A Theory of Defensive Skill-Biased Innovation and Globalization

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This paper considers a dynamic model of innovations in which firms can endogenously bias the direction of technological change. Both in a North–North and North–South context, we show that, when globalization triggers an increased threat of technological leapfrogging or imitation, firms tend to respond to that threat by biasing the direction of their innovations towards skilled-labor-intensive technologies. We show that this process of defensive skill-biased innovations generates an increase in wage inequalities in both regions. We then discuss suggestive empirical evidence of the existence of defensive skill-biased technical change. (*JEL* F12, O33, J31)

The sustainability of technological competitiveness, either at the firm or the country level, has long been a prominent issue in the theory of development and the business literature. This paper specifically investigates a mechanism of defensive skill-biased innovation and its relationship to openness. In a nutshell, to reduce informational leakages and spillovers which can be freely acquired by outside competitors, and thereby lessen the threat of imitation and technological leapfrogging, firms have incentives to increase the share of tacit knowledge and non-codified know-how embedded in their production process. But they do so at the cost of a larger share of skilled labor in their workforce. In this context, openness, by intensifying international technological competition, triggers a race to imitation and innovation. As a consequence, it may induce firms to develop innovations of a new kind, less imitable and *endogenously* more skill intensive.

This theory links trade and technical change in an interesting fashion. In particular, it brings about new insights into "the trade versus technology" debate about the causes of the recent widening of the wage gap between low- and highly educated workers in industrialized countries.[1] While part of the answer has to do with a slowdown of the supply of highly educated workers in the 1980's, the most popular explanation points to a demand shift toward skilled workers. Two main reasons have been put forward to explain such a shift. The first is growing international trade integration between advanced economies and low-wage countries which, according to standard Heckscher-Ohlin theory, has shifted labor demand away from unskilled workers in high-wage economies. The second is technological change and informational technologies which would *by nature* be biased towards high-education workers. Our theory reconciles the two explanations by arguing that the latter may be a direct consequence of the former.

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[1] In the United States, the wage gap between college education and high school education increased by about 20 percent in the 1980's (George J. Borjas and Valerie A. Ramey, 1994). 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).

Again, the starting point of our analysis is the possibility for firms to change and influence the rate of diffusion of specific knowledge embodied in their production process. More precisely, we argue that firms may render their products or technologies more immune to imitation at the cost of reinforcing the skill intensiveness of their production process. This phenomenon has been highlighted in the theory of economic development on catching-up[2] and is nowadays widely debated among firm practitioners and in the business literature.[3] Scholars in corporate strategy for instance specifically address the issue of finding business strategies to sustain some competitive advantage once it has been created. In particular, emphasis is put on the fact that strategic decisions in companies are (and should be) shaped by the concern of reducing the imitation of the firm's core capacities (Michael E. Porter, 1985).

The economic literature has also long recognized the highly intangible nature of specific knowledge embodied in a product or a technology and the fact that as such, it is difficult to protect, even by legal means (Kenneth J. Arrow, 1962). This partial nonexcludability of information generates so-called technological spillovers and opportunities for firms to "acquire information created by others without paying for that information in a market transaction" (Gene M. Grosman and Elhanan Helpman, 1991, p. 16). However, technological spillovers depend crucially on the degree of tacitness of the specific knowledge embodied in production. Indeed, for any innovation, there is a share of specific information which is codified in the form of (potentially patentable) blueprints while the rest remains tacit and informal. Even though that second part cannot be legally protected, it has the advantage of being more difficult to imitate and to transfer. Conversely, well codified knowledge and routinized procedures are much easier to learn and to be used for imitation or further innovation.

Given that technological spillovers promote imitation and innovation and that they are limited by knowledge tacitness,[4] firms may then have incentives to reinforce the tacitness and nonreplication of their technologies and reduce the diffusion of technical information in the economy. This can be done by complexifying products or work organizational methods, and by relying more on noncodified workers' know-how.[5] This last solution, in turn, requires relatively more skilled workers:[6] (a) either because less codified technologies require more learning efforts to be handled (Richard R. Nelson and Sidney G. Winter, 1977), or (b) because skilled workers have the right cognitive capacities to deal with complex tasks (Alice H. Amsden, 1986) and nonroutine procedures (David Autor et al., 2001).

This paper provides a simple framework incorporating these aspects. We construct a dynamic general-equilibrium quality ladder model in which the direction of technical progress

[2] Raymond Vernon (1966) pinpoints the link between transferability (and thus imitation threat) and the skill content of production. In his celebrated product cycle model, "technologies are not transferred (or transferable) to LDCs until they have matured to the point where processes have been invented that enable the use of unskilled labor in mass production" (Robert E. Evenson and Larry E. Westphal, 1995, p. 2261).

[3] Robert B. Reich (1991, Ch. 5, p. 74) illustrates this point vividly when he discusses the shift observed during the 1980's from Tayloristic, high-volume business to high-value business:

> These [high-value] businesses are profitable both because customers are willing to pay a premium for goods or services that exactly meet their needs and because these businesses cannot easily be duplicated by high-volume competitors around the world. While competition among high-volume producers continues to compress profits on everything that is uniform routine and standard—that is, on anything that can be made, reproduced, or extracted in volume almost anywhere on the globe—successful businesses in advanced nations are moving to a higher ground based on specially tailored products and services. The new barrier to entry is not volume or price; it is skill in finding the right fit between particular technologies and particular markets. Core corporations no longer focus on products as such; their business strategies increasingly center upon specialized knowledge.

[4] Quoting Evenson and Westphal (1995, p. 2256), "Owing to the tacitness of technology, substantial investments in acquiring production capability are always required [for LDCs] to master a new technology."

[5] On this subject, see Porter (1985), Kim B. Clark (1988), and Jeffrey R. Williams (1992).

[6] According to Amsden (1983, p. 333), "Skilled production processes, more than most others, remain *tacit* rather than codifiable in blueprints."

(neutral versus skill biased) is endogenous. Following the above discussion, informational externalities are assumed to spread more easily for "simple" or standard goods (i.e., goods produced with "easy-to-learn" less skill-intensive technologies) than for "crafted" goods (i.e., goods produced with "harder-to-learn" skill-intensive technologies). This aspect of knowledge diffusion induces firms to increase the sophistication of their product or technology and make it harder to be leapfrogged.

We use this framework to investigate the consequences of trade integration both between similar regions (North–North trade) and between dissimilar regions (North–South trade). In both cases, integration triggers a process of defensive skill-biased technical change. This, in turn, is accompanied by a rise in skill premium in the two integrating regions and, for some sectors, a rise in skill intensity at the sectoral level. The mechanism delineated here is therefore consistent with three main stylized facts of the trade and wage literature, namely: (1) the dramatic changes observed in industrialized countries' labor markets cannot be explained solely by the increase in North–South trade (i.e., between OECD and LDCs) (Paul R. Krugman, 2000); (2) inequality between skilled and unskilled workers has increased in developing countries as well as in developed economies; (3) the rise in the wage gap between skilled and unskilled workers is associated with a rising skill intensity within many industries.[7] A last noticeable feature of our model is the fact that in the case of North–South trade, defensive skill-biased technical change is accompanied along the transition path by an interesting shift in the pattern of trade and specialization of the South with skill upgrading in production and exports, which is consistent with the recent experience of some newly industrialized countries.

The rest of the paper then briefly discusses some empirical evidence consistent with the existence of defensive skill-biased innovations. After reviewing suggestive industry case studies from the literature, we present new evidence in line with our theory of a defensive skill-biased innovation model using panel data for manufacturing at the firm level. According to our theory, firms more exposed to the *threat* of external competition tend to bias more their innovations toward skilled labor and to increase their share of skilled workers. The empirical analysis is broadly supportive of this implication.

