. Indeed there may be a tradeoff between adoption of a neutral innovation with production located according to standard comparative advantage and, on the other hand, adoption of an innovation technically biased toward skilled workers with production located in the northern region enjoying more secure property rights. For a certain range of products, we show that the optimal outcome of this tradeoff is the emergence of endogenous technological bias in the North towards skilled labor technologies.

Intuitively, trade allows cost minimizing firms to produce in different regions according to their comparative advantage. Low skill intensive goods are produced in South and high skill intensive goods are produced in North. Consider then, at a given point of time, a good produced in South (namely with a low enough skill intensity technology) and suppose that there is a cost reducing innovation falling on that particular good. A firm adopting such an innovation has the opportunity to choose the direction of technical change on the good. A neutral technical change direction implies that the factor intensity of the sector does not change. Therefore, production associated to that sector is still optimally located in South with low labor wages. Given our specification of technical bias, a technical change biased towards skilled labor reduces the incremental cost reduction but also upgrades the skill intensity of the sector. This makes it more likely to have then cost minimizing production located in North, with more secure property rights and a smaller threat of

[4]See also Hall and Jones (1999) for such a view.

future imitation. Clearly, if the good has a skill intensity close enough to the specialization frontier between the two regions, then the gains of "bringing back" production of this good in the "more secure" northern location through endogenous skill bias technical change more than compensates the benefits of adopting a neutral innovation and producing in South with low wages. Hence, for a whole range of products in South, close enough to the specialization frontier, biased technical change will occur naturally in equilibrium.

What are then the implications of this "trade induced" technological bias on the dynamics of international trade and the evolution of relative wages? Interestingly, two effects are at work. First, there is the static impact effect of the *trade induced technical bias* described above. This bias, being applied to the sector close to the specialization frontier, will increase (resp. reduce), at a given point of time, the number of low-skill intensive (resp. high-skill intensive) goods produced in North (resp. South). This effect shifts up (resp. down) the relative labor demand for unskilled workers in North (resp. South), thereby increasing (resp. reducing) wages in North (resp. in South) and reducing wage inequalities in both regions. Paradoxically, though Wood was right in arguing on the possibility of *trade induced technical bias*, this effect suggests that he would be wrong in arguing that this is a justification to an increase in wage inequality. The story however does not stop here. Indeed, a second countervailing dynamic effect comes into play. The change in factor prices associated with *trade induced technical bias* makes in turn production location in South more attractive, displacing forward the specialization frontier between South and North and thereby upgrading the average skill intensity of goods produced in South and North. This dynamic skill upgrading of technologies then, by an inverse argument, shifts down (resp. up) relative unskilled labor demand in North (resp. in South) and therefore tends to increase wages inequalities in both regions.

Clearly enough, the process of *trade induced technical bias* and *dynamic skill upgrading* proceed as long as the world economy has not reached a stationary situation. While it is difficult to characterize the complete path of technical change and endogenous bias with perfectly forward looking firms, we are able to show that the process of *defensive innovation bias* and *dynamic skill upgrading* converges to a stationary situation in which there is no trade induced biased technical change. Still, because of the transition, wage inequalities in the long run will be different from wage inequalities at the beginning of the process. An interesting question is then to see the conditions under which such wage inequalities have increased. While our purpose is not to assess empirically our theory, still, in order to get more insights on the nature of the transition process, we consider the question with some simple numerical simulations. This allows us to investigate which effect (instantaneous impact of *defensive innovation bias* as opposed to the *dynamic skill upgrading*) dominates in the evolution of trade patterns and wages inequalities. We show in particular that our theory is able to generate a pattern of increasing inequalities in North and South consistent with very low variations of South Import Penetration. This reproduces important stylised facts which, acccording to Krugman (1995), are at the heart of the Trade and Inequalities Puzzle. We see however that the transition path is sensitive to initial conditions and elasticity parameters. This suggests that the *trade induced technical bias* idea, while theoretically possible, merits further serious empirical investigation before being taken for granted.

Besides the original idea of Adrian Wood, the work most closely related to ours is Acemoglu (1999). It also develops a growth model with endogenous technical bias and North South trade. As in the present work, "trade induced biased technical change" emerges a a natural outcome of North South trade. However the mechanism is different from ours. In this paper, skill bias technical change occurs because of market size and scale effects. Here the mechanism does not depend on scale effects [5]. It occurs more as a defensive response to unsecure property rights in South and as an incentive to maintain or bring back production location in North. Hence our mechanism seems to be more directly related to the idea of "Defensive Innovations" suggested by Adrian Wood.

The paper is organized in the following way. Section 2 present the model of trade and biased technical change. Section 3 describes the autarkic equilibrium. Section 4 shows how trade integration between North and South generates some "trade induced technical bias". Section 5 investigates the dynamic implications for trade and inequality. Section 6 provides then some simple numerical simulations to analyze the model along the transition path. Finally section 7 concludes.

[5] which may be subject to the critics of Jones (1995).

2. A Model of trade and biased technical change.

We consider a continuous time model a la Aghion and Howitt (1998) and Grossman and Helpman (1991) with a continuum of final goods on the interval $[0,1]$. There are three types of factors of production: skilled labor and unskilled labor used in the production of the final goods, and research specific labor used for the activity of innovation and R&D. There is a perfect credit market.

2.1. Preferences

The representative consumer is endowed with the following intertemporal separable utility function: $U = \int_0^{+\infty} \ln D_t.e^{-\rho t}dt$ where D_t is defined, in a standard way, as a Cobb Douglass instantaneous utility on the continuum of final goods: $\ln D_t = \int_0^1 \ln c_t(i).di$. Normalizing to 1 instantaneous spendings in each period, $E_t \equiv 1$, the intertemporal maximization of the consumer's utility under his intertemporal budget constraint gives, as usual, equality between the interest rate and the discount factor $\rho = r_t$. The instantaneous demand for good i with price $p_t(i)$ is then given by:

$$x(i) = 1/p_t(i) \tag{2.1}$$

2.2. Technologies

Each good i is produced with a CES technology

$$Y_{<s_t(i),u_t(i)>}(l,h) = A.\left[\left(\frac{l}{u_t(i)}\right)^{\frac{1-\sigma}{\sigma}} + \left(\frac{h}{s_t(i)}\right)^{\frac{1-\sigma}{\sigma}}\right]^{\frac{\sigma}{1-\sigma}}$$

using skilled labor h and unskilled labor l. The elasticity of substitution between skilled and unskilled labor is σ with $0 < \sigma < 1$ and A is a productivity parameter. Thus production functions belong to a Family of technologies which each element has the same elasticity σ and is characterized by technological coefficients $(u,s) \in \mathbb{R}^{+*} \times \mathbb{R}^{+*}$. Let w_t and q_t be the unskilled and skilled labor wages. The unit cost function of good i using technology $(u_t(i), s_t(i))$, is then given by:

$$C_{<s_t(i),u_t(i)>}(w_t,q_t) = \frac{1}{A}\left[(u_t(i).w_t)^{1-\sigma} + (s_t(i).q_t)^{1-\sigma}\right]^{\frac{1}{1-\sigma}} \tag{2.2}$$

Corresponding to this technology, there is an optimal skilled-unskilled labor intensity:

$$\left.\frac{h}{l}\right|_t (i) = \left(\frac{q_t}{w_t}\right)^{-\sigma} \left(\frac{s_t(i)}{u_t(i)}\right)^{1-\sigma} \quad \text{at time } t. \tag{2.3}$$

The ratio $x_t = \frac{s_t}{u_t}$ is going to be a crucial variable of the analysis because it determines skilled-unskilled labor intensity and thus skilled labor relative demand. It is then useful to consider $\alpha_t(x)$ the density function on $\mathbb{R}^+$ describing how goods are distributed at time t on production technologies according to x. Hence $\alpha_t(x)dx$ reflects the mass of goods whose production technology (u_t, s_t) is such that the factor intensity parameter s_t/u_t is between x and $x + dx$. $\alpha_t(.)$ therefore summarizes at a given point of time the technological structure of the economy. In the sequel, we will see how this distribution $\alpha_t(.)$ is endogenously evolving because of technological bias and its consequences on the economic equilibrium.

2.3. Technological Change

There is a R&D sector using a sector specific factor H_{RD}. This sector is composed of a large number of research labs selling their innovations as monopoly patents to firms in the final good sector. Innovation is incremental and affects the technological coefficients (u, s) in the following way. When an innovation occurs on a given good i (in the following, we omit good index i), the coefficients $(u(i), s(i))$, become $(\delta_u u(i), \delta_s s(i))$ with (δ_u, δ_s) taking two possible values: 1 or $\delta < 1$. Depending on the value, technical change is neutral, biased towards skilled labor or biased towards unskilled labor. More precisely, when $\delta_u = \delta_s = \delta$, technical change is neutral (ie. the new technology has the same skilled unskilled labor intensity as the old one). When $\delta_u = \delta$ and $\delta_s = 1$, technical change is biased towards skilled labor. Finally the case $\delta_u = 1$ and $\delta_s = \delta$ corresponds to technical change biased towards unskilled labor.

