LABOR MARKET RIGIDITIES AND R&D-BASED GROWTH IN THE GLOBAL ECONOMY[*]

by

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Abstract

This paper constructs a dynamic innovation-driven model of trade between two countries, one with flexible wages (America) and another with a rigid wage for less-skilled workers (Europe). The arrival of innovations follows a stochastic Poisson process which implies random switches in trade patterns between America and Europe. The model uncovers the role of asymmetric labor market institutions and international trade in mediating shocks throughout the global economy. Using the model, I investigate the recent labor market and R&D trends in America and Europe, specifically, the rise in European unemployment and the increases in wage inequality, R&D intensity, and skill intensity in both regions. I find that technology shocks coupled with responses from labor market institutions can generate results consistent with the stylized trends.

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1. Introduction

Over the past three decades, the less-skilled workers in most of the advanced countries have experienced a substantial deterioration in their well being. In the US, between 1973-1989, the wage premium of college graduates over high school graduates has increased by 20 percentage points [Freeman and Katz, 1995 p.34]. The widened wage gap persisted in the 1990s with the exception of a modest narrowing in the late 90s. In Europe, on average, there has been a mild increase in the wage premium with some cross-country heterogeneity [Freeman and Katz (1995), Nickell and Bell (1995)]. However, all European countries have experienced a secular and substantial increase in the rate of unemployment, mostly concentrated among the unskilled. In 1973, the average rate of unemployment in OECD Europe was 2.21 percent. By 1995 it reached 9.32 percent and remained high since then.[1]

In search of explanations, researchers have focused on two culprits: increased international trade and skill-biased technological change (henceforth SBTC) [see Bhagwati (2002) and Acemoglu (2002) for recent overviews]. Most economists have considered the issue using the perfect-competition based Heckscher-Ohlin (henceforth H-O) model of trade. In this model, for increased trade to have an impact on relative wages, the Stolper-Samuelson mechanism must come into play. This mechanism implies that the prices of less-skilled labor-intensive goods must go down in order to generate a reduction in the relative wage of less-skilled labor. Moreover, according to the H-O model if trade is the main cause of the rising relative wage, then within each industry firms should substitute away from skilled labor towards less-skilled labor—the factor which becomes relatively cheaper. Nevertheless, there is no strong evidence that the prices of less-skilled intensive goods have been falling. Moreover, the relative employment of skilled workers within industries has risen in both the US and Europe.[2] As a result, many scholars have rejected the trade explanation in favor of SBTC.

However, there is an emerging literature that seriously challenges the above deduction by considering trade models based on monopolistic and oligopolistic market structures.[3] Dinopoulos and Segerstrom (1999) and Sener (2001) consider two-country endogenous growth models in which firms can exercise temporary monopoly power if successful in their R&D efforts. These models propose a Schumpeterian version of the Stolper-Samuelson mechanism which establishes a positive link between the relative price of innovation and the relative wage of skilled labor. Neary (2002a, 2002b) constructs an oligopolistic general equilibrium model of trade in which higher levels of strategic investment by incumbent firms is associated with rising skill premium. In addition, Dinopoulos et al. (2001) construct a monopolistic competition model of intra-industry trade to study the effects of trade on relative wages. In these papers trade can cause rising wage inequality while conforming with empirical regularities.

In all of the papers cited above, the trading countries exhibit the same institutional structures in their labor markets. Consequently, these models cannot account for the observed differences in wage and unemployment patterns between Europe and the US, which have often been attributed to institutional differences. The popular view is that in Europe strong unions, high minimum wages and generous benefits have propped up less-skilled wages at the expense of employment, whereas in the US the relatively flexible labor market has allowed less-skilled wages to fall and thereby created jobs.[4] Recently, Krugman (1995) and Davis (1998) have incorporated institutional differences in H-O type trade models by considering a structure in which one country (Europe) implements a rigid wage policy and another country (America) has flexible wages. Using this asymmetric structure, a number of studies have examined the role of labor market institutions in mediating shocks through the web of trade. Nevertheless, these studies have exclusively used the static H-O setting and ignored the growth and R&D dynamics of the global economy.[5] This is quite contrary to the recent findings of the empirical trade literature, which provides strong support for the role of innovative activity in explaining trade flows between advanced countries.[6] It also contrasts with the recent findings of the empirical labor literature, which establishes a strong and robust relationship between skill upgrading and R&D intensity for high income OECD countries.[7] Table 1 helps us visualize this relationship by presenting the trends in skill upgrading (measured either by the employment share or wage bill share of non-production workers) and R&D intensities (R&D spending divided by value added) for a select group of European countries and the US. The values indicate that between 1973-1988 skill upgrading has been a pervasive phenomenon in advanced countries that has coincided with sustained increases in R&D intensities.