Several recent theoretical papers have explored the relationship between trade, technological change and the skill premium.[8] Our work is directly inspired by Adrian Wood's (1994) informal discussion of "defensive innovation," arguing that technical change could be biased towards skilled labor as an *endogenous* reaction of developed country firms to trade with low-wage countries.[9] However, the work most closely related to our approach is by Daron Acemoglu on directed technical change. Acemoglu (1998) develops a general theory where the skill intensity of the workforce drives the direction of technical change. Relying on this theory, Acemoglu (1999) analyzes how trade integration affects labor markets. He shows that North–South trade may induce skill-biased technical change, an increase in inequality in the North and in the South without any significant changes in tradable good prices. The mechanism highlighted in the present paper is different from, and complementary to, Acemoglu's where North–South trade integration

[7] A fourth empirical fact mentioned in the literature is that the relative price of less skilled-labor-intensive goods has not decreased significantly. However this aspect is less clear-cut and more controversial. In particular, Robert C. Feenstra and Gordon H. Hanson (1999) argue that more complete price data reestablish significant price movements in agreement with standard trade theory (i.e., a continuous decline of relative prices of low-skilled-intensive sectors during the period 1979–1990). All of these four facts conflict with the standard Heckscher-Ohlin view that the increase in the skill premium is caused by increased import competition from low-wage countries.

[8] See in particular James R. Markusen and Anthony J. Venables (1998), Elias Dinopoulos and Paul Sergestrom (1999), Peter J. Neary (2000), Karolina Ekholm and Karen-Helene Midelfart-Knarvik (2001), and Paolo Epifani and Gino Gancia (2002).

[9] Wood's evidence of this phenomenon rests on suggestive case studies and anecdotal evidence. Statistical support for "defensive innovation" is also to an extent suggested by Jeffrey D. Sachs and Howard J. Shatz's (1994) findings of faster total factor productivity growth during the 1980's in low-skill-intensive manufacturing sectors. See also Robert Z. Lawrence and Matthew J. Slaughter (1993) and Edward E. Leamer (1994) for similar observations of higher productivity growth in low-skill rather than in high-skill sectors.

impacts the direction of technical change through a short-run increase in the prices of skill-intensive tradable goods. The mechanism we emphasize is not price driven: Trade openness triggers increased technological predation. This induces domestic firms to bias innovations toward skilled labor in order to reduce the future threat of imitation or leapfrogging. In that sense we are closer to the mechanism of defensive innovation whereas Acemoglu's price-driven mechanism is more related to the induced innovation literature. Furthermore, our framework allows us to deal with North–North trade which is mainly where globalization has taken place recently.

The plan of the paper is the following. Section I presents a simple model of endogenous defensive skill-biased innovation capturing the trade-off between future technological predation and costly skill-biased technologies. After analyzing the equilibrium steady states of this economy, we perform in the following sections some comparative dynamic exercises. Section II looks at trade integration between similar countries. Section III considers North–South integration. Section IV discusses the empirical evidence, and Section V concludes. Proofs are relegated to the Appendix.

I. A Simple Model of Defensive Skill-Biased Innovation

We consider a continuous time model à la Grossman and Helpman (1991) with a continuum of final goods distributed on the interval [0, 1]. There are three types of production factors: skilled labor and unskilled labor used in the production of the final goods, and research-specific labor used for innovation activities. There is a perfect credit market.

A. *Preferences and Technologies*

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

$$x(i) = 1/p(i). \tag{1}$$

We assume that each good i can be produced with two types of constant elasticity of substitution (CES) technologies $k \in \{1, s\}$ with:

$$Y_{kt}(l, h) = A_t \cdot \left[\left(\frac{l}{k} \right)^{(\sigma - 1)/\sigma} + h^{(\sigma - 1)/\sigma} \right]^{\sigma/(\sigma - 1)} \tag{2}$$

using skilled labor h and unskilled labor l. The elasticity of substitution[10] between skilled and unskilled labor is σ with $\sigma > 1$ and A_t is the value, at date t, of a productivity parameter which rises after each innovation. The two technologies therefore differ in their skill intensities as indexed by $k \in \{1, s\}$ with $s > 1$. Letting w and q be the wages of unskilled and skilled labor, the unit cost function of technology $k \in \{1, s\}$ is $C_{kt}(w, q) = \frac{1}{A_t} C_k(w, q)$ where:

$$C_k(w, q) = [(wk)^{1-\sigma} + q^{1-\sigma}]^{1/(1-\sigma)}. \tag{3}$$

We note that $C_s(w, q) > C_1(w, q)$: technology s is always more costly to use than technology 1. In spite of its higher cost, we will show in the following sections that some firms can be induced to use this technology as a result of increased trade integration. Optimal skilled-unskilled labor intensity for technology k is given by:

$$\frac{h}{l}(k) = \left(\frac{q}{w} \right)^{-\sigma} k^{\sigma - 1} \text{ for } k \in \{1, s\}. \tag{4}$$

Hence technology s is more skill intensive than technology 1. We denote α_t the fraction of goods produced with technology 1: α_t therefore summarizes at a given point of time the tech-

[10] There is quite a large variation in the estimates of that "macro" elasticity available from the empirical literature. So far, the consensus seems to be that the mean estimate of this elasticity is larger than 1 (Richard B. Freeman, 1986).

nological structure of the economy. In the sequel, we will see how α_t endogenously evolves due to the technological bias, and its economic consequences.

B. *Technological Change*

There is a research sector composed of a large number of research labs selling their innovations as monopoly patents to firms in the final good sector. For the moment property rights are perfectly enforced and imitation is impossible. Each innovation reduces the costs of production by switching the productivity parameter from A_t to $\delta^{-1}A_t$ with $\delta < 1$. However we depart from a standard vertical innovation model in two ways.

First, in line with the discussion above, we assume that informational spillovers and knowledge externalities depend on the skill intensity of the existing leading technology. Simple unskilled-labor-intensive technologies are more easily copied than complex skill-intensive technologies. Conversely, skill-intensive technologies are more "tacit-knowledge" intensive and, therefore require additional effort to be assimilated directly by outside observers. More precisely, we make the contrasting assumption that technologies of type $k = 1$ are subject to instantaneous informational spillovers whereas technologies of type $k = s$ do not generate any informational spillovers. Moreover, we assume that the next generation technology can be developed by outside competitors only if information about the current generation has circulated in the economy. This rather drastic but simple specification implies that type-1 technologies can be leapfrogged by competitors while type-s technologies cannot.

Our second departure from the standard vertical innovation growth model is to allow for the possibility of endogenous technical bias. Specifically, we consider that once an innovation is made (necessarily with respect to technology $k = 1$), the firm buying the patent can craft its new technology "in house," make it more complex and increase the tacitness of its technical knowledge and, as a consequence, increase the skill intensity from $k = 1$ to $k = s > 1$.

Technical progress is therefore *neutral* when a more efficient technology $k = 1$ replaces an old technology of the same type. On the other hand, technical progress becomes *biased* when a more efficient skill intensive technology $k = s$ is adopted while the old one was $k = 1$. In that case, according to equation (4), the skill intensity after innovation is larger than the one before innovation. As already noted, under our specification technology $k = s$ is always more costly than $k = 1$. Indeed, for the same cost reduction δ, under neutral technical change, production costs are reduced by $[C_1(w, q) - \delta C_1(w, q)]/C_1(w, q) = 1 - \delta$ while the cost reduction under biased technical change from $k = 1$ to $k = s$ is given by $[C_1(w,q) - \delta C_s(w,q)]/C_1(w,q) = 1 - \delta\left(\frac{w^{1-\sigma}s^{1-\sigma} + q^{1-\sigma}}{w^{1-\sigma} + q^{1-\sigma}}\right)^{1/(1-\sigma)} < 1 - \delta$. It follows that neutral technical change is a priori more efficient than biased technical change. As we will see, our set of assumptions allows us to focus on the pure skill-biased technical change effects induced by the threat of future technological competition.[11]

C. *To Bias or Not to Bias?*

Consider now a particular sector i where the incumbent firm produces a good with a technology indexed by $k = 1$. The new monopoly, owning the last innovation's patent, chooses the production technology for good i. Then it practices limit pricing at the unit cost of the closest competitor in the sector. Instantaneous profits on good i depend on the type of technology ($k = 1, s$) used by the new monopoly and its closest competitor (the former monopoly). Two cases can emerge:

- The first case corresponds to a situation where the two firms use the same technology $k = 1$. Under limit pricing, cash flows are given by: $\pi^1 = 1 - \delta$. Although there is instantaneous diffusion of information for technologies of type 1, we assume that intellectual property rights are perfectly protected and that no technology can be imitated.

[11] This aspect, of course, does not deny that in reality, biased technical change can sometimes be more efficient than neutral technical change. Hence, all our results should be viewed as additional to what can happen without *trade-induced* skill-biased technical change.