[figure I]

We assume that, once an innnovation is made, the firm buying the patent has the choice of the direction of technical bias, that is it can decide whether the implementation of the innovation will be done through a factor neutral or factor biased new technology. One way to justify this is to consider that firms can buy innovations (ideas and general research results) from the R&D sector. However they are doing in-house applied research at the development stage and can decide the direction of technical change to be implemented in the firm. Note that the specification we consider for biased technical change corresponds to the case where the efficient frontier of innovation possibilities is reduced to the point $(\delta_u, \delta_s) = (\delta, \delta)$. Hence neutral technical change is *a priori* more efficient than biased technical change[6].

As in other schumpeterian models, we assume that the patent price paid by a final sector firm to the R&D sector reflects the expected discounted monopoly rents that the firm will enjoy with the innovation. We also assume that R&D is *ex-ante* not specific to a given final good sector. More precisely, at the time R&D is undertaken, research labs do not know the sector for which the innovation will be useful. Actually each time an innovation is made, it falls randomly on one of the final good sectors. This assumption[7] simplifies greatly the analytics of the model without changing the basic insights we want to illustrate. One can also justify this assumption by recalling that the R&D sector produces basic and general research results whose usefulness may be quite difficult to predict, *a priori*, for a given sector of the economy.

Given this assumption, the rate of creative destruction θ will be identical across the continuum of goods and will remain constant[8] through time (because of factor specific R&D).

3. Autarkic equilibrium

It is first useful, as a benchmark, to discuss the stationary equilibrium which prevails for an economy in autarky. We suppose that the factor endowments of unskilled and skilled labor are respectively L and H. In the stationary equilibrium , wages for unskilled and skilled labor are constant and given by (w, q).

[6] This specification can be considered as a special case of the Theory on "Induced Invention" where a reduction of factor intensity is associated to a convex innovation possibility set $\left(\delta_u^{-1}, \delta_s^{-1}\right)$ defined by a function η such that: $\delta_s^{-1} = \eta(\delta_u^{-1})$. Moreover, our specification by making neutral technical change more efficient in cost reducing, limits the mechanism we want to emphasize.

[7] Thoenig (1999) describes a model where innovations may be good specific.

[8] The model is then formally equivalent to a schumpeterian model with an exogenous rate of creative destruction of innovations. This specification therefore allows us to focus on the link between Trade and the *direction* of technical Change (with an exogenous *rate* of innovation) whereas existing Literature has extensively analysed the link between Trade and the rate of innovation (with an exogenous neutral direction of technical Change).

Let us consider first a particular sector i where incumbent firm produces good i with a technology indexed by (u, s). In the sequel of this section, for convenience, we omit the indice i. The newcomer monopoly firm , owning the last innovation's patent, must choose a (δ_u, δ_s) type of innovation. Then it practices limit pricing at the unit cost of the closest competitor in the sector. Therefore its intantaneous profits are given by:

$$\pi = 1 - \frac{\tilde{c}}{c} \tag{3.1}$$

where $\tilde{c}$ et c are respectively the unit cost of the new and the old monopoly firm.Taking (2.2) into account, this profit function can be rewritten as:

$$\pi(s/u) = 1 - \left[\frac{\delta_u^{1-\sigma} + \left(\delta_s \frac{s}{u} \frac{q_t}{w_t}\right)^{1-\sigma}}{1 + \left(\frac{s}{u} \frac{q_t}{w_t}\right)^{1-\sigma}} \right]^{\frac{1}{1-\sigma}} \quad \text{with } \delta_{u,s} \in \{1, \delta\} \times \{1, \delta\} \tag{3.2}$$

Discounted expected monopoly profits are then given by $V(s/u) = \underset{\tau}{E} \left[\int_0^\tau e^{-rt}.\pi(s/u).dt \right]$ where τ is the date of next innovation discovery (determined by a Poisson Process). We get:

$$V(s/u) = \frac{\pi(s/u)}{r + \theta}$$

Result 1 *In autarky, technical change is neutral.*

The result is quite obvious. As already noticed, neutral technological change is more efficient in terms of unit cost's reduction than any biased direction. Hence firms will preferably choose this direction than any biased direction. A direct implication of this is that for any good i the factor intensity ratio s/u remains constant as $\delta_s.s/\delta_u u = \delta s/\delta u = s/u$. Consequently, the distribution function $\alpha_t(.)$ remains *invariant* through time under autarky.

For each good i, skilled and unskilled labor demands can be easily obtained from (2.1-2.2) and are given respectively by $\delta/[w.\frac{l_t}{h_t} + q]$ and $\delta/[w + q.\frac{h_t}{l_t}]$. Using (2.3), and the notation $x = \frac{s}{u}$, the aggregate demands for unskilled labor (resp. skilled) are easily obtained as:

$$D_L(q/w) = \frac{1}{w} \int_0^\infty \frac{\delta \ . \ \alpha_t(x)dx}{\left[1 + \left(\frac{q}{w}\right)^{1-\sigma} x^{1-\sigma}\right]}., \quad D_H(q/w) = \frac{1}{q} \int_0^\infty \frac{\delta \ . \ \alpha_t(x)dx}{\left[1 + \left(\frac{q}{w}\right)^{\sigma-1} x^{\sigma-1}\right]}. \tag{3.3}$$

As the distribution function $\alpha_t(x)$ is time invariant, the aggregate demands are also time invariant and the equilibrium in the skilled and unskilled labor markets is given by:

$$H = D_H(q, w) \text{ and } L = D_L(q, w)$$

It is then easy to show (see appendix B) that there exists a unique autarkic equilibrium (w^*, q^*). This autarkic equilibrium[9] is characterized by neutral technological change and constant relative wages. This feature of the autarkic equilibrium will be particularly useful to contrast the impact of trade on the direction of technological change and relative wages between trading economies.

4. Trade induced technological bias

This section considers first the issue of endogenous technical bias in a temporay partial equilibrium context. We omit therefore the time index and factor prices are supposed to be fixed. Consider then two economies (North and South) trading with each other on the final goods. North is supposed to be relatively better endowed with skilled labor than South. Hence denoting by L^n, H^n, L^s, H^s, the levels of unskilled and skilled labor respectively in North and South, we assume that $H^n/L^n > H^s/L^s$ and that the differential is sufficiently large such that there is complete specialization of both economies. We consider also that R&D is made in North while firms in South have the possibility to imitate northern technologies without paying the patent price. Wages are determined by the equilibrium in the domestic labor markets. Because of the relative abundance of skilled labor in North, the following inequality is true at equilibrium: $(q^n/q^s) < 1 < (w^n/w^s)$. Specialisation and local production will be given by the comparison of unit costs (2.2):

$$\frac{c^n}{c^s}(s/u) = \frac{w^n}{w^s}\left[\frac{1 + \left(\frac{q^n}{w^n}\right)^{1-\sigma}\left(\frac{s}{u}\right)^{1-\sigma}}{1 + \left(\frac{q^s}{w^s}\right)^{1-\sigma}\left(\frac{s}{u}\right)^{1-\sigma}}\right]^{\frac{1}{1-\sigma}} \tag{4.1}$$

There exists[10] therefore a point f, (called the frontier of specialization) and such that

[9] The general equilibrium is indeed easy to compute though we have potentially a continuum of production technics. As a matter of fact, the global dynamics is markovian: in the bertrand competition context, the crucial aspect in the profit functions is the unit cost relative to the previous innovator. This markovian feature and the assumption of Cobb Douglass utility simplify greatly the dynamics of the system and allows to have stationarity.

[10] It is easy to check (as $\sigma < 1$) that : $\frac{d(c^n/c^s)}{d(s/u)} < 0$, $\lim\limits_{s/u \to 0} \frac{c^n}{c^s}(s/u) = w^n/w^s > 1$, $\lim\limits_{s/u \to +\infty} \frac{c^n}{c^s}(s/u) = q^n/q^s < 1$.

all goods with a technic's factor intensity parameter s/u less than f are cheaper to produce in the South while all goods with an intensity larger than f are less expensive to produce in the North. Obviously f is determined by the relationship: $c^n/c^s(f) = 1$.

We define therefore the comparative advantage zones of South R_S and North R_N as a partition of the family of CES functions in functions such that (s/u) belongs respectively to $[0, f]$ and $[f, +\infty[$. In the sequel, we will show that the existence of these zones plus the fact intellectual property rights are less protected in South than in North, generates the possibility for endogenous bias in the direction of technological change.