Motivated by these considerations, I construct a model of trade in a growth-theoretic context to investigate the recent labor market trends. In particular, I have three objectives in mind. The first is to use a dynamic trade model with endogenous R&D instead of a static perfect competition based H-O framework. The second is to capture the differences between Europe and the US in a unified framework where the two countries are integrated via trade and yet differ in their labor market institutions. The third is to analyze the role of asymmetric institutions in mediating local (i.e., affecting only one country) and global shocks (i.e., affecting the two countries simultaneously.[8]

The setting is a dynamic two-country model of trade. In each country, there are two types of labor: skilled and less-skilled, and two types of activities: R&D and final goods manufacturing. The countries differ in terms of their wage setting behavior. Following the terminology of Krugman (1995), and Davis (1998), I call the country with flexible wages America and the country with a rigid less-skilled wage Europe. In America, due to flexible wages, there is no unemployment whereas in Europe, the rigid less-skilled wage is binding and less-skilled workers are exposed to unemployment. In each country, individuals respond to increases in the skill premium by undertaking training. Hence, the ratio of skilled to less-skilled labor is determined endogenously. On the production side, the world economy consists of a continuum of industries. In each industry, entrepreneur firms of both countries participate in sequential R&D races to innovate higher quality products. The winner of an R&D race sustains temporary monopoly power in the global market and sells its product to both America and Europe. Hence, successful innovation by an American (European) entrepreneur firm implies industry leadership for America (Europe). In equilibrium, each country commands leadership in a constant fraction of industries.

The dynamic trade model differs from the standard H-O model in two major aspects. First, in each industry the pattern of trade is determined by whether a European or an American entrepreneur becomes a quality leader. Since the arrival of innovations is governed by a stochastic process, the model allows for random switches in trade patterns for each industry. Second, in my model, two countries participate in a zero-sum sequential competition to capture leadership in a fixed continuum of industries, that is, one country's industry leadership comes at the expense of the other country. These ingredients capture the role of innovation in determining trade patterns (see endnote 7) and the nature of *within-industry competition* among the advanced countries.

Using this analytical model, I investigate the factors behind the stylized long-run trends in Europe and the US: rising unemployment in Europe, rising relative wages for skilled workers (with a larger increase in America), skill-upgrading, and rising R&D intensities. As explanations, I consider local and global technology shocks, institutional adjustments and demographic shocks. I find that there is no single shock or institutional adjustment that can explain the stylized trends; instead a combination of factors can be at work. In this vein, I identify two combinations. The first is global technological change in R&D

(henceforth TCRD) coupled with an institutional response from Europe that props up the relative wages of less-skilled workers. This combination generates results that are consistent with the observed trends across the board. The second is global SBTC in manufacturing coupled with an institutional response from Europe again aimed at maintaining wage equality. This combination generates the same results except for one caveat: it leads to a reduction in R&D intensity in both regions. Hence, a positive shock to R&D technology appears to be a *necessary* condition to fully explain the recent trends.

What about the role of trade in affecting labor market outcomes? I find that a movement from autarky to free trade raises European unemployment and reduces wage inequality in both regions. Thus, opening up of trade does not seem to fully capture the stylized trends nor does it appear to be a part of a reasonable shock-response combination.[9] However, in the presence of asymmetric labor market institutions, economic integration plays a crucial role in mediating shocks. In an integrated world, the rigid European economy is subject to more volatility compared to the flexible American economy. In all instances, shocks originating from America exert a sizeable influence on the European economy. On the other hand, America is almost immune to shocks originating from Europe—except for shocks that directly affect European manufacturing costs and thus final goods prices.[10]

The paper also complements the recent literature which endogenizes the *direction* of technological change. In a series of papers Acemoglu (1998, 2003a) finds that increased trade or an exogenous increase in the supply of skilled labor can endogenously stimulate SBTC and thereby raise the skill premium. In a closed economy model with search unemployment, Acemoglu (2003b) shows that the wage compression efforts of institutions can discourage SBTC and thus explain the divergent wage and unemployment patterns between US and Europe. Using a two-country model with endogenous innovation, Thoenig and Verdier (2003) find that economic integration can increase the threat of leapfrogging and force more firms to pursue skilled-labor intensive production technologies, leading to endogenous SBTC. In an alternative model, Beaudry and Green (2003) show that introduction of a new technology can lead to rising skill premium if there is under-accumulation of physical capital relative to human capital. Using data from Germany and the US, they find that differences in the evolution of capital intensities between countries can explain the divergent patterns of skill premia.