Monopolistic rents of an incumbent firm can therefore only be destroyed by further innovation on the technology of that firm. It follows that the intertemporal value V_t^1 of a new monopoly on a type-1 technology depends on the rate θ_t at which it can be leapfrogged through the following Bellman equation:

$$rV_t^1 = \dot{V}_t^1 + (1 - \delta) - \theta_t V_t^1.$$

- The second case corresponds to the situation where the new monopoly biases its technology to the skill-intensive technology $k = s$ while the closest rival uses $k = 1$. Instantaneous cash flows are then given by $\pi_t^s = 1 - \delta \frac{C_s(w_t, q_t)}{C_1(w_t, q_t)}$ and, given that technology $k = s$ is not subject to informational spillovers (and therefore cannot be leapfrogged at any time), discounted expected profits V_t^s satisfy the following Bellman equation:

$$rV_t^s = \dot{V}_t^s + \left[1 - \delta \frac{C_s(w_t, q_t)}{C_1(w_t, q_t)}\right].$$

Firms will not opt for defensive skill-biased innovation when $V_t^s < V_t^1$: all new goods are produced with technologies of type $k = 1$ and α_t stays constant. When this condition does not hold, innovating firms choose to craft their technology and to produce with technologies of type $k = s$. Hence α_t, the number of goods produced with technologies $k = 1$ decreases over time as new goods are produced with sophisticated technologies of type $k = s$.

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 from the innovation. We assume that innovation is governed by a Poisson process and that the R&D sector uses a sector-specific factor H_R. R&D firms may target their effort on a particular good, and having an instantaneous probability of discovery θ on one particular targeted good entails research cost $c\theta$ with $c > 0$.

Given that informational spillovers from the leading technology are necessary for successful innovations, and that only technologies of type $k = 1$ can generate these spillovers, R&D labs will target sectors currently using technology $k = 1$ which have been subject to information dissemination. By symmetry, the rate of creative destruction θ will be the same for all these sectors and free entry in the R&D sector ensures that:

$$\operatorname*{Max}_{\theta}\{\theta \operatorname{Max}\{V_t^1, V_t^s\} - w_R c\theta\} = 0$$

where w_R is the wage rate of researchers. The R&D resource constraint is given by:

$$\alpha_t c\theta_t = H_R. \tag{5}$$

The dynamics of α is then:

$$\dot{\alpha}_t = -\upsilon\theta_t\alpha_t \tag{6}$$

with

$$\begin{cases} \upsilon = 0 & \text{when } V_t^1 > V_t^s \\ \quad = 1 & \text{when } V_t^1 < V_t^s \\ \quad \in [0, 1] & \text{when } V_t^1 = V_t^s \end{cases}$$

reflecting the fact that defensive skill-biased technical change occurs whenever $V_t^1 \leq V_t^s$.

D. *Labor Markets and Equilibrium Wage Premium*

Let L (resp. H) denote the endowment of unskilled (resp. skilled) labor, paid at wage w (resp. q). The aggregate demands for unskilled and skilled labor are of the form $D_L(w, q, \alpha)$ and $D_H(w, q, \alpha)$ and the labor market clearing conditions at each point in time t are given by equality between labor demands and labor endowments. It is shown in the Appendix that the equilibrium wage premium $z = q/w$ is easily obtained from the equality between the relative demand for skilled workers and the skilled-labor/unskilled-labor ratio in the economy:

$$\frac{D_H}{D_L}(\underset{(-)}{z}, \underset{(-)}{\alpha}) = \frac{H}{L} \tag{7}$$

where $\frac{D_H}{D_L}(z, \alpha)$ can be shown to depend negatively on z and α. From this relationship, the wage premium z is a decreasing function of α, the share of goods on the technology 1, and is denoted by $z(\alpha)$. It also follows that:

$$\frac{C_s(w, q)}{C_1(w, q)} = \left[\frac{s^{1-\sigma} + z(\alpha)^{1-\sigma}}{1 + z(\alpha)^{1-\sigma}}\right]^{1/(1-\sigma)} = \underset{(-)}{\Psi(\alpha)}$$

which is a decreasing function of α. Intuitively, the larger the fraction α of unskilled-labor-intensive technologies, the smaller the relative demand for skilled labor in the economy, leading to a smaller equilibrium wage premium $z(\alpha)$. This in turn implies that skilled-labor-intensive technologies are relatively cheaper to use than unskilled-labor-intensive technologies.

E. *Steady-State Equilibria*

The analysis of the steady states of this economy is quite straightforward.[12] In a steady state α, θ, w, q, V^1, and V^s are constant. Therefore $V^1 = (1 - \delta)/(r + \theta)$, and $V^s = [1 - \delta\Psi(\alpha)]/r$. As α is constant in the steady state, there should be no skill bias and $V^s \leq V^1$ holds. This "no bias" condition is given by:

$$(8) \qquad 1 - \delta\Psi(\alpha) \leq \frac{1 - \delta}{1 + \theta/r}.$$

One may represent in a straightforward way the structure of steady-state equilibria in the plane (θ, α). In Figure 1, the "no bias" condition (8), stated as an equality, defines a negative relationship $\Gamma\Gamma$ between α and θ at the steady state.[13] The region below (resp. above) $\Gamma\Gamma$ describes the set of points (θ, α) compatible (resp. not compatible) with the absence of skill bias. The research resource constraint (5) describes a curve STR with a negative slope. A steady-state equilibrium (θ^*, α^*) is then a point below the no bias frontier $\Gamma\Gamma$ and located on STR. From equation (7), we obtain the equilibrium wage premium $z^* = z(\alpha^*)$.

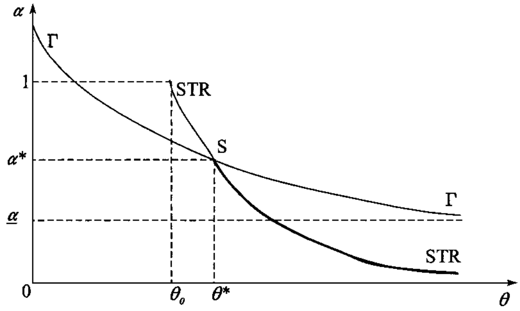

FIGURE 1. STEADY-STATE EQUILIBRIA IN TECHNOLOGIES AND INNOVATION

Various situations are a priori possible.[14] In Figure 1 we restrict ourselves to the most interesting case where $\alpha = 1$ cannot be a steady state (when $\alpha = 1$, firms have an incentive to undertake defensive skill-biased innovations) and an interior steady state with $\alpha > 0$, still exists.[15] All points on the STR curve and below the $\Gamma\Gamma$ locus are indeed steady states in the sense that if the economy starts from such a point, it remains there forever. On the other hand, no point on the STR curve and above $\Gamma\Gamma$ can be a steady state: For such points, the "no bias" condition is violated.

We are now ready to run various comparative static experiments and analyze their impact on defensive skill-biased innovations and the dynamics of wage inequality.

[12] Though in this simple model, there are only cost-reducing innovations on technologies of type 1, one may ensure the existence of interior steady states with a constant fraction of technologies of type s because of Cobb-Douglas preferences on the demand side.

[13] Intuitively, a higher rate of creative destruction θ increases firms' incentives to sophisticate their technologies and make them more skill intensive. To prevent that from happening, the relative cost of skilled-labor-intensive technologies should increase. This is equivalent to an increase in the equilibrium wage gap $z(\alpha)$, which in turn is obtained by a lower value of α.

[14] When $\Gamma\Gamma$ is always above STR for all relevant values of $\alpha \in [0, 1]$ we obtain an uninteresting case where all initial situations with $\alpha_0 \in [0, 1]$ are steady states satisfying the no-skill-bias condition, and there is no defensive skill-biased innovation. When, on the other hand, $\Gamma\Gamma$ is always below STR, then no point with $\alpha > 0$ can be a steady state, and in the long run technologies are all skilled-labor-intensive.

[15] Figure 1 assumes for convenience that $\Gamma\Gamma$ and STR intersect only once at (θ_s, α_s). Again, this is ensured when H_R is large enough. The case with multiple intersections could be discussed in the same way with appropriate modifications. Formally, a sufficient condition for a unique intersection is: $\frac{1 - \delta\Psi(1)}{r} > \frac{1 - \delta}{r + H_R/c}$ and H_R large enough.