Intellectual property rights are not fully protected in South and firms in that region can imitate an innovation appearing in North. Obviously, southern firms have an incentive to imitate technics of production with factor intensities only in R_S, as these technologies are the ones to enjoy a unit cost advantage in South. For simplicity, we consider the risk of imitation as exogenous and given by an imitation rate I, constant and identical accross all technologies belonging to R_S[11]. Hence any product produced with a technic in R_S can be subject to imitation.

Firms maximize then profits according to (3.1). Therefore production localisation is determined by unit cost minimization with the realized unit cost function on technic s/u given by $\hat{c}(s/u) = \min[c^n(s/u), c^s(s/u)]$. Instantaneous profits are then:

$$\pi(\delta_u, \delta_s) = 1 - \frac{\hat{c}(\delta_s s/\delta_u u)}{\hat{c}(s/u)} \text{ with } (\delta_u, \delta_s) \in \{1, \delta\} \times \{1, \delta\} \tag{4.2}$$

For each choice of technical change direction (δ_u, δ_s), it is convenient to denote the instantaneous profit function as $\pi = \pi(\delta, \delta)$, $\pi^+_{s/u} = \pi(\delta, 1)$ and $\pi^-_{s/u} = \pi(1, \delta)$. Hence $\pi, \pi^+_{s/u}$ and $\pi^-_{s/u}$ correspond respectively to the cases of neutral, skill biased and unskilled biased technical change. They are represented[12] in figure 1.

[figure II]

[11] Firms in South do not have any incentive to imitate technologies in R_N. As a matter of fact, doing so would not allow them to capture market shares as they face a northern firm which already uses the technology with smaller unit costs (ie. which is such that $c^s > c^n$).

[12] We easily check that for $x \in [0, \delta f_t] \cup [f_t, +\infty]$, $\frac{\partial \pi_t^+(x)}{\partial x} < 0$
and for $x \in [\delta f_t, f_t]$,
$\frac{\partial \pi_t^+(x)}{\partial x} = -\underbrace{\Gamma}_{>0} \cdot \underbrace{[q_t^n/q_t^s - \delta w_t^n/w_t^s]}_{<0}$

When an innovation becomes imitated by a firm in South, bertrand competition in price with constant unit costs leads to zero profits. Hence, for the firms, imitation acts as a destruction process. Therefore, one can write the expected intertemporal profits associated to an innovation as:

$$V(s/u) = \max_{\delta_u,\delta_s} \frac{\pi(\delta_u u, \delta_s s)}{r+\theta+1_{\{\delta_s s/\delta_u u \leq f\}}.I} \tag{4.3}$$

with $1_{\{\delta_s s/\delta_u u \leq f\}}$ the indicator function taking value 1 when $\delta_s s/\delta_u u \leq f$ and 0 otherwise. The global rate of destruction of the innovation's rents is associated first to the fact that a new innovation may appear (with instantaneous probability θ) and second, that for technics localized in South (ie. with $\delta_s s/\delta_u u \leq f$) there is a risk of imitation with instantaneous probability I. Consequently the choice $(\delta_u u, \delta_s s)$ of direction of technical change made by a firm buying a newcoming innovation, has to take into account two aspects: the direct effect on the unit cost of production and secondly, the induced effect on production localisation and the subsequent threats of imitation.

Result 2 *When the imitation rate I is high enough, there is an "induced"skill-bias technical change for all goods whose factor intensity s/u is in some interval $[f^*, f]$ where f^* belongs to the "interface" $[\delta f, f]$.*

Proof. In terms of the choice of "induced" technical change, the problem of a typical firm can be summarized as:

$$V_{s/u} = \max[\frac{\pi}{r+\theta+1_{\{s/u\leq f\}}.I}, \frac{\pi^+_{s/u}}{r+\theta+1_{\{s/\delta u, \leq f\}}.I}, \frac{\pi^-_{s/u}}{r+\theta+1_{\{\delta s/u, \leq f\}}.I}] \tag{4.4}$$

But as neutral technical change is more efficient $\pi \geq \max(\pi^+_{s/u}, \pi^-_{s/u})$. Consequently an technical bias may be profitable only for goods on $[\delta f, f]$, the interface of the international specialization frontier and initially produced in South. In that case, a skill-bias technical change is profitable if and only if:

$$\frac{\pi}{r+\theta+I} < \frac{\pi^+_{s/u}}{r+\theta} \text{ and } \delta f \leq s/u \leq f \tag{4.5}$$

This condition is illustrated on figure II. The horizontal line is plotted at value $\pi.(\frac{r+\theta}{r+\theta+I})$. The fact that $\pi^+(.)$ is increasing in the interval $[\delta f, f]$ implies that the above condition is satisfied on an interval $[f^*, f]$ when I is sufficiently strong. ■

The threat of imitation in the South implies that, for a range of goods initially produced in South, it may be optimal to bias the direction of technical change towards skilled labor whenever an innovation occurs. A skill-bias technical change is costly because it implies choosing no reduction in the input coefficient for skilled labor (ie. $\delta_s = 1$ rather than $\delta_s = \delta$). However, the bias also permits a competitive production localisation in the Northern region where intellectual property rights are secure and there is no threat of imitation. Result 2 actually says that there is a range of goods produced with technics close to the interface of specialization for which it is profitable to implement a skill-bias technical change in order to bring the production technic in North and escape therefore southern imitation. On the other hand, for goods outside the interval (ie. for which s/u is smaller than δf), a skill-technical bias on one innovation cannot allow competitive production in North. Therefore for those goods, whenever an innovation comes on them, it is better to choose the neutral technical change direction which provides a higher unit cost reduction at the region's factor prices.

The mechanism described by result 2 is interesting because it provides a rationale to what Adrian Wood had described as a case of "defensive technical innovation" in sectors threatened by delocalisation. It also corresponds also to the empirical fact described by Mouhoud (1992) of delocalisation to low wages countries, and relocalisation in developed economies induced by the introduction of skill-bias technologies.

Note that the process of technical bias towards skilled labor in North hinges solely on the possibility of trade and production delocalisation in a lower wage economy. According to result 1, in autarky, our specification of technological progress does not provide any incentives to firms to bias the direction of technical change. Trade, however, between a high wage region and a low wage region in which property rights are less secure, creates an incentive for some firms to bias endogenously the process of innovation towards skilled labor. Hence, our framework illustrates the fact that, for exposed sectors, technological bias toward skilled labor is not separable from trade and actually may be "induced" by trade itself.

It should also be noticed that this *induced technogical bias* in the present model is restricted to sectors located close to the interface. This is so because firms have a short term view on innovations. As a matter of fact, when deciding the bias of technical change, firms only take into account the impact of this bias for the present innovation they buy. If however, they were able to internalize the gain of the bias for more than one generation of innovations (because say, of in-house R&D or a restricted number of firms likely to benefit from further innovations), then clearly, more sectors would choose to bias the direction of technological change in order to escape the threat of imitation in the South (see Thoenig (1999) for such an analysis in a simple framework). In that case, the extent of "trade induced" technological skill-bias will be larger than in the present model.

Skilled biased technological change, as opposed to trade, is often described as the major culprit of the increase in income inequality in developed economies (Katz and Murphy (1992), Autor, Katz and Krueger (1998) Berman, Bound and Machin (1998)). Interestingly, it should be noted that, everything else being equal, the "trade-induced" technological bias effect described here, tends, on the contrary, to reduce inequalities in both regions. This effect is actually closely related to the effect of outsourcing of capital as described by Feenstra and Hanson (1995) and (1999) with a close technology structure. In their work, Feenstra and Hanson show that an outflow of capital from North to South can lead to a simultaneous increase of inequalities between skilled and unskilled labor in the two regions. Here, "trade-induced" skill intensive technical bias can be viewed, on the contrary, as a process of "insourcing" towards production in North. Hence, everything else being equal, inequalities tend to decrease because of that bias.

Note finally that because of the "induced" technological bias, the distribution $\alpha_t(x)$ of technics with factor intensity x is changing over time as some technics ae becoming more skilled labor intensive. In the present framework, the process of "trade-induced" technological bias is generally not compatible with a stationary distribution of technics[13]. In the sequel, we will analyze, under some simplifying assumptions, the implications of this endogenous technical bias on the transitory dynamics of the economy.

5. General equilibrium and transition dynamics

In this section we want to discuss the implications of the trade induced technical bias on the economic dynamics of the two regions. It is however analytically difficult to characterize in full generality the general equilibrium path of the whole economic system

[13] Unless the distribution $\alpha_t(.)$ is "empty" on $[\delta f, f]$.

essentially because the spread of distribution $\alpha_t(.)$ resulting from technical bias can be too "drastic". And, as already observed, this spread implies that the dynamic equilibrium is not generally stationary as factor intensities, and therefore regions' relative factor prices are time varying. In order to introduce some "smoothness" in the transition dynamic, we need to specify a framework where the spread of $\alpha_t(.)$ is marginal.