In this paper, I depart from the above SBTC literature on two accounts. First, I consider asymmetric labor market institutions and emphasize the role of trade linkages. In the above cited papers either closed economy models or multi-country models with symmetric labor market institutions are considered. Second, I model the skill intensity differentials between R&D and manufacturing activities and uncover implications of TCRD and SBTC for labor markets. I argue that TCRD can be an alternative to SBTC in explaining the stylized labor market and R&D intensity trends.

The rest of the paper consists of four parts. Section 2 develops the model. Section 3 presents the comparative steady-state results. Section 4 presents the numerical simulations. Section 5 provides an overall discussion and Section 6 concludes the paper. Proofs of all propositions and other technical details are relegated to Appendices (available at http://www1.union.edu/~senerm/ and also upon request).

2. The Model

The building blocks of the model are as follows. Household behavior, R&D races, and product market structure are based on the quality-ladders model of growth without scale effects [see Dinopoulos and Segerstrom 1999 and Sener 2001]. The trade structure builds on the work of Grossman and Helpman (1991). The introduction of endogenous skill formation follows Dinopoulos and Segerstrom (1999), which in turn builds on the papers by Findlay and Kierzkowski (1983) and Borsook (1987).

2.1. Household behavior and skill formation

The global economy consists of two countries, America and Europe. In each country, there are two types of labor: skilled and less-skilled. The proportion of each type of labor within a country is endogenously determined. Labor is immobile across countries. The countries differ in their wage setting behavior. In America, flexible wages prevail in both skilled and less-skilled labor markets. In Europe, flexible wages prevail only in the skilled labor market, and a rigid wage is intact in the less-skilled labor market. The rigid wage can be viewed as the outcome of a centralized wage formation that reflects the institutional structure of the labor market. For our purposes, and in the spirit of Davis (1998, 1999), it is most convenient to refer to it as the minimum wage. I assume that the European minimum wage is binding and thus generates unemployment. In the rest of the paper, superscripts A and E will refer to American and European variables, respectively. The parameters that do not bear either A or E are common to both countries. Throughout the paper, I restrict attention to the steady-state equilibrium. For variables that grow at the steady-state a time index (t) is attached, otherwise the variables are constant.

Each economy consists of a continuum of families, indexed by their ability level $\theta \in (0, 1)$. I assume that θ is uniformly distributed across households. All members within a household have identical ability levels. The size of each household grows at a rate of $n = \beta - \delta > 0$, where the exogenous parameters β and δ refer to deterministic birth and death rates, respectively. Each member of a household lives for a finite period of time $D > 0$. The size of the global population at time t equals $N(t) = N_0e^{nt}$, where N_0 denotes the initial level of the global population. Each country accounts for a fixed fraction of the global population given by η^i, for i = A, E.

Households choose the allocation of consumption expenditure across goods at each instant in time and the pattern of consumption expenditure over time. I assume that there is perfect risk sharing within households such that each member enjoys the same level of consumption regardless of individual earnings. A household with ability θ in country i maximizes the discounted lifetime utility

$$F_\theta^i = \int_0^\infty \eta^i N_0\, e^{-(\rho-n)t} \log Z_\theta^i\, dt, \qquad \text{for } i = A, E, \tag{1}$$

where ρ is the subjective discount rate with $\rho - n > 0$, and $\log Z_\theta^i$ is the instantaneous utility of each household member

$$\log Z_\theta^i(t) \equiv \int_0^1 \log\left[\sum_j \lambda^j d_\theta^{\,i}(j,\omega)\right] d\omega, \qquad \text{for } i = A, E, \tag{2}$$

where $d_\theta^i(j, \omega)$ shows the quantity demanded of product quality j at industry ω, and $\lambda > 1$ represents the size of quality improvements (innovation size). A household with ability θ allocates per capita consumption expenditure c_θ^i to maximize Z_θ^i given prices at time t. The solution to this static problem yields a unitary elastic demand function for each product line $d_\theta^i = c_\theta^i/p$, where d_θ^i is the quantity demanded and P is the relevant market price for the product with the lowest quality-adjusted price. Quantity demanded for all other products becomes zero. Given the static demand behavior, the intertemporal maximization problem of a household with ability θ can be simplified to