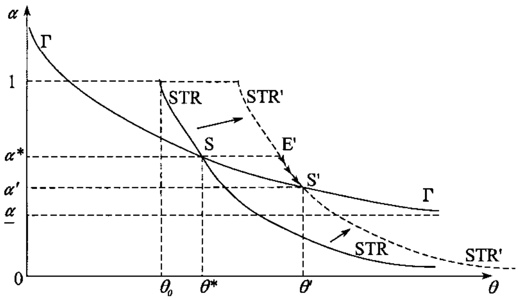

FIGURE 2. NORTH–NORTH TRADE INTEGRATION AND INDUCED SKILL-BIASED TECHNICAL CHANGE

II. North–North Trade Integration

Let us start with trade integration in a North–North context. Consider n_c similar countries which are all initially at a steady-state equilibrium like point S = (α^*, θ^*) in Figure 2 with no skill-biased technical change.[16] Trade integration between these economies is formally equivalent to an increase in the size of the economy from a factor endowment (H_R, H, L) to ($n_c H_R$, $n_c H$, $n_c L$).

Figure 2 shows the changes implied by trade integration. The research resource constraint STR shifts up to STR′ while the "no bias" condition schedule ΓΓ does not move. Clearly, for a sufficiently large number of countries n_c the new curve STR′ intersects ΓΓ at some point S′ with coordinates (θ', α') such that $\alpha^* > \alpha'$ and $\theta' > \theta^*$.

Given that α is a backward state variable, the World economy should immediately jump after integration from S to E′ on STR′ corresponding to $\alpha = \alpha^*$. Now, this point E′ lies above ΓΓ and consequently cannot be a steady state. Hence, there is some skill-biased technical change and α decreases. The system moves downwards along the R&D resource constraint STR′ until it reaches the intersection point S′ between STR′ and the "no bias" condition ΓΓ. Intuitively, integration intensifies technological competition and R&D. That increases the rate of creative destruction in simple unskilled-intensive technologies which are easily learned by outsiders. In order to dampen the increased threat of technological competition, firms undertake defensive skilled-biased innovations. This reduces the extent of knowledge spillovers and increases the skill intensity of the new technologies. As a consequence, the fraction α of goods produced with simple unskilled-intensive technologies monotonically decreases, implying an increase in the relative demand for skilled labor and a monotonic increase in the equilibrium wage premium $z(\alpha)$. This, in turn moves up the relative cost $\frac{C_s(w, q)}{C_1(w, q)}$ of skilled-labor-intensive technologies. The whole transition process of defensive skill-biased innovation continues until the economy reaches S′. At this point, incentives to bias the direction of technical change disappear as the gain from reduced technological predation is just balanced by the higher relative cost of using a skilled-labor-intensive technology.

The consequence of this process for wage inequality is immediate. As the new steady state S′ is necessarily associated with a lower value $\alpha' < \alpha^*$, the steady-state equilibrium wage premium $z' = z(\alpha')$ is larger than the initial level $z^* = z(\alpha^*)$ and wage inequality has increased in all countries.

One may summarize this discussion by saying that *trade integration between a sufficiently large number of similar countries induces skill-biased technical change: it strictly reduces* α *and increases the wage gap between skilled and unskilled workers.*[17]

Additional comments are in order. A first feature is that the process of "trade-induced technical change" only works along the transition path. Though we might not observe induced technical bias in the long run, the existing

[16] For convenience of exposition, we have chosen S to be the intersection point between ΓΓ and STR (i.e., the interior steady state with the highest level of α).

[17] This result suggests that wage inequality is positively related to the size of the economy, as empirically illustrated by Epifani and Gancia (2002). This result however does not necessarily imply that the growth rate depends positively on the size of the economy. Indeed, in our framework two counterbalancing effects are at work. As size increases, the total amount of researchers increases, and this impacts positively on growth. On the other hand, because of skill-biased technical change, the fraction of goods $(1 - \alpha)$ using a technology of type s increases, and for these goods the cost of innovation is larger than for the type-1 goods (in our simple framework, this cost is infinite). This second effect impacts negatively on the growth rate.

pattern of trade and wages in that situation clearly depends on the existence of technical bias during the transition. This suggests that empirical analyses looking only at static or steady-state impacts of trade integration on inequalities may actually underestimate the magnitude of the integration effect. Second, coupled with an increase in the wage premium, "induced skill-biased technical change" produces a skill intensity increase at the sectoral level for all sectors of the economy subject to the process of defensive skill-biased technical change.

III. North–South Integration

Many discussions on trade and wages have been framed in the context of North–South trade. Our framework can easily be extended in this direction to show that integration between dissimilar economies is also likely to give rise to defensive skill-biased innovations. Consider therefore integration between a northern region (referred to as the North) and n^c southern similar countries (referred to as the South). Research occurs only in the North (i.e., there is no research base H_R in the South). The North is also supposed to be relatively better endowed with skilled labor than the South. Denoting by L^N, H^N, n^cL^S, n^cH^S, the levels of unskilled and skilled labor respectively in the North and the South, we assume that $H^N/L^N > H^S/L^S$. Wages (w^N, q^N, w^S, q^S) are determined by domestic labor market clearing conditions. We still denote by α the fraction of goods produced under technology $k = 1$ in the World economy.

Integration between the North and the South brings two specificities. First, it is much less likely that the two regions share the same legal framework for intellectual property rights protection than two regions with the same level of institutional development. In particular, intellectual property rights are certainly less properly enforced in LDC economies than in developed industrialized countries. We capture this aspect by assuming that intellectual property rights are fully protected in the North and are weakly enforced in the South. More precisely, we assume that in *each southern country* and for each patent the probability for property rights to be correctly enforced is $\tau < 1$. Firms can freely imitate type-1 goods for which there is immediate spreading of informational externalities. However, in order to produce the imitated good, they must localize in one of the southern countries where intellectual property rights for this patent are not respected. It is then straightforward that such a country exists with probability $1 - \tau^{n_c}$. Hence the probability for a good to be *effectively* imitated increases with n_c, the number of southern countries. Given that all goods of type 1 are vulnerable to imitation, a fraction $(1 - \tau^{n_c})$ of these goods is effectively imitated while the fraction τ^{n_c} will keep their monopolistic rents until they are leapfrogged by a superior technology in the North.

Second, large differences in factor endowments induce different patterns of factor prices in the two regions.[18] As is standard in this type of Heckscher-Ohlin setup, firms are free to localize their production according to unit production cost minimization. More precisely, from the point of view of a new monopoly firm holding a patent in the North, instantaneous profits depend on the adopted technology k and the location of production (in the North or the South). In what follows, it will be useful to denote the minimum unit cost of production at time t as $\hat{C}_{kt} \equiv \text{Min}\{C_k(w_t^N, q_t^N), C_k(w_t^S, q_t^S)\}$ with $k \in \{1, s\}$.

Three regimes of specialization are then possible. The first, denoted as regime A, involves incomplete specialization of the North and complete specialization of the South in type-1 goods. Regime B is a regime of complete specialization of both regions with the South (resp. North) specialized in type-1 (resp. type-s) goods. Finally, there is a third regime (regime C) symmetric to regime A: incomplete specialization of the South and complete specialization of the North in goods of type s. Despite this apparently tedious taxonomy, the model continues to be very simple.[19] In the Appendix (cf., Lemma 2) we solve for the labor market clearing conditions and show that at the steady state, the different regimes of specialization only

[18] This is always true when H^N/L^N is large enough compared to H^S/L^S. We assume this to be the case in the sequel of the paper.

[19] In regime A: $\hat{C}_{1t} = C_1(w_t^N, q_t^N) = C_1(w_t^S, q_t^S)$ and $\hat{C}_{st} = C_s(w_t^N, q_t^N) < C_s(w_t^S, q_t^S)$; in regime B: $\hat{C}_{1t} = C_1(w_t^S, q_t^S) < C_1(w_t^N, q_t^N)$ and $\hat{C}_{st} = C_s(w_t^N, q_t^N) < C_s(w_t^S, q_t^S)$; in regime C: $\hat{C}_{1t} = C_1(w_t^S, q_t^S) < C_1(w_t^N, q_t^N)$ and $\hat{C}_{st} = C_s(w_t^N, q_t^N) = C_s(w_t^S, q_t^S)$.

depend on the value of α. Indeed there exists a threshold $\hat{\alpha}$ such that[20]: regime A occurs for $\alpha > \hat{\alpha}$, regime C occurs for $\alpha < \hat{\alpha}$, and regime B occurs at $\alpha = \hat{\alpha}$.