Assumption 1 We assume that innovation is incremental: δ is close to 1.

This assumption ensures that the size of the interface between North and South $[\delta f_t, f_t]$ is small compared to the whole support of $\alpha_t(.)$. This assumption will help us in the derivation of the instantaneous general equilibrium and it makes sure that the spread of $\alpha_t(.)$ is marginal. Consequently, it allows us to set the following assumption.

Assumption 2 Wages variations are small along the average life cycle of an innovation.

This assumption implies that, on each life cycle, firms act as if they were in a stationnary state. Consequently they trade-off between neutral and biased technical progress in the same manner as in the previous section. While clearly implying a certain degree of myopia, it helps significantly in terms of analytical tractability[14]. Also in the simulations, it provides a good approximation of what arises along the transition path when indeed the "characteristic time" of creative destruction dynamics is small compared to that of wages dynamics[15].

5.1. The instantaneous General Equilibrium

In appendix we show that equilibria on factor markets in South are given by the following relations:

$$L^s = \frac{\beta}{w_t^s}.\int_0^{f_t} \frac{\alpha_t(x)dx}{[1+\left(\frac{q_t^s}{w_t^s}\right)^{1-\sigma} x^{1-\sigma}]} \text{ and } H^s = \frac{\beta}{q_t^s}.\int_0^{f_t} \frac{\alpha_t(x)dx}{[1+\left(\frac{q_t^s}{w_t^s}\right)^{\sigma-1} x^{\sigma-1}]} \tag{5.1}$$

[14] See also in section 7, the discussion on how results would be affected with more forward looking firms.

[15] Neutral profit π does not vary through time (it is always equal to $1-\delta$) whereas the "biased" profit $\pi^+_{s/u}$ does change. Hereafter, in the reference simulations, the rate of creative destruction is equal to 0.25 which means that the average lifecycle duration of patent is about 4 years. The corresponding variation of relative wages in both areas are about 0.6% which means that $\pi^+_{s/u}$ may vary by a very small amount on the four years period.

These relations are similar to the autarky case, except that the range of goods produced in South is $[0, f_t]$. The coefficient β which is equal to $\delta.\frac{\theta}{\theta+I} + \frac{I}{\theta+I}$ highlights the fact that in South, a share $(\theta/\theta + I)$ of goods is produced under monopoly and a complementary share is produced, after imitation succeeds, under limit pricing competition. In the North Market, clearing conditions are similar, except for the fact that the range of goods is now $[f_t, \infty[$ and all sectors are driven by monopolies:

$$L^n = \frac{\delta}{w_t^n} \int_{f_t}^{+\infty} \frac{\alpha_t(x)dx}{[1 + \left(\frac{q_t^n}{w_t^n}\right)^{1-\sigma} x^{1-\sigma}]} \text{ and } H^n = \frac{\delta}{q_t^n} \int_{f_t}^{+\infty} \frac{\alpha_t(x)dx}{[1 + \left(\frac{q_t^n}{w_t^n}\right)^{\sigma-1} x^{\sigma-1}]} \tag{5.2}$$

Finally, recall that the specialization frontier f_t corresponds to the point where unit costs are the same in North and South (cf. equation (4.1)):

$$\frac{c_t^n}{c_t^s}(f_t) = 1 \tag{5.3}$$

The instantaneous equilibrium[16] is the solution $(w_t^s, q_t^s, w_t^n, q_t^n, f_t)$ of (5.1-5.2-5.3). The model is then a two country model with two factors of production and a continuum of technologies where factor endowments are sufficiently different for total specialization to happen. The general case in a static framework is discussed in Dornbusch, Fisher, Samuelson (1980): here we add the possibility for production functions to evolve over time which, in turn, induces some dynamics on specialization and wages.

5.2. Dynamic Equilibrium

From Result 2, we know that there exists f_t^* in the interval $[\delta f_t, f_t]$, such that goods with factor intensity in $[f_t^*, f_t]$ and subject to an innovation, have a final post innovation technology with factor intensity in $[\delta^{-1} f_t^*, \delta^{-1} f_t]$ and are produced in North. This technical biais induces a spread of technical distribution $\alpha_t(.)$. Using figure III, we can compute the

[16]Formally, at each point of time, the instantaneous equilibrium in our model can be seen as a generalization of Feenstra and Hanson (1995) model with the differences that, in our setting, $\alpha(.)$ represents a distribution of goods rather than a cobb douglass coefficient and that they use Leontieff production functions which are a subcase of CES specification.

law of motion[17] of the distribution $\alpha_t(.)$ of technologies as:

$$\begin{cases} \frac{\partial \alpha_t(x)}{\partial t} = -\theta.\alpha_t(x) \text{ if } x \in [f_t^*, f_t] \\ \frac{\partial \alpha_t(x)}{\partial t} = \delta.\theta.\alpha_t(\delta x) \text{ if } x \in [\delta^{-1} f_t^*, \delta^{-1} f_t] \\ \frac{\partial \alpha_t(x)}{\partial t} = 0 \text{ otherwise} \end{cases} \tag{5.4}$$

[figure III]

What are the consequences of the dynamics of $\alpha_t(.)$ on the pattern of trade, specialization and relative wages?. We have first the following result:

Result 3 *The specialization frontier South-North f_t is increasing over time.*

The proof is provided in appendix.

Result 3 says that during the transition path, the southern region "upgrades" progressively its technologies of production, in the sense that there is progressively delocalization to the South of technologies with higher skill intensities. The intuition of this is illustrated in figure IV. The direct impact of *Induced technical bias* is to shift sectors of production initially from South to North. Because of this, labor demands in South decrease and labor demands in North increase. This leads to lower wages in South and higher wages in North. This in turn affect the structure of unit costs of production and make production in South more profitable at a given factor intensity. Hence, it induces an upward shift of the specialization frontier between South and North.

[figure IV]

How far can this process go? The next result shows that, indeed, there is convergence of the frontier f_t towards a long run steady state in which there is no more *trade induced technical bias* towards skilled labor.

Result 4 *The system converges towards a steady state with no trade induced technical bias.*

[17] It is easy to check that this law of motion does conserve the (unit) measure of $\alpha_t(.)$. Indeed, using (5.4) some basic computations lead to: $\frac{\partial\left[\int_0^{+\infty} \alpha_t(x)dx\right]}{\partial t} = 0$

There are two reasons for stationarization of the system. First, spread of the distribution of skill intensity at some time t may be such that there is no more sectors which may be subject to skill bias (ie the support of the distribution $\alpha_t(.)$ has an empty intersection with the interval $[\delta f_t, f_t]$). More interestingly, the system may also converge to a steady state with no trade induced technical bias when condition (4.5) stops to be satisfied. Intuitively, this occurs because skill biased technical change is increasingly less profitable for sectors with higher skill intensities. Because of this, there is an upper bound on the sectorial skill intensity at which profitable technical bias can be implemented. As a consequence, along with the process of skill upgrading, the return to biased technological change in North decreases over time and the system converges towards a steady state (with no biased technical change).

5.3. Wage Inequalities

A first insight from the previous analysis is the fact that the process of induced technical change works only along the transition path of the economy. Asymptotically this effect becomes less and less important. Still, though we might not observe induced technical bias in the long run, the existing pattern of trade and wages in that situation clearly depends on the existence of technical bias during the transition.

An interesting issue is then the importance of that impact (ie. the importance of the difference between f_0 and f_∞). It should be noted that the wedge between f_0 and f_∞ depends very much on the initial conditions[18] of the distribution of technologies (ie. the shape of $\alpha_0(.)$). Take for instance first the case of $\alpha_0(.)$ as represented in figure (V) namely the case where $\alpha_0(.)$ is close to the sum of two dirac functions at H_s/L_s and H_n/L_n, $\alpha_0(.) \simeq \delta_{H^s/L^s} + \delta_{H^n/L^n}$. Then it is clear that there is no bias and $f_0 = f_\infty$. On the other hand,suppose that $\alpha_0(.)$ is an uniform density on a finite interval. Then there is some induced technical bias and $f_0 < f_\infty$.

[figure V]

[18]This property of persistency at the macro level relies on the existence , at the micro level, of a *lock-in* effect in technological change, namely the technical coefficient today $(s/u)_t$ depends of all the former chronicle $(s/u)_{t' \leq t}$.

The impact of the trade induced technical bias on wages inequalities $(q^s/w^s)_t$ and $(q^n/w^n)_t$ is ambiguous. If we denote Γ_t^s and Γ_t^n their rate of growth , we proove in appendix (B) that they depend on "sensibility" of relative demand of skill labor:

$$\Gamma_t^j = \underbrace{\frac{1}{-\varepsilon_t^{1j}}}_{>0} .[\underbrace{\varepsilon_t^{2j}}_{<0} + \underbrace{\varepsilon_t^{3j}.\frac{\dot{f}_t}{f_t}}_{>0}] \text{ with } j \in \{North, South\} \tag{5.5}$$

where ε_t^{1j} is the elasticity of skill labor relative demand according to relative price (q^j/w^j); ε_t^{2j} is the "sensitivity" of skill labor relative demand according to the spread of $\alpha_t(.)$ and ε_t^{3j} is the elasticity of skilled labor relative demand according to f_t.