$$\max \int_0^\infty \eta^i N_0\, e^{-(\rho-n)t} \log c_\theta^i\, dt, \qquad \text{for } i = A, E, \tag{3}$$

subject to the budget constraint $\dot{A}_\theta{}^i(t) = W_\theta^i(t) + r^iA_\theta^i(t) - c_\theta^i\eta^iN(t)$, where $A_\theta^i(t)$ denotes the financial assets of the household, $W_\theta^i(t)$ is the expected wage income of the household, and r^i is the instantaneous rate of return. The solution to this dynamic problem yields the usual differential equation:

$$\frac{\dot{c}^i{}_\theta}{c^i{}_\theta} = r^i - \rho, \qquad \text{for } i = A, E. \tag{4}$$

In each country firms engage in two types of activities: R&D and manufacturing of final goods. R&D employs skilled labor only, whereas manufacturing employs both skilled and less-skilled labor. Each household must decide whether to enter the labor force as skilled or less skilled given their ability. The ability levels are common knowledge to both workers and firms. Denote with u^i the unemployment rate of less-skilled workers, with $w_L{}^i$ the wage of less-skilled labor and with $w_H{}^i$ the wage per efficiency unit (i.e. wage per ability level) of skilled worker. A worker that chooses to remain less skilled can only find a job in manufacturing. The less-skilled worker earns $w_L{}^i$ regardless of her ability at the rate of employment $(1 - u^i)$. On the other hand, a worker that chooses to become skilled must undertake training for a period of time $T < D$. During the training the worker does not receive any income. Therefore, the cost of training is basically the foregone less-skilled wage earnings for a period of T. Skilled labor is entitled to lifetime job security due to the assumption of flexible wages in the skilled labor market. A skilled worker with ability θ earns $\theta w_H{}^i$, a wage that is positively related to her ability level.

The training decision of each household aims at maximizing the expected discounted household earnings given the level of ability. A household member with ability θ^i born at time $t = 0$ chooses training and becomes a skilled worker if and only if

$$\int_0^D e^{-\rho(s-t)} w_L{}^i (1 - u^i) ds < \int_T^D e^{-\rho(s-t)} \theta^i w_H{}^i ds , \qquad \text{for } i = A, E, \tag{5}$$

where the LHS of the inequality shows the expected lifetime earnings of a less-skilled worker, and the RHS denotes the earnings of a skilled worker.[11] Both expressions are appropriately discounted to time t at the steady-state interest rate $r^i(t) = \rho$. Rewriting equation (5) as an equality and solving for θ^i yield the critical ability level,

$$\theta_0{}^i = \left[\frac{1 - e^{-\rho D}}{e^{-\rho T} - e^{-\rho D}} \right] \frac{(1 - u^i) w_L{}^i}{w_H{}^i} = \sigma \frac{(1 - u^i) w_L{}^i}{w_H{}^i} , \qquad \text{for } i = A, E. \tag{6}$$

which determines the skill distribution of population. All families with ability levels below $\theta_0{}^i$ remain less skilled, whereas those with ability levels above $\theta_0{}^i$ undergo training and enter the workforce as skilled labor. With $\sigma > 1$ and $\theta_0{}^i < 1$ (which must hold in equilibrium), it follows that $w_H{}^i > (1 - u^i) w_L{}^i$. Note that in America less-skilled wages are flexible, hence $u^A = 0$. In Europe, there is a binding minimum wage $w_L{}^*$, thus $u^E > 0$. The "training arbitrage" conditions for Europe and America are:

$$\theta_0{}^A = \sigma \frac{w_L{}^A}{w_H{}^A}, \qquad \textbf{TA(A)} \qquad (7)$$

$$\theta_0{}^E = \sigma \frac{(1-u^E)w_L{}^*}{w_H{}^E}. \qquad \textbf{TA(E)} \qquad (8)$$