Finally, one can show (cf., Lemma 1 and 3 in the Appendix) that, as type-s technologies are more skill intensive than type-1 technologies, wage premia are still increasing in both regions when α decreases.

Consider now the firm's value functions under the two technologies. At each date t under limit pricing, monopoly cash flows can again be written as $\pi_t^1 = 1 - \delta$ for a technology of type 1 and now $\pi_t^s = 1 - (\delta \hat{C}_{st}/\hat{C}_{1t})$ for a technology of type s. Also, duopoly Bertrand competition on imitated goods in the South drives prices down to the unit costs of production and leads to zero profits. Therefore imitation acts like a destruction process.

The *ex post* value V_t^{1ni} of a technology of type 1 which has not been imitated is given by:

$$rV_t^{1ni} = \dot{V}_t^{1ni} + (1 - \delta) - \theta_t V_t^{1ni}.$$

Given the imperfection of protection of intellectual property rights in the South, the *ex ante* value V^1 of a technology of type 1 simply becomes: $V_t^1 = \tau^{n_c} V_t^{1ni}$.

As in Section III, the value V^s of a biased innovation is:

$$rV_t^s = \dot{V}_t^s + \left[1 - \delta \frac{\hat{C}_{st}}{\hat{C}_{1t}}\right].$$

The R&D resource constraint (5) continues to hold and equation (6) describes the dynamics of type-1 technologies.

[20] It may seem strange that the complete specialization regime for both regions (regime B) occurs only in the degenerate case where $\alpha = \hat{\alpha}$. This comes from the fact that as type-s technologies are never leapfrogged in this model, their closest rival is a technology of type 1, which can always be produced in the South. Limit pricing at the marginal production cost of that closest rival implies that, in the regime of complete specialization for both regions, the demand for unskilled labor in the North does not depend on the unskilled labor wage w^N in the North [see equation (A12) in the Appendix]. As unskilled labor supply L^N is inelastic, the market clearing condition for unskilled labor in the North can therefore only hold for a given value $\alpha = \hat{\alpha}$ of fraction of goods of type 1 in the World economy.

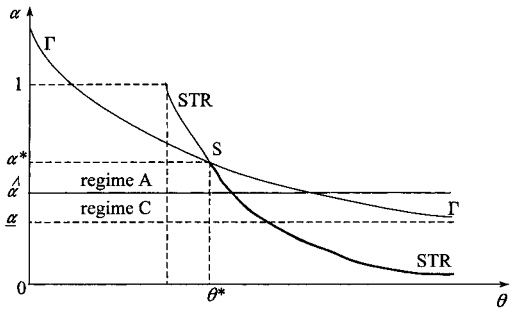

FIGURE 3. STEADY-STATE EQUILIBRIA AND SPECIALIZATION PATTERNS

At the steady state, $V^1 = \tau^{n_c}(1 - \delta)/(r + \theta)$ and $V^s = \left[1 - \delta \frac{\hat{C}^s}{\hat{C}^1}(\alpha)\right]/r$. Consequently the "no bias" condition (8) becomes:

$$1 - \delta \frac{\hat{C}^s}{\hat{C}^1} \underset{(-)}{(\alpha)} \leq \tau^{n_c} \frac{(1 - \delta)}{1 + \theta/r} \tag{9}$$

where $\frac{\hat{C}^s}{\hat{C}^1}(\alpha)$ can be shown to be a decreasing and continuous function of α (see Lemma 4 in the Appendix). The structure of stationary states of the World economy is described by equations (5) and (9). Graphically, it is represented on Figure 3 in a way similar to that in Section II with one additional feature. Because of differences in factor endowments, long-run patterns of specialization across regions emerge and characterize the location of goods produced with unskilled-labor-intensive and/or skilled-labor-intensive technologies. Regime A (resp. C) prevails above (resp. below) the flat line $\alpha = \hat{\alpha}$. Figure 3 shows a situation such that, along the R&D constraint STR, depending on the value of α, both types of specialization regimes can be steady states without skill-biased innovations.

Insights regarding the North–South context can be obtained by simple comparative statics on n_c, the number of integrating southern countries. Start in Figure 4 from a World steady state at S = (θ*, α*) in a specialization regime A (incomplete specialization of the North and complete specialization of the South in type-1

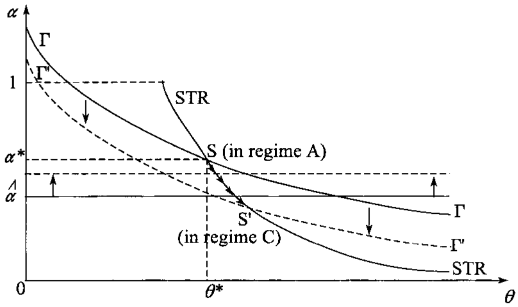

FIGURE 4. NORTH–SOUTH TRADE INTEGRATION AND INDUCED SKILL-BIASED TECHNICAL CHANGE

goods). Consider then an increase in n_c. As discussed above, this increases the rate of *effective* imitation $(1 - \tau^{n_c})$. Indeed, with more southern countries with weak legal institutions integrating into the World economy, effective protection of intellectual property rights decreases significantly and imitation by delocalized firms in such countries becomes easier.

Graphically, with an increase in n_c, the "no bias" curve shifts downward from $\Gamma\Gamma$ to $\Gamma'\Gamma'$. When the shift in n_c is large enough, getting back to a new steady state at S′ requires a decrease in α, the fraction of type-1 technologies: this means defensive skill-biased technical change along the transition path.

Simple algebra (see Lemma 2 in the Appendix) also shows that the frontier of specialization $\hat{\alpha}$ shifts up as n_c increases.[21] In Figure 4, the shift in n_c is large enough for the new steady state S′ to lie below the new specialization frontier $\hat{\alpha}'$, though the initial steady state S was above $\hat{\alpha}$. During the transition process, defensive skill-biased technical change is accompanied by a shift of specialization from regime A to regime C.

The impact on wage inequalities in the two regions can then easily be deduced. First notice that, as long as one region remains completely specialized in one type of goods, its wage premium is pinned down by its relative factor endowment H/L and therefore remains constant. On the other hand, when a region is incompletely specialized, a fall in α implies an upward shift of its domestic relative skilled/unskilled labor demand, leading to an increase in its equilibrium wage premium. It follows that in regime A during the transition, the wage premium in the North $z^N = q^N/w^N$ increases while that of the South $z^S = q^S/w^S$ remains constant. With skill-biased technical change, α goes down and eventually crosses the new threshold $\hat{\alpha}'$. The World economy then enters regime C. The wage gap therefore starts to increase in the South while it remains constant in the North. In the end, at the new steady state S′, the steady-state value of the wage premium has increased in both regions.

This requires a number of comments. First, as in the North–North context, defensive skill bias works only along the transition path of the economy. Second, this is coupled with an increase in the wage premium in both regions. Last, as in the North–North context, this is associated with skill-intensity increase at the sectoral level for all sectors subject to the process of defensive skill-biased technical change.[22] Interestingly, this process is now accompanied by specialization shifting and technical upgrading of the South from less skill-intensive technologies to more skill-intensive technologies. Of course, with only two types of technologies, the process is quite extreme. With more types of technologies, skill upgrading may however follow several steps and be more pronounced.[23] While other explanations can certainly be given for the shifting structure of comparative advantage of the South, our framework presents an additional channel which is consistent with an increase in inequalities in both regions.[24]

Finally, it has often been argued that North–South trade cannot explain the increase in inequality in the North because trade volumes between the two regions are not large enough to explain factor price movements (Krugman,

[21] The underlying intuition for this result is common to all two-country models. A larger value of n_c induces an increase in the absolute size of the South with respect to the North. As a consequence this reduces $[\hat{\alpha}, 1]$, the subsets of equilibria where the South is completely specialized (and when n_c becomes infinite α converges to 1).