There are two effects going in opposite direction. First, as was readily observed, for a given position of the specialization frontier f_t, one has a direct effect of reduction of wages inequalities because of the "insourcing" process of goods from South to North due to the bias towards skilled labor ($\varepsilon_t^{2j} < 0$). There is however a countervailing effect due to the shift in the specialization frontier ($\varepsilon_t^{3j} > 0$) and the *Skill upgrading* of South in its production technologies ($\dot{f}_t/f_t > 0$). This dynamic effect tends to increase wage inequalities inside the two regions.

The import penetration of South imports in North is given by: $TP_t = \int_0^{f_t} \alpha_t(x)dx$. The time evolution of this variable is ambiguous as the direct effect of technical bias tends to lower the import penetration ratio while, on the contrary, the process of skill upgrading tends to increase it. Intuitively, the number of goods produced in North continually increases because of trade induced technical bias (spread of $\alpha_t(.)$), while southern wages react donwards in order to catch new goods (f_t increases).

Thus, our model breaks the link between absolute variations of penetration rate and variations of wages: indeed, Krugman (1995) argues that the true puzzle concerning trade and wages involves the fact that the observed southern import penetration ratio is too low to explain such a move in factor prices in OECD countries. In the following simulations, we will see that wages inequalities may significantly move without any variation of the South penetration rate.

6. Simulation

In this section, we present illustrative numerical simulations to get some insights on the dynamics of the transition path and on various comparative statics of parameters on the evolution of skill premia in North and South. The Benchmark Model (B.M) to which we will compare all our simulation results corresponds to the model in which our technical bias mechanism is absent. In such a Benchmark, the technical distribution is invariant because skill biased technical change is forbidden: consequently there is no transition path and after trade openness, it is exactly equivalent to a version of the static Heckscher-Ohlin model extended to a continuum of goods (Dornbush, Fischer and Samuelson (1980)). When firms can choose the direction of technical change, there is a transition path toward the long term equilibrium. As the main variable of the dynamic system $\alpha_t(.)$ is backward looking, it is clear that the equilibrium of the Benchmark $(q^n, q^s, w^n, w^s)_{BM}$ corresponds to the initial equilibrium of the economy with technical bias $(q^n, q^s, w^n, w^s)_{t=0}$. Hence, in all our simulations, comparing the results of model with bias to the results of BM means that relevant variables are the ratios between the current date and the initial date: $(q^n_t/q^n_0, q^s_t/q^s_0, w^n_t/w^n_0, w^s_t/w^s_0)$.

6.1. A Simulation of Reference

As a reference, we set the following value for parameters (Table I):

[Table I]

The relative factor endowment ratios have been chosen for convenience to be $H_N/L_N = 1$ in North and $H_S/L_S = 0.1$ in South.[19]The growth rate 2.6% has been chosen to reflect the OECD average annual growth rate (from 1970 to1994); $\theta = 0.25$ corresponds to an average lifecycle duration of 4 years, the imitation rate is set to $I = 1$ in order to have a transition path which does not stationnarize immediately. The elasticity of substitution is taken as $\sigma = 0.5$ (Wood (1994)) and the North relative size is set at 1/6 reflecting the ratio of the OECD population to the World population.We estimate $\alpha_0(.)$ from the data set used in Thesmar and Thoenig (1999). Figure VI depicts the distribution of ratio of

[19]These values are close to the actual values of skilled labor (ie education level above high school) to unskilled labor (ie education level below high school) ratios of 1.5 OECD countries and 0.2 for non OECD countries (OCDE, 1994, vol1, p.102).

skilled on unskilled labor used by firms in France in (1985). Consequently, we choose for α_0 a lognormal density.

Figure VII depicts the evolution of the specialization frontier f_t, the skill premium evolution and the shape of the distribution of factor intensity at date $t = 0$ and at date $t = 25$ years. As can be seen there is, as expected a skill upgrading in the specialization region of South and North (ie. f_t is increasing over time). Also for that configuration of parameters, the simulation depicts an increase of the skill premium both for South and North with no variations of South Import Penetration.

6.2. Comparative Statics

Comparative statics on the elasticity σ

It is interesting to get also some insights on how the various structural parameters of the model affect the evolution of wage inequalities in North and South. Table II reports the final percentage variation of wage inequalities in North and South for different elasticities of substitution σ between skilled and unskilled labor. Recall that to ensure that North (resp. South) gets specialized in skilled (resp. unskilled) intensive goods, one needs $\sigma < 1$. It should be noted that this "elasticity" cannnot be directly translated to the one found in empirical studies. The reason is that, here we have a continuum of sectors with different factor intensities. Hence, the macro elasticity of substitution between skilled and unskilled labor clearly depends on the shape of the distribution of skill intensities $\alpha_t(.)$[20]. The impact of "trade induced" defensive innovation is highest for low elasticities of substitution. To get an idea of why changes in inequalities are decreasing with the elasticity of substitution between skilled and unskilled labor, it is useful to observe, in equation (5.5), that variation of skill premia depend on inverse of price-elasticity of skill relative demand ε_t^{1j} : when σ increases, this elasticity increases in absolute terms (see appendix B).

[20] There is quite a large variation of estimates of that "macro" elasticity in the empirical literature. So far, the consensus seems to be that the mean estimate of this elasticity is larger than 1 (Freeman 1986). However, there is considerable variance: in their review of 20 estimates of elasticity of substitution between blue collar and white collar workers, Hamermesh and Grant (1979) found a mean estimate of 2.3 with half the studies yielding estimates below 1 and half above that value. Further, a very recent estimate found that measure to be close to 0.16 (Ciccone, Peri and Almond (1999)) when taking into account local externality effects of skill labor on unskilled labor.

[table II]

Comparative statics on innovation and creative destruction

Another interesting parameter on which one may do some comparative statics is the creative destruction rate θ. Table III summarizes the impact of an increased θ. In both cases, the impact of "trade induced technical bias" is larger, the larger the rate of growth of the world economy. Obviously the effect is larger for the low elasticity but still, when $\sigma = 0.5$, an innovation rate of $\theta = 0.4$ translates into a wage inequality increase of about 6% for North and 3.5% for South. These number may appear at first sight to be relatively low for a period of 25 years. Still one has to recall that they reflect on the effects of *trade induced technical bias* which would come above the usual Stoper Samuelson effects so much debated in the literature on trade and distribution. A larger innovation rate increases the opportunity for norther sectors with low skills to bias the direction of technical change towards skilled labor.This in turn strengthens the impact of *trade induced technical bias* and the associated general equilibrium effects on the evolution of wages inequalities.

[table III]

Comparative statics[21] *on the increment* δ

Finally, Table IV reports the impact of changes in δ on wages inequalities, holding constant the growth rate of the economy. A larger δ reduces the impact of trade induced technical bias on the skill distribution across goods, and as shown in the table for the elasticity $\sigma = 0.5$, reduces the extent of wage inequality changes.

[table IV]

7. Discussion and conclusions

In this paper, we have presented a general equilibrium model of trade and innovation to investigate the Adrian Wood's hypothesis of "defensive innovation bias" and its implications on the dynamics of wage inequalities in high wage and low wage economies. Our model incorporated the possibility for endogenous technical change and generated

[21] Comparative Statics on imitation do not change very much the wages dynamic paths but , when imitation rate is low, transition path is shorter and consequently , long term inequalities are lower.

the emergence of “trade induced technical bias” as an optimal response by firms to the problem of differential degree of property rights protection between North and South. The model also allowed us showing that “trade induced technical bias” has generally ambiguous effects on the dynamics of wage inequalities in the two regions. Simple numerical simulations though reveal that it is possible to obtain patterns of increasing wage inequalities in North and South associated with pure “trade induced technical bias”. At this stage several observations are in order.

For most of the dynamic analysis, we made two important assumptions. First we considered only marginal technical bias possibilities. Doing this down plays actually the potential impact of trade induced technical bias on the dynamics of wages and specialization.