The economy-wide supply of less-skilled labor is:

$$L^i(t) = \theta_0{}^i\eta^i N(t)\,, \qquad \text{for } i = A, E, \qquad (9)$$

where $\theta_0{}^i$ now represents the fraction of the population that remains less skilled. In the skilled labor, the subpopulation with complete training consists of workers who are born between time (t – D) and (t – T):

$$\int_{t-D}^{t-T} \beta(1-\theta_0{}^i)N(s)\,ds = (1-\theta_0{}^i)\phi\,\eta^i\,N(t)\,, \qquad \text{for } i = A, E, \qquad (10)$$

where $\phi = [e^{n(D-T)} - 1]/[e^{nD} - 1] < 1$. The average skill level of these workers equals $(1 + \theta_0{}^i)/2$. Thus, the supply of skilled labor in terms of efficiency units is:

$$H^i(t) = \frac{(1-(\theta_0{}^i)^2)}{2}\phi\eta^i N(t), \qquad \text{for } i = A, E. \qquad (11)$$

Equations (6), (9) and (11) fully characterize the supply side of the labor market for each country.

2.2. Product markets and trade

The global market consists of a continuum of industries indexed by $\omega \in (0, 1)$. In each industry entrepreneurs of both countries participate in sequential and stochastic R&D races to innovate higher quality products. The arrival of innovations follows a Poisson process. The winner of an R&D race (the quality leader) can manufacture a product that is λ times better than the existing product. In country i, production of one unit of final good requires b^i units of less-skilled labor and h^i units of skilled labor regardless of the quality level; hence, marginal cost of final good production is $MC^i = (b^i w_L{}^i + h^i w_H{}^i)$. Manufacturing firms compete in prices under free trade conditions. Therefore, the quality leader can drive its closest rival out of the market by charging a price that is λ times as high as the marginal cost of the rival. In this way, the quality leader can sell its high quality product to both America and Europe. The nearest rival producing the previous generation product can do no better than break-even.

Denote with P^{ij} the price charged by a quality leader located in country i whose nearest rival resides in country j. To maximize profits the quality leader charges

$$P^{ij} = \lambda MC^j = \lambda(b^j w_L{}^j + h^j w_H{}^j), \qquad \text{for } i = A, E, j = A, E.$$

Let c represent per capita consumption expenditure of a representative world citizen given by $c = (c^A N^A(t) + c^E N^E(t))/N(t)$. The quality leader sells $cN(t)/P^{ij}$ units to the global market. The profit margin for each unit sold is equal to $P^{ij} - MC^i = \lambda(b^j w_L^j + h^j w_H^j) - (b^i w_L^i + h^i w_H^i)$. Thus, the monopoly profits of the quality leader residing in country i with nearest rival in country j equal:

$$\pi^{ij}(t) = \frac{cN(t)}{P^{ij}}(P^{ij} - MC^i), \qquad \text{for } i = A, E, j = A, E. \qquad (12)$$

Note that entrepreneurs in each country may target their research at the state-of-the-art good currently produced either domestically or abroad. Equation (12) suggests that firms earn higher profits when their nearest competitor resides in the country with higher unit cost of manufacturing. Thus, entrepreneurs, regardless of their location, will prefer to target the products that are currently manufactured in the high-cost country.

The above implication, however, is not consistent with a steady-state equilibrium where both countries manufacture strictly positive amounts of final goods. To see this, consider an equilibrium in which America exhibits higher unit costs in manufacturing. Then, entrepreneurs in both countries will solely target the industries with American leadership. Each success by a European entrepreneur will permanently take the industry leadership away from America. Over time, America will lose its competitiveness in all industries and European firms will become quality leaders in all industries. Hence, an interior steady-state equilibrium with both countries actively engaged in manufacturing requires that entrepreneurs in each country be indifferent between targeting European or American industries. This, in turn, implies the equalization of unit costs of manufacturing between the countries.[12]

Lemma 1: *If both America and Europe produce strictly positive amounts of final goods at the steady-state equilibrium, then unit costs of manufacturing between the countries must be equalized:* $MC^i = MC^j = MC$ *for* $i = A, E, j = A, E$. *With European less-skilled wage* w_L^E *fixed at* w_L^*, *this implies:*

$$MC = b^A w_L^A + h^A w_H^A = b^E w_L^* + h^E w_H^E \text{ and } P = \lambda MC. \qquad (13)$$