[22] This is so only for these sectors because of our assumption that neutral technical change is a priori more efficient than skilled-bias technical change in autarky.

[23] See Thoenig and Verdier (2000) for such an analysis with a continuum of technologies.

[24] See for instance Bela Balassa (1979) or Leamer (1984) for alternative explanations.

2000). In a model of trade-induced technical change in which the factor content of trade is still the main mechanism, Acemoglu (1999) showed that the magnitude of trade effects on inequality could be substantially larger, though still short of explaining the empirically observed variations in factor prices. It is worth noticing that in our present framework, what triggers an increase in the wage premium in both regions is not the importance of trade volumes or variations in goods prices but the degree of transferability of information across firms and the intensity of imitation and technological competition.[25] This suggests that "induced technical bias" between trading economies with different intellectual property right protection systems may generate larger wage premia effects than those usually implied by variations of trade penetration ratios between northern and southern regions.

IV. Empirical Evidence

In this section we provide some evidence supporting the mechanisms of skill-biased defensive innovation.

A. *Case Studies*

First, there is a body of suggestive evidence, composed of case studies and newspaper articles on particular firms, industries and countries, which has emphasized the importance of defensive innovation in coping with increasing international pressure.[26] For example, Kurt Hoffman and Raphael Kaplinsky (1988) consider the restructuring of U.S. and European automobile industries in response to increased Japanese competition in the 1970's. Relying on various case studies, they show that a major strategy for U.S. firms was to develop comprehensive innovation programs aimed at making their product closer to their final market. Whereas until the mid-1970's capital and R&D expenditures for U.S. auto firms had been running at well below \$5 billion a year, they subsequently rose sharply, exceeding \$10 billion annually between 1979–1982, and reaching a record level of more than \$11 billion in 1984 and 1985. Moreover, diminishing competitiveness pushed these industries to reinforce the pace of adoption of electronic components (such as microprocessor-based powertrain control systems) and to use new, highly durable materials such as plastics, ceramics, aluminum, and composite material. Finally these competitive pressures triggered "the search for productivity improvements via new assembly techniques based around new design concepts and the use of large scale molded structures in order to reduce labor input in final assembly" (Hoffman and Kaplinsky, 1988, p. 126).

The case of the automobile industry can be interpreted as a technological response by northern firms (the United States and Europe) to increased international competition from other northern firms (Japan). An example more directly related to North–South trade competition is the case of the North American clothing industry. Facing fierce competition from LDCs in the 1970's, this industry went through important restructuring, relying on technological improvements and a general move toward high-quality clothes and new, high-tech textiles. The story is similar to the automobile experience and again suggests some defensive skill-biased innovations on the part of northern firms (for a detailed study, see North-South Institute, 1989).

B. *Empirical Evidence*

While case studies may provide suggestive evidence consistent with the existence of defen-

[25] A simple way to see this is to imagine, in our framework, the size of each southern country (H_S, L_S) to become very small, keeping constant the ratio H_S/L_S. For a given value of n_c, it is simple to see that at the limit, the World economy becomes close to an autarkic northern region with very little trade between North and South (as a proportion of North output). Consider then equation (9), the "no bias" condition in the North–South context. The right-hand side (RHS) of (9) gets close to $1 - \delta\Psi(\alpha)$, the RHS of equation (8) which stands for the "no bias" condition in an autarkic northern region. The left-hand side (LHS) of (9) on the other hand does not depend on the size (H_S, L_S) of a southern country. It follows that an incremental change in n_c the number of small southern countries, still has an impact on the North–South "no bias" condition (9) through the term τ^{n_c}. The associated threat of imitation, resulting from an additional negligible southern country, may trigger a process of induced skill-biased technical change and still affect factor prices at least in the North.

[26] See Wood (1994, p. 161) for a rich set of references.

sive skill-biased innovation, finding a direct statistic for defensive innovations seems difficult as this would require data on the nature and the type of innovations developed at the firm level. This exercise is beyond the scope of the present paper. Rather, we conclude this section by providing some empirical support for an important prediction of the model, namely the correlation between foreign competition and the share of skilled workers within the firm.

An increase in international competitive pressures should induce domestic firms to adopt defensive innovations in order to escape future predation (imitation or leapfrogging). According to the model, these defensive innovations should be biased toward skilled workers. Moreover, it is important to note that from the firm's point of view, what is relevant here is the *threat* of predation and not only effective competition. Hence, we should observe that firms reinforce the share of skilled workers when their environment becomes more exposed to international competition even if these firms *do not participate* effectively in international trade (through export or import).

In order to investigate this issue, we use data from Eric Maurin et al. (2002). These are derived from the combination of French Customs' data and two administrative datasets (*Enquête sur la Structure des Emplois* and *Bénéfices Industriels et Commerciaux*) handling an unbalanced panel of French manufacturing firms with over 20 employees. On average, there are 3,000 observations per year over the 1986–1992 period. Information is provided on (a) total sales at the firm and industry level, (b) employment structure by skill at the firm level, (c) whether the firm exports part of its production and imports part of its intermediate consumption, and (d) exports and imports of directly substitutable goods at the industry level.

As an empirical proxy for the threat of predation we consider the degree of openness of the 2-digit industry the firm belongs to. Accordingly, we restrict our study to nonoligopolistic (2-digit) sectors with more than 100 firms[27] and we define *openness* as the sum of exports and imports in substitutable competitive final goods divided by the total output of the sector. Moreover, our dependent variable, *skill,* corresponds to the ratio of skilled over unskilled workers in the firm.[28] As we use *openness,* an industry level variable in a firm-level regression, we correct all the standard errors for clustering effects (Brent R. Moulton, 1986). In Table 1, regression (1) shows a positive correlation between *skill* and *openness:* the more open to international trade an industry is, the more skill intensive are the firms of this industry. This result supports the predictions of our theory. However this correlation could also be explained by competitive theories.

First, in relatively open industries, firms import a large share of their intermediate inputs. As illustrated in Feenstra and Hanson (1999), firms substitute these imports for their unskilled workers so that importing firms usually exhibit a larger share of skilled workers in their workforce. In regression (2) we control for this mechanism by including a dummy variable 1_{IMP} (resp. 1_{EXP}) for firms which participate in international trade through imports of inputs (resp. exports of outputs). Robustness of our result illustrates in some sense the fact that skill upgrading is sensitive to the degree of competition in the firm's environment even when the firm does not participate directly in trade.[29]

Second, this result could be a direct consequence of firms' unobserved characteristics. For example, it could be the case that relatively skill-intensive products and technologies correspond to French comparative advantage in international trade. In that case, we should observe a positive correlation between *skill* and *openness.* Regression (3), in Table 1, explicitly addresses this issue by introducing firm-level fixed effects in order to purge this mechanism. The positive impact of *openness* on *skill* is still robust to that specification.

Third, there is still a potential endogeneity

[27] The results are robust to changes in the values of this threshold (for example estimations with industries larger than 500 firms).

[28] We do not deal with wage bills because wages at the firm level are not available in our dataset. However, we control hereafter for firm-level fixed effects and year effects. This enables us to control for some of the unobserved wage heterogeneity.

[29] We can also restrict the estimations to the subsample of firms which neither export nor import. In this case the result (not reported) is still robust.