Second, we considered that firms were myopic in terms of their decisions to adopt biased technical change. If firms were more forward looking, the effects presented along the transition path would still occur qualitatively though presumably in a weakened way. A simple way to see this is the following. Observe first that the possibility of endogenous technical bias prevents the economy to be immediately in a stationary equilibrium. From our analysis in partial equilibrium (ie. result 2) at a given specialization frontier f between North and South, there is always a positive mass of products for which there is skill bias technical change. This implies that the frontier f cannot stay stationary as the distribution $\alpha_t(.)$ is affected by this technical bias. Therefore there will be skill upgrading of southern exports with the same qualitative implications for wage premia as before. The main difference comes from the fact that firms now anticipate the forward moving path of the specialization frontier. When they decide to adopt skill biased technologies to “bring back” production location in North, forward looking firms foresee that this location will be eventually shifted back to South under the pressure of more competitive wages. This obviously weakens the trade induced technological skill bias effects emphasized here.

In the analysis, northern innovating firms decide whether to produce in North or to delocalize in South where the imitation rate is exogenous and uniform across sectors. The framework can be extended easily to the case with no delocalization and endogenous imitation efforts by South (Thoenig 1999). In such a case, the rate of imitation by southern firms is not anymore uniform acros sectors but depends actually negatively on the sectorial skill intensity. Because of this, northern firms have an additional incentive to develop skill biased innovations as by doing so they reduce the rate of imitation by South on their good. For that reason, trade induced technical bias effects will be even stronger than in the present framework.

Another element, which again downplays the trade induced technical bias effects is the fact that we assumed the rate of creative destruction in North to be uniform across sectors. Sachs and Shatz (1994) argue, on the other hand, that technical progress is more intensive in low skill intensive sectors. Following such an observation, we could then expect the rate of creative destruction in North to be higher close to the specialization frontier with South than for more skill intensive goods.This by itself, would magnify our results (see table III). Larger innovation rates close to the North-South interface increase the opportunity for northern sectors with low skills to bias the direction of technical change towards skilled labor. This in turn strengthens the impact of trade induced technical bias and the associated general equilibrium effects on wages

Finally, our illustrative simulations suggest that the nature of the transition path and the magnitude of the results on wage premia is quite sensitive to the value of various parameters (the elasticity of substitution between skilled and unskilled labor, the rate of creative destruction and the size of the technological increment). This suggests that, while Adrian Wood's intuition on trade induced technical bias can be put into consistent theoretical terms, its implications on the pattern of wage inequalities in industrialized countries certainly merits more serious empirical investigation before being completely dismissed or accepted.

APPENDIX

A. Computation of the instantaneous Equilibrium in the open Economy

A good can be produced by a monopoly or a duopoly when imitated. Hereafter, we detail the different cases.

<u>case 1:</u> Imitated goods (only in South). This case concerns a share $(I/\theta + I)$ of goods produced in South.

When a good of technology (u, s) is imitated, sector is under a duopolistic competition à la Bertrand where both competitors use the same technology (u, s). The price is then equal to the unit cost and factor demands in skilled and unskilled labor are given by:

$$d^h_{imit.}(t) = \frac{1}{\left[w^s_t \cdot \left(\frac{q^s_t}{w^s_t}\right)^{+\sigma}\left(\frac{s(t)}{u(t)}\right)^{-1+\sigma} + q^s_t\right]} \text{ and } d^U_{imit.}(t) = \frac{1}{\left[w^s_t + q^s_t \cdot \left(\frac{q^s_t}{w^s_t}\right)^{-\sigma}\left(\frac{s(t)}{u(t)}\right)^{1-\sigma}\right]}$$

<u>case 2:</u> Non imitated goods produced after a choice of neutral progress (South and North). This case concerns a share $(\theta/\theta + I)$ of goods produced in South and almost all goods produced in North.Each of these goods is produced by a monopoly with technology (u, s) whereas its competitor uses a technology $(\delta^{-1}u, \delta^{-1}s)$. This case is similar to the case in autarky and we get easily demands of skilled and unskilled labor (with $j \in \{North, South\}$):

$$d^h(t) = \frac{\delta}{\left[w^j_t \cdot \left(\frac{q^j_t}{w^j_t}\right)^{+\sigma}\left(\frac{s(t)}{u(t)}\right)^{-1+\sigma} + q^j_t\right]}; \; d^U(t) = \frac{\delta}{\left[w^j_t + q^j_t \cdot \left(\frac{q^j_t}{w^j_t}\right)^{-\sigma}\left(\frac{s(t)}{u(t)}\right)^{1-\sigma}\right]}$$

<u>case 3:</u> Non imitated goods produced after a choice of biased technical progress (South and North). This case concerns a share M_t of the continnum of goods. The dynamics of M_t are given by: $\dot{M}_t = \theta \int_{f^*_t}^{f_t} \alpha_t(x)dx - \theta M_t$ where the first term corresponds to the number of goods which are innovated whith a bias and the second term corresponds to the number of goods of M_t which are innovated. From this law of motion, we obtain that , at each date t, $M_t \leq \int_{f^*_t}^{f_t} \alpha_t(x)dx$: thus M_t is inferior to the number of goods on the interface $[\delta f_t, f_t]$. But, from assumption 1 (*i.e* δ close to 1), we know that the size of interface is quite "small" compared to the total amount of goods. Consequently M_t represents only a small share of goods.

In case 3, the monopolistic firm produces with a technology (u, s) whereas its competitor uses a technology $(\delta^{-1}u, s)$: hence, this case is an intermediate case between case 1 and case 2 (and, here, both competitors may be located in different countries). In order to limit the analytical complexity of general equilibrium equations , we use assumption 1 which says that δ is close to 1, to argue that the competitor's technology is quite close (as a first approximation) to $(\delta^{-1}u, \delta^{-1}s)$: consequently, case 3 can be reasonably approximated by case 2 and factor demands are thus similar. This approximation concerns in fact a very small amount of goods (because M_t is very low) that is why we are sure, when aggregating on the continuum of goods, that this approximation does not alter the aggregated factor demands and general equilibrium equations.

Aggregated factor demands are easily derived from the good factor demands by summing up over the continuum of goods.

B. Some results on relative demands

The relative skilled-unskilled labor demand functions in South and North are equal to

$$D^s_{H/L}(q/w) = \left(\frac{q}{w}\right)^{-\sigma} \int_0^f \frac{\alpha_t(x)dx}{[x^{-(1-\sigma)} + (q/w)^{1-\sigma}]} / \int_0^f \frac{\alpha_t(x)dx}{[1 + x^{1-\sigma}.(q/w)^{1-\sigma}]} \quad \text{(B.1)}$$

$$D^n_{H/L}(q/w) = \left(\frac{q}{w}\right)^{-\sigma} \int_f^{+\infty} \frac{\alpha_t(x)dx}{[x^{-(1-\sigma)} + (q/w)^{1-\sigma}]} / \int_f^{+\infty} \frac{\alpha_t(x)dx}{[1 + x^{1-\sigma}.(q/w)^{1-\sigma}]} \quad \text{(B.2)}$$

Using Lemma 1 of Feenstra-Hanson (1995) and a basic variables change in (B.1-B.2), we can show that $\partial D^j_{H/L}/\partial(q/w) < 0$ for $j \in \{n, s\}$: clearly, an increase of skilled labor relative wage decreases the relative demand. We also have the other following results: $D^s_{H/L}(0) = D^n_{H/L}(0) = +\infty$ and $D^s_{H/L}(+\infty) = D^n_{H/L}(+\infty) = 0$. These two conditions, and the monotonicity of relative demands allow us concluding that a general equilibrium exists and is unique in autarky. Noting $\varepsilon_t^{1j} = [(q/w)/D^j_{H/L}][\partial D^j_{H/L}/\partial(q/w)]$ the price elasticity of relative demand, we can show, using Feenstra-Hanson (1995), that $\varepsilon_t^{1j} = -\sigma + (1-\sigma)\varepsilon_{fh}$ where ε_{fh} is the (negative) price elasticity of relative demand in Feenstra-Hanson. In their model, sectoral production functions are Leontieff, such that $-1 < \varepsilon_{fh} < 0$. This last result allows to show that:

$$\frac{\partial \left|\varepsilon_t^{1j}\right|}{\partial \sigma} > 0$$

The price elasticity of the relative demand increases , ceteris paribus, when the elasticity of substitution between skilled and unskilled labor σ increases.