TABLE 1—DEGREE OF OPENNESS AND SHARE OF SKILLED WORKERS

	Dependent variable: *Skill*			
Independent variable	(1)	(2)	(3)	(4)
Openness	0.07	0.058	0.033	0.055
	(0.01)	(0.012)	(0.018)	(0.022)
1_{IMP}		0.035	0.0004	0.002
		(0.004)	(0.001)	(0.002)
1_{EXP}	—	0.039	0.0007	−0.0006
		(0.004)	(0.001)	(0.002)
Year dummies	yes	yes	yes	yes
Firm-level fixed effects	no	no	yes	yes
Instrumental variables	no	no	no	yes
Sargan test (P)				0.81
R^2	0.01	0.04	0.94	0.96
Number of observations	16,430	16,430	16,430	13,098

Notes: Skill is the ratio of skilled workers to unskilled workers in each firm. *Openness* is the degree of openness at the (2-digit) industry level. 1_{EXP} and 1_{IMP} are dummy variables for exporting and importing firms. Models (1) and (2) present results from OLS estimation. Model (3) includes firm-level fixed effects. Model (4) is a 2SLS regression taking as instrumental variables: the lagged (by 1, 2 periods) values of industry real exchange rates, transport expenditure, and relative transport prices. All standard errors (adjusted for clustering on *openness*) are in parentheses.

problem in all the previous regressions. Consider for instance an exogenous spread of a new technology at the sector level (i.e., not caused by international competitive pressure). If this technology is skill biased, firms will increase the share of skilled workers among their workforce. At the same time, the introduction of this technology will increase the average productivity, and the competitiveness of the sector, and consequently the degree of openness should be affected. As we have no technological variable in our regressions, there is an endogeneity problem. Our solution is to instrument the degree of openness by prices such as transport costs and exchange rates at the industry level. For this purpose we consider three types of instruments: (1) an industry-level measurement of the effective nominal exchange rate. This variable corresponds to the geometric mean of the contemporary French franc value of the deutschmark and the dollar weighted respectively by the industry's proportion of exports (a) to the European Union and (b) outside the European Union, in 1986; (2) the proportion of transport expenditure in the sector's sales as reported in the national accounts; and (3) the industry price of transport expenditure divided by the industry's production price, again taken from the national accounts. The presumption is that those variables affect *openness* without significantly impacting *skill*, the technological environment of the firm. Regression (3) shows that the effect of foreign competition on the share of skilled workers is robust to this instrumentation.

Finally, our model predicts that skill bias is induced by an increase in predation and in the dynamic process of creative destruction. In contrast, an increase in the degree of "static" competition (in terms of price or quantity) is not expected to induce skill bias. In order to test this, we consider the Herfindahl index, HHI, which measures the degree of domestic concentration at the industry level. Table 2 performs the same regressions as Table 1 except that we include now both *openness* and HHI. The positive effect of *openness* on *skill* is preserved. Concerning the impact of the Herfindahl index, HHI, the results suggest that HHI is negatively correlated with *skill.* Indeed a larger HHI reflects a decrease in competition and, in line with our theory, this induces less skill-biased defensive innovations. However, as can be seen in regressions (2) and (3) of Table 2, the effect of HHI is not robust to the use of firm-level fixed effects and instrumentation. This finding suggests that a change in HHI may capture more a change in static "oligopolist" competition than in the intensity of dynamic predation.

TABLE 2—PREDATION AND PRICE EFFECTS

	Dependent variable: *Skill*		
Independent variable	(1)	(2)	(3)
Openness	0.076	0.033	0.066
	(0.016)	(0.018)	(0.025)
HHI	−0.44	−0.074	−0.144
	(0.181)	(0.162)	(0.262)
Year dummies	yes	yes	yes
Firm-level fixed effects	no	yes	yes
Instrumental variables	no	no	yes
Sargan test (P)			0.43
R^2	0.04	0.94	0.96
Number of observations	16,430	16,430	13,098

Notes: Skill is the ratio of skilled workers to unskilled workers in each firm. *Openness* is the degree of openness at the (2-digit) industry level. HHI is the Herfindahl index at the industry level. Each regression includes a dummy variable for exporting and importing firms. Model (1) presents results from OLS estimation. Model (2) includes firm-level fixed effects. Model (3) is a 2SLS regression taking as instrumental variables: the lagged (by 1, 2 periods) values of HHI, industry real exchange rates, transport expenditure, and relative transport prices. All standard errors (adjusted for clustering on *openness* and HHI) are in parentheses.

V. Conclusion

In this paper, we presented a dynamic general-equilibrium model of trade and innovation to investigate the mechanism of defensive innovation and its implications on the dynamics of wage inequalities in integrating regions. Our model incorporates the possibility of endogenous technical change and emphasizes the emergence of technical bias as an optimal response by firms to the problem of anticipated predation on their monopoly rents. We investigated the implications of this "nonprice" mechanism in the two different contexts of North–North and North–South trade. In both cases, we obtained an increase of the wage premium in *both* integrating regions. Also, we presented some empirical evidence for one main implication of defensive skill-biased innovations, namely the correlation between the threat of foreign competition and the share of skilled workers at the firm level.

Clearly, several extensions could be pursued in future research. To simplify our argument as much as possible, we made a number of assumptions which downplay the potential impact of trade-induced technical bias on the dynamics of wages and specialization. First, it was assumed that skill-biased technical change was a priori less efficient than neutral technical change. Second, for most of the dynamic analysis, we considered marginal technical bias possibilities. Also, we only discussed the case of two production technologies with the sophisticated technology being completely sheltered from technological predation. Relaxing each of these assumptions would strengthen and amplify the effect of defensive innovations on technical change and wages.

Introducing endogenous imitation in the North–South context could also be interesting. One may expect, for instance, the rate of imitation by southern firms to depend negatively on sectoral skill intensity (as more skill-intensive technologies are more costly to use in the South). This extension could then actually combine both insights from the North–South and the North–North trade models. Endogenous imitation in the South will be very similar to leapfrogging in the North–North context and firms will have additional incentives to develop skill-biased innovations to protect their product from imitation by the South.

Finally, by showing that Wood's intuition on trade-induced technical bias can be put into consistent theoretical terms, this paper has emphasized more generally the potential importance of "nonprice" effects of trade on factor prices and the dynamic nonseparability of technology and trade. Suggestive evidence consistent with the existence of defensive skill-biased innovations has been brought up but clearly more systematic empirical work on trade "nonprice" effects is crucially needed to get a better understanding of the impact of trade on the recent pattern of wage inequalities in industrialized and developing countries.

Appendix: Labor Market Equilibrium

In this Appendix we study the labor market clearing conditions in order to establish the validity of equation (7). The whole analysis is valid at the steady state and all along the transition path.

Benchmark Case: North–North Trade

Technologies of production $k \in \{1, s]$ are given by equation (2) and C_k; the detrended cost function is given by (3). For each technology k, skilled and unskilled labor demand functions are: $d_{kH}(w, q) = q^{-\sigma}A_t^{-1}[C_k(w, q)]^{\sigma}x(i)$ and $d_{kL}(w, q) = k^{1-\sigma}A_t^{-1}w^{-\sigma}[C_k(w, q)]^{\sigma}x(i)$ where $x(i)$ is the demand for good i, (w, q) are unskilled and skilled labor wages, A_t is the technology parameter which diminishes after each innovation. From (1) we know that $x(i) = 1/p(i)$ where $p(i)$ is the monopoly price. Under limit pricing we thus know that $p(i)$ is the unit cost of production of the second best product in line. Hence:

(1) *For type-1 goods:* Firms' labor demands are given by

$$d_H^{1m} = \delta q^{-\sigma}[C_1(w, q)]^{\sigma-1} \tag{A1}$$

$$d_L^{1m} = \delta w^{-\sigma}[C_1(w, q)]^{\sigma-1}. \tag{A1$'$}$$

(2) *For type-s goods:* For these goods firms produce with technology s whereas their former competitors use technology 1. Hence the unit cost of production of the closest rival is $C_1(w, q)/\delta$. The firm's factor demands are then given by:

$$d_H^{sm} = \delta q^{-\sigma}\frac{[C_s(w, q)]^{\sigma}}{C_1(w, q)} \tag{A2}$$

$$d_L^{sm} = \delta s^{1-\sigma}w^{-\sigma}\frac{[C_s(w, q)]^{\sigma}}{C_1(w, q)}. \tag{A2$'$}$$

At the country level relative demand for skilled labor is then obtained by aggregating (A1)–(A1′)–(A2)–(A2′) on the whole continuum of industries. Noting that a share α (resp. $1-\alpha$) of the continuum uses technology 1 (resp. s) and reminding equations (3), (A1)–(A2′) we get:

$$\frac{D_H}{D_L}(\alpha, z) = \frac{\alpha d_H^{1m} + (1-\alpha)d_H^{sm}}{\alpha d_L^{1m} + (1-\alpha)d_L^{sm}} \tag{A3}$$

$$= z^{-\sigma}\frac{\alpha + (1-\alpha)\left[\dfrac{s^{1-\sigma}+z^{1-\sigma}}{1+z^{1-\sigma}}\right]^{\sigma/(1-\sigma)}}{\alpha + (1-\alpha)s^{1-\sigma}\left[\dfrac{s^{1-\sigma}+z^{1-\sigma}}{1+z^{1-\sigma}}\right]^{\sigma/(1-\sigma)}}$$

where $z \equiv q/w$. From this last equation we get the labor market clearing condition (7) with $\partial\left(\frac{D_H}{D_L}\right)/\partial\alpha < 0$ and $\partial\left(\frac{D_H}{D_L}\right)/\partial z < 0$.

The Case with Imitation: North–South Trade

Labor demands at the firm level are basically similar to the previous case except that we now have to take into account two things. First, due to regime of specialization wages and unit costs of production are different in the North and the South: Therefore demands (A1)–(A2′) keep the same analytical form but the unit cost of production C_k is now replaced by $\hat{C}_k \equiv \text{Min}\{C_k(w^N, q^N), C_k(w^S, q^S)\}$ because firms can localize their production with respect to the North *vs.* South comparative advantage structure. Secondly, due to property rights' imperfect enforcement, an amount β of type-1 good is imitated where $\beta = (1 - \tau^{n_c})\alpha$. For imitated goods, there is a duopoly regime à la Bertrand, such that $p(i)$, the duopoly price, is the unit cost of production. Hence labor demands for imitated goods are simply given by:

$$d_H^{1d} = \delta^{-1} d_H^{1m} \tag{A4}$$

$$d_L^{1d} = \delta^{-1} d_L^{1m}. \tag{A4′}$$

Hereafter we look at steady-state equilibria. For the ease of exposition we call regime A the equilibrium of North incomplete specialization in type-1 goods, regime B the equilibrium of complete specialization and regime C the equilibrium of South incomplete specialization in type-s goods.

Characterization of Regime A.—In this regime the costs of production for type-1 goods are similar in North and South, so that we have:

$$w^N \cdot [1 + (z^N)^{1-\sigma}]^{1/(1-\sigma)} = w^S \cdot [1 + (z^S)^{1-\sigma}]^{1/(1-\sigma)} \tag{A5}$$

where $z^i \equiv q^i/w^i$ stands for the wage premium in country i. For type-1 goods: an amount β are imitated and produced in the South, $\zeta(\alpha - \beta)$ are produced in the North and $(1 - \zeta)(\alpha - \beta)$ are produced in the South under a monopoly regime where $\zeta \in [0, 1]$. Moreover there are $(1 - \alpha)$ goods of type s which are produced in the North. Aggregating firm-level labor demands (A1)–(A2′), and (A4)–(A4′) we obtain four labor market clearing conditions which can be written:

$$\frac{H^N}{L^N} = (z^N)^{-\sigma} \times \frac{\alpha\zeta\tau^{n_c}[1 + (z^N)^{1-\sigma}]^{\sigma/(1-\sigma)} + (1-\alpha)[s^{1-\sigma} + (z^N)^{1-\sigma}]^{\sigma/(1-\sigma)}}{\alpha\zeta\tau^{n_c}[1 + (z^N)^{1-\sigma}]^{\sigma/(1-\sigma)} + (1-\alpha)s^{1-\sigma}[s^{1-\sigma} + (z^N)^{1-\sigma}]^{\sigma/(1-\sigma)}} \tag{A6}$$

$$H^S/L^S = (z^S)^{-\sigma} \tag{A7}$$

$$L^N = \alpha\zeta\tau^{n_c} \frac{\delta}{w^N[1 + (z^N)^{1-\sigma}]} + (1-\alpha)\delta s^{1-\sigma} \frac{[s^{1-\sigma} + (z^N)^{1-\sigma}]^{\sigma/(1-\sigma)}}{w^S[1 + (z^S)^{1-\sigma}]^{1/(1-\sigma)}} \tag{A8}$$

$$n_c L^S = \alpha\{1 - \tau^{n_c}[1 - \delta(1 - \zeta)]\} \frac{1}{w^S[1 + (z^S)^{1-\sigma}]}. \tag{A9}$$

For a given α the equilibrium is given by the system of equations (A5)–(A6)–(A7)–(A8)–(A9) and the five endogenous variables $(w^S, z^S, w^N, z^N, \zeta)$. By totally differentiating this system with respect to α and using a Cramer's rule argument, we may show the following unambiguous results (the details of these computations are available from the author):

LEMMA 1: *In regime A:* $\dfrac{d\zeta}{d\alpha} > 0, \dfrac{dz^N}{d\alpha} < 0, \dfrac{dz^S}{d\alpha} = 0.$

Characterization of Regime B.—The regime of complete specialization is similar to the previous one except that unit costs for type-1 goods are no longer equalized: as a consequence the amount ζ of type-1 good produced in the North is null. So the set of equations characterizing regime B equilibria can be obtained from the previous system of equations (A6)–(A9) by setting $\zeta = 0$ and relaxing the equality (A5) to a strict inequality. At equilibrium there are four equations and four endogenous variables (w^S, z^S, w^N, z^N). We thus obtain:

$$H^N/L^N = s^{\sigma - 1}(z^N)^{-\sigma} \tag{A10}$$

$$H^S/L^S = (z^S)^{-\sigma} \tag{A11}$$

$$L^N = (1 - \alpha)\delta s^{1-\sigma} \frac{[s^{1-\sigma} + (z^N)^{1-\sigma}]^{\sigma/(1-\sigma)}}{w^S[1 + (z^S)^{1-\sigma}]^{1/(1-\sigma)}} \tag{A12}$$

$$n_c L^S = \alpha\{1 - \tau^{n_c}[1 - \delta]\} \frac{1}{w^S[1 + (z^S)^{1-\sigma}]}. \tag{A13}$$

Dividing (A13) by (A12) and using (A10)–(A11) we have:

$$\frac{n_c L^S}{L^N} = \delta s^{\sigma - 1}\left[\frac{s^{1-\sigma} + s^{1-\sigma}H^N/L^N}{1 + H^S/L^S}\right]^{\sigma/(1-\sigma)} \times \frac{\alpha}{1-\alpha}[1 - \tau^{n_c}(1 - \delta)]. \tag{A14}$$

In (A14) the only endogenous variable is α. As this equation must always hold in regime B we can conclude that (A14) characterizes the only value $\hat{\alpha}$ which is compatible with regime B. Moreover differentiating (A14) with respect to α and n_c shows that $\hat{\alpha}$ is increasing in n_c. And from Lemma 1 we know that ζ is increasing with α. As $\zeta = 0$ for $\alpha = \hat{\alpha}$ we see that regime A occurs only when $\alpha > \hat{\alpha}$.

The analysis of regime C is symmetric to that for regime A except that now ζ represents the share of type-s goods produced in the South. To sum up, we have:

LEMMA 2: *Regime B occurs only for $\alpha = \hat{\alpha}$ where $\hat{\alpha}$ is characterized by equation* (A14) *and $\partial\hat{\alpha}/\partial n_c > 0$. For $\alpha > \hat{\alpha}$, the economy is in regime A. Symmetrically for $\alpha < \hat{\alpha}$ the economy is in regime C.*

LEMMA 3: *In regime C,* $\dfrac{dz^S}{d\alpha} < 0, \dfrac{dz^N}{d\alpha} = 0.$

Finally consider condition (9). In regime A: $\dfrac{\hat{C}^s}{\hat{C}^1}(\alpha) = \left[\dfrac{s^{1-\sigma} + (z^N)^{1-\sigma}}{1 + (z^N)^{1-\sigma}}\right]^{1/(1-\sigma)}$. From Lemma 1, we conclude that $\dfrac{\hat{C}^s}{\hat{C}^1}(\alpha)$ is decreasing with respect to α in regime A. In regime C: $\dfrac{\hat{C}^s}{\hat{C}^1}(\alpha) = \left[\dfrac{s^{1-\sigma} + (z^S)^{1-\sigma}}{1 + (z^S)^{1-\sigma}}\right]^{1/(1-\sigma)}$. From Lemma 3, we conclude that $\dfrac{\hat{C}^s}{\hat{C}^1}(\alpha)$ is decreasing with respect to α in regime C. As discussed previously, the case of regime B is a limit case between regime A and C. Hence the function $\dfrac{\hat{C}^s}{\hat{C}^1}(\alpha)$ is continuous in $\hat{\alpha}$. Consequently we can state:

LEMMA 4: $\dfrac{\hat{C}^s}{\hat{C}^1}(\alpha)$ *is a continuous decreasing function with respect to* α.

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