C. Dynamic General Equilibrium.

After basic rearrangements of equations (5.1-5.2-5.3), the international equilibrium with trade is characterized by the following set of equations:

$$\begin{cases} H^s/L^s = D^s_{H/L} & (e_1) \\ H^n/L^n = D^n_{H/L} & (e_2) \\ L^s = D^s_L & (e_3) \\ L^n = D^n_L & (e_4) \\ (w_t^n)^{1-\sigma}(1 + (q_t^n/w_t^n)^{1-\sigma} f_t^{1-\sigma}) = (w_t^s)^{1-\sigma}(1 + (q_t^s/w_t^s)^{1-\sigma} f_t^{1-\sigma}) & (e_5) \end{cases} \quad \text{(C.1)}$$

where demands have the following expressions:

$$D^s_{H/L} = \left(\frac{q^s_t}{w^s_t}\right)^{-\sigma} \int_0^{f_t} \frac{\alpha_t(x)dx}{[x^{-(1-\sigma)} + (q^s_t/w^s_t)^{1-\sigma}]} / \int_0^{f_t} \frac{\alpha_t(x)dx}{[1 + x^{1-\sigma}.(q^s_t/w^s_t)^{1-\sigma}]}$$

$$D^n_{H/L} = \left(\frac{q^n_t}{w^n_t}\right)^{-\sigma} \int_{f_t}^{+\infty} \frac{\alpha_t(x)dx}{[x^{-(1-\sigma)} + (q^n_t/w^n_t)^{1-\sigma}]} / \int_{f_t}^{+\infty} \frac{\alpha_t(x)dx}{[1 + x^{1-\sigma}.(q^n_t/w^n_t)^{1-\sigma}]}$$

$$D^s_L = \frac{\beta}{w^s_t}.\int_0^{f_t} \frac{\alpha_t(x)dx}{[1 + x^{1-\sigma}.(q^s_t/w^s_t)^{1-\sigma}]}$$

$$D^n_L = \frac{\delta}{w^n_t}\int_{f_t}^{+\infty} \frac{\alpha_t(x)dx}{[1 + x^{1-\sigma}.(q^n_t/w^n_t)^{1-\sigma}]}$$

C.1. Differenciation of Equilibrium

By differentiating the system (C.1), we get:

$$\begin{bmatrix} \beta_1 \\ \beta_2 \\ \beta_3 \\ \beta_4 \\ 0 \end{bmatrix} dt = \begin{bmatrix} a_{11} & -a_{12} & 0 & 0 & 0 \\ a_{21} & 0 & -a_{23} & 0 & 0 \\ a_{31} & -a_{32} & 0 & -a_{34} & 0 \\ a_{41} & 0 & a_{43} & 0 & a_{45} \\ a_{51} & a_{52} & -a_{53} & a_{54} & -a_{55} \end{bmatrix} \begin{bmatrix} df \\ d(\frac{q^s}{w^s}) \\ d(\frac{q^n}{w^n}) \\ dw^s \\ dw^n \end{bmatrix} \quad \text{(C.2)}$$

Lemma 1 $\forall(i,j)$, $a_{ij} > 0$ and $\beta_i > 0$.

After some computations, we can prove that the coefficient $a_{11} = \frac{\partial D^s_{H/L}}{\partial f}$ has the sign of

$$Sg(a_{11}) = Sg[\frac{\frac{\alpha_t(f)}{[f^{-(1-\sigma)}+(q^s_t/w^s_t)^{1-\sigma}]}}{\frac{\alpha_t(f)}{[1+f^{1-\sigma}.(q^s_t/w^s_t)^{1-\sigma}]}} - \frac{\int_0^f \frac{\alpha(x)dx}{[x^{-(1-\sigma)}+(q^s_t/w^s_t)^{1-\sigma}]}}{\int_0^{f_t} \frac{\alpha(x)dx}{[1+x^{1-\sigma}.(q^s_t/w^s_t)^{1-\sigma}]}}]$$

The coefficient a_{11} is then positive: a move toward more skill intensive areas of the frontier f_t indeed increases the South relative demand.

Now we compute the partial derivative of South relative demand according to time: this corresponds to the consequences of the spread of $\alpha_t(.)$ over time on the relative demands. In order to adress this point, we use the law of motion given by system (5.4): $-\beta_1 = \frac{\partial D^s_{H/L}}{\partial t}$. and we can prove:

$$Sg(-\beta_1) = Sg[\frac{\int_0^{f_t} \frac{\alpha_t(x)dx}{[x^{-(1-\sigma)}+(q^s_t/w^s_t)^{1-\sigma}]}}{\int_0^{f_t} \frac{\alpha_t(x)dx}{[1+x^{1-\sigma}.(q^s_t/w^s_t)^{1-\sigma}]}} - \frac{\int_{f^*_t}^{f_t} \frac{\alpha_t(x)dx}{[x^{-(1-\sigma)}+(q^s_t/w^s_t)^{1-\sigma}]}}{\int_{f^*_t}^{f_t} \frac{\alpha_t(x)dx}{[1+x^{1-\sigma}.(q^s_t/w^s_t)^{1-\sigma}]}}]$$

which is negative. The reason is that technical bias concerns the most skill intensive goods produced in South: consequently, the direct effect of $\alpha(.)$ dynamics is to lower the South relative demand.

Now we compute the symmetric coefficient for North. Coefficient signs can be explained by similar arguments as for South. We have $a_{21} = \frac{\partial D^N_{H/L}}{\partial f}$ and $-\beta_2 = \frac{\partial D^N_{H/L}}{\partial t}$ and we can prove, using (5.4) and assumption 1:

$$Sg(a_{21)} = Sg[\frac{\frac{\alpha_t(f)}{[1+f_t^{1-\sigma}.(q_t^n/w_t^n)^{1-\sigma}}}{\frac{\alpha_t(f)}{[f^{-(1-\sigma)}+(q_t^n/w_t^n)^{1-\sigma}]}} - \frac{\int_{f_t}^{+\infty}\frac{\alpha_t(x)dx}{[1+x^{1-\sigma}.(q_t^n/w_t^n)^{1-\sigma}]}}{\int_{f_t}^{+\infty}\frac{\alpha_t(x)dx}{[x^{-(1-\sigma)}+(q_t^n/w_t^n)^{1-\sigma}]}} \textit{ which is positive.}$$

After a variable change $y = \delta x$ we get:

$$Sg(-\beta_2) = Sg[\delta^{-1}.\frac{\int_{f_t^*}^{f_t}\frac{\alpha_t(y)dy}{[y^{-(1-\sigma)}+(q_t^n/\delta w_t^n)^{1-\sigma}]}}{\int_{f_t^*}^{f_t}\frac{\alpha_t(y)dy}{[1+y^{1-\sigma}.(q_t^n/\delta w_t^n)^{1-\sigma}]}} - \frac{\int_{f_t}^{+\infty}\frac{\alpha_t(x)dx}{[x^{-(1-\sigma)}+(q_t^n/w_t^n)^{1-\sigma}]}}{\int_{f_t}^{+\infty}\frac{\alpha_t(x)dx}{[1+x^{1-\sigma}.(q_t^n/w_t^n)^{1-\sigma}]}}]$$

which, by assumption 1 is negative.

Finally, the coefficient a_{51} is obtained through the differentiation of the "frontier condition":

$$a_{51} = [(q^s)^{1-\sigma} - (q^n)^{1-\sigma}].(1-\sigma).f^{-\sigma} > 0$$

The sign of the other coefficients are straightforward to obtain by simple differentiation. ■

Lemma 2 The frontier f_t is increasing through time

This result is obtained by solving system (C.2) for df, and after computations, we get the following relation:

$$df = \frac{c_4 + c_5\Sigma_2 + c_6\Sigma_1}{c_1 + c_2\Sigma_2 + c_3\Sigma_1}dt \tag{C.3}$$

where: $c_1 = a_{51} + a_{54}\frac{a_{31}}{a_{34}} + a_{55}\frac{a_{41}}{a_{45}}$; $c_2 = \frac{a_{21}}{a_{23}a_{45}}$; $c_3 = \frac{a_{11}}{a_{12}a_{34}}$; $c_4 = \frac{a_{54}}{a_{34}}\beta_3 + \frac{a_{55}}{a_{45}}\beta_4$, $c_5 = \frac{\beta_2}{a_{45}a_{23}}$ and $c_6 = \frac{\beta_1}{a_{21}a_{34}}$.

From lemma 1, we know that $c_i > 0$ for all i. But expressions of Σ_1 and Σ_2 are more complicated:

$$\begin{aligned}\Sigma_1 &= (a_{52}a_{34} - a_{32}a_{54}) \\ &= \delta(1-\sigma)(w^s)^{-(1+\sigma)}f^{1-\sigma}\left(\frac{q^s}{w^s}\right)^{-\sigma} \\ &\times\left[\int_0^f \frac{\alpha_t(x)dx}{[1+(\frac{q^s}{w^s}x)^{1-\sigma}]} - \int_0^f \frac{(\frac{x}{f})^{1-\sigma}.(1-\sigma)\alpha_t(x)dx}{[1+(\frac{q^s}{w^s}x)^{1-\sigma}]^2}.(1+(\frac{q^s}{w^s}f)^{1-\sigma}\right]\end{aligned}$$

So we obtain that: $Sg(\Sigma_1) = Sg([\frac{1}{x^{1-\sigma}} + (\frac{q^s}{w^s})^{1-\sigma}] - (1-\sigma)[\frac{1}{f^{1-\sigma}} + (\frac{q^s}{w^s})^{1-\sigma})])$ which is positive for all $x < f$.

$$
\begin{aligned}
\Sigma_2 &= (a_{43}a_{55} - a_{45}a_{53}) \\
&= \delta(1-\sigma)(w^n)^{-(1+\sigma)} f^{1-\sigma} \left(\frac{q^n}{w^n}\right)^{-\sigma} \times \\
&\quad \times \underbrace{\left[\int_f^{\infty} \frac{(\frac{x}{f})^{1-\sigma}.(1-\sigma)\alpha_t(x)dx}{[1+(\frac{q^n}{w^n}x)^{1-\sigma}]^2}.(1+(\frac{q^n}{w^n}f)^{1-\sigma}) - \int_f^{\infty} \frac{\alpha_t(x)dx}{[1+(\frac{q^n}{w^n}x)^{1-\sigma}]}\right]}_{\Phi(\sigma)}
\end{aligned}
$$

The coefficient $\Phi(\sigma)$, with $0 < \sigma < 1$, has an ambiguous sign; for σ close to 0, $\phi(\sigma)$ is positive, which means that $\Sigma_2 > 0$. For σ close to 1, $(1-\sigma)$ is close to 0 and it is easy to show that Σ_2 is negative but is very small compared to other the terms in equation (C.3). For intermediate values of σ, we conjecture that potential negative effect of Σ_2 do not dominate the positive contribution of other terms in equation (C.3) (and this conjecture will always be true in our simulations). ■

Lemma 3 The system converges towards a steady state with no trade induced technical bias.

The steady state is reached as soon as there is no spread of $\alpha_t(.)$. This arises if $\alpha_t(x) = 0$ on $[f_t^*, f_t]$, or if firms do not choose some technical bias ($f_t^* = f_t$). There is induced technical bias as long as condition (4.5) is satisfied for f_t, which gives, after some computations:

$$
\left(\frac{B-\delta^{1-\sigma}}{1-B}\right).\frac{w_t^n}{q_t^n} \geq f_t \tag{C.4}
$$

with $B = \frac{I+\delta(r+\theta)}{I+r+\theta} < 1$. Moreover, on the transition path, (q_t^n/w_t^n) is bounded from below (cf.lemma 4) and $\min_t (q_t^n/w_t^n) = A$. Setting $f_{\max} = \left(\frac{B-\delta^{1-\sigma}}{1-B}\right).A^{-1}$, we know that, as long as $f_t \leq f_{\max}$, it is profitable to bias the direction of technical change for goods in the neighborhood of f_t. As the sequence f_t is increasing and bounded from above, it converges towards a limit f_∞. At the limit, the steady state is reached $f_t = f_\infty$ and one of the following situations necessarly emerges: either condition (4.5) is not satisfied or there are no more technics on which to apply an induced technical bias (ie. $\alpha_\infty(x) = 0$ on $[f_\infty^*, f_\infty]$). ■

C.2. Proof of Relation (5.5)

From rank 1 and rank 2 of system (C.2), we get $\beta_1 = a_{11}df - a_{12}d(q^s/w^s)$ and $\beta_2 = a_{21}df - a_{23}d(q^n/w^n)$ which can be rewritten:

$$
\frac{d(\frac{q^j}{w^j})}{dt} = \frac{-\partial D^j_{H/L}/\partial t}{\partial D^j_{H/L}/\partial(q^j/w^j)} + \frac{-\partial D^j_{H/L}/\partial f}{\partial D^j_{H/L}/\partial(q^j/w^j)}.\dot{f} \text{ with } j \in \{n, s\} \tag{C.5}
$$

After some basic computations this relation is equivalent to $\Gamma_t^j = \frac{1}{-\varepsilon_t^{1j}}.[\varepsilon_t^{2j} + \varepsilon_t^{3j}.\frac{\dot{f}_t}{f_t}]$ where:

$$\begin{cases} \varepsilon_t^{1j} = \frac{q^j/w^j}{D^j_{H/L}}.\frac{\partial D^j_{H/L}}{\partial(q^j/w^j)} < 0. \text{ is the price elasticity of relative demand} \\ \varepsilon_t^{2j} = \frac{1}{D^j_{H/L}}.\frac{\partial D^j_{H/L}}{\partial t} < 0. \text{ is the ``sensitivity'' of the relative demand to the spread of } \alpha_t(.) \\ \varepsilon_t^{1j} = \frac{f}{D^j_{H/L}}.\frac{\partial D^j_{H/L}}{\partial f} > 0. \text{ is the elasticity of the relative demand to a move of the frontier } f \end{cases} \tag{C.6}$$

C.3. Existence and uniqueness of general equilibrium

We demonstrate, in this section, that at each date t, the instantaneous general equilibrium exists and is unique. We omit the time index. Let f be given. We give hereafter a demonstration based on property of relative separability of general equilibrium system (C.1). Equations (e_1) and (e_2) of general equilibrium system (C.1) can be rewritten as follow: $H^s/L^s = D^s_f(q/w)$ and $H^n/L^n = D^n_f(q/w)$. From appendix (B), we know that these two implicit equations have unique positive solutions $(\frac{q^s}{w^s}(f), \frac{q^n}{w^n}(f))$. Plunging f and the associated values $\frac{q^s}{w^s}(f)$ and $\frac{q^n}{w^n}(f)$ in (e_3) and (e_4) we immediatly get $w^s(f)$ and $w^n(f)$. Then, plunging $(f, \frac{q^s}{w^s}(f), \frac{q^n}{w^n}(f), w^s(f), w^n(f))$ in (e_5) we can define $LHS(f)$ and $RHS(f)$ as respectively the left hand side and the right hand side of (e_5). Noting $\Delta(f) = LHS(f) - RHS(f)$, tedious but straightfroward computations give:

$$\Delta(f) = \frac{\sigma}{L^s}\int_0^f \alpha(x)\frac{1+(q^s/w^s).f}{1+(q^s/w^s).x} - \frac{\delta}{L^n}\int_f^0 \alpha(x)\frac{1+(q^n/w^n).f}{1+(q^n/w^n).x} \tag{C.7}$$

The equilibrium corresponds to the set $\{f^* \in \mathbb{R}^+ \text{ such that } \Delta(f^*) = 0\}$. We can differentiate $\Delta(.)$:

$$\Delta'(f) = (q^s - q^n) + \frac{a_{54}.a_{31}}{a_{34}} + \frac{a_{11}}{a_{12}.a_{34}}.\Sigma_2 + \frac{a_{55}.a_{41}}{a_{45}} + \frac{a_{21}}{a_{23}.a_{45}}.\Sigma_1$$

Using the appendix (C.1), we know that $\Delta'(f) > 0$. Furthermore, it is easy to show that $\Delta(0) < 0$ and $\Delta(+\infty) > 0$. This last property and the monotonicity of $\Delta(.)$ implies that the set $\{f^* \in \mathbb{R}^+ \text{ such that } \Delta(f^*) = 0\}$ is reduced to one and only one point f.

D. Inferior bound of q^n/w^n and q^s/w^s

To make the point, we have to keep in mind the two following facts. First, the spread of $\alpha(.)$ resulting from the induced technical change always decreases wage inequalities in both regions (coefficient β_1 and β_2 in appendix C.1). Second, when f_t increases, wage inequalities increase in both regions (coefficient a_{11} and a_{21}). The question is what is the lowest value northern wage inequalities can take along the transition path? This value corresponds to a particular shape of $\alpha_t(.)$. As we have proved, f_t is increasing through time. Thus, it is clear that the lowest value of northern wage premium corresponds to a case where $f_t = f_0$ and the shape of α_t corresponds to a spread of α_0 where all goods on $[\delta f_0, f_0]$ are moved on $[f_0, \delta^{-1} f_0]$. Hence, this setup gives the lower bound of q^n/w^n on transition path. Similarly we get the inferior bound of q^s/w^s.

[figure VIII]

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Tables

Table I : value of parameters

H^n/L^n	H^s/L^s	North relative size	σ	θ	δ	rate of growth	I
1	0.1	1/6	0.5	0.25	0.9	2.6%	1

Table II : comparative statics of elasticity of substitution σ

elasticity	$\sigma = 0.4$	$\boldsymbol{\sigma = 0.5}$	$\sigma = 0.6$	$\sigma = 0.7$
Premium in North	3.7%	**3.0%**	2.8%	2.2%
Premium in South	5.5%	**2.5%**	1.2%	0.6%

Table III : comparative statics of growth rate

rate of growth	1%	2%	**2.6**%	4%
Premium in North	1.0%	2.8%	**3.0%**	6.0%
Premium in South	1.4%	2.3%	**2.5%**	3.5%

Table IV : comparative statics of technical increment

Increment	$\delta = 0.7$	$\delta = 0.8$	$\boldsymbol{\delta = 0.9}$
Premium in North	8.7%	7.3%	**3.0%**
Premium in South	12%	11%	**2.5%**