In what follows, I assume that Lemma 1 holds, This simplifies the profits of a quality leader to:

$$\pi^{ij}(t) = \pi(t) = \frac{(\lambda - 1)}{\lambda} cN(t). \qquad (14)$$

2.3. R&D races

In each industry, entrepreneur firms engage in innovative activity to participate in R&D races. Let $\Pi^i(t)$ represent the expected discounted profits of a successful innovator located in country i. Let $a^iX(t)$ stand for the unit labor requirement of R&D activity, where $X(\omega,t)$ captures the degree of R&D difficulty, which is introduced to remove the scale effects from the model. R&D difficulty is specified as [13]:

$$X(\omega,t) = kN(t), \qquad k > 0\,. \tag{15}$$

Free-entry into R&D races implies:

$$\Pi^i(t) = a^i w_H^i X(t)\,, \qquad \text{for } i = A, E, \tag{16}$$

where the LHS is the rewards to innovating and the RHS is the marginal cost of an R&D firm located at country i.[14]

There is a global stock-market that channels consumer savings to firms engaged in R&D. To calculate $\Pi^i(t)$ I use the stock market arbitrage condition. Over a time interval dt, the stockholders of the leader firm receive $\pi(t)$ in the form of dividends. Let I^i denote the worldwide R&D intensity targeted at an industry whose current leader resides in country i. Thus, a quality leader in country i faces a probability $I^i dt$ of being replaced by another entrepreneur. In this case, the stockholders suffer a loss of $\Pi^i(t)$. With probability $(1 - I^i dt)$ no innovation takes place and the stockholders realize an appreciation of $d\Pi^i = \dot{\Pi}^i\,dt$. The absence of any arbitrage opportunities in the stock market implies that the expected rate of return from holding a stock issued by a quality leader must be equal to the risk-free market interest rate r^i. Taking limits as $dt \to 0$, this yields:

$$\Pi^i(t) = \frac{\pi(t)}{\left[r^i + I^i - \dfrac{\dot{\Pi}^i}{\Pi^i}\right]}\,, \qquad \text{for } i = A, E. \tag{17}$$

Combining (16) and (17), and substituting for $\pi(t)$ from (14) and $X(\omega,t)$ from (15) into the resulting expression using $r^i = \rho$ and $\dot{\Pi}^i / \Pi = n$ (which must hold at the steady-state equilibrium) one can obtain the "free entry condition":

$$a^i w_H^i k = \frac{c(\lambda - 1)}{\lambda(\rho + I^i - n)} \qquad \textbf{FE(i)} \quad \text{for } i = A, E. \tag{18}$$

Let I^{ji} denote the aggregate R&D intensity in country j targeted at industry leaders in country i, for i = A, E, j = A, E. Hence worldwide R&D intensity targeted at an industry with country i leadership equals $I^i = I^{Ai} + I^{Ei}$. Let n^i represent the fraction of industries with country i leadership. At the steady-state equilibrium, American entrepreneurs capture leadership from European producers with a probability of innovation $I^{AE}dt$ in a fraction of industries n^E. At the same time European entrepreneurs capture leadership from American producers with a probability of innovation $I^{EA}dt$ in a fraction of industries n^A. In equilibrium, n^i must remain constant for i = A, E. Hence, the flow of industries America captures from Europe must be equal to the flow of industries Europe captures from America:

$$I^{AE}n^E = I^{EA}n^A .$$

Adding $I^{ii}n^i$ to both sides of the above equation and using $I^i = I^{Ai} + I^{Ei}$ for i = A, E yields respectively:

$$I^{AE}n^E + I^{AA}n^A = I^A n^A, \qquad (19)$$

$$I^{EA}n^A + I^{EE}n^E = I^E n^E. \qquad (20)$$

These equations imply that the aggregate intensity of R&D conducted in America (Europe) must be equal to the worldwide R&D targeted at industries with American (European) leadership.

2.4 Labor market equilibrium

European less-skilled workers experience unemployment due to the minimum wage legislation in this country. I define the *effective* supply of less-skilled labor in Europe as $(1 - u^E)$ multiplied by $\eta^E\theta_0^E N(t)$. With $P^{ij} = P = \lambda MC$ (Lemma 1), the aggregate demand for less-skilled labor in Europe is $n^E[cN(t)/P]b^E$. Equilibrium in the European "less-skilled labor market" requires:

$$(1 - u^E)\theta_0^E\eta^E = \frac{n^E c}{P} b^E \qquad \textbf{LM(E).} \qquad (21)$$

American less-skilled workers are fully employed due to flexible wages in that country. In America, the supply of less-skilled labor is $\eta^A\theta_0^A N(t)$ and the aggregate demand for less-skilled labor is $n^A[cN(t)/P]b^A$. Equilibrium in the American "less-skilled labor market" requires:

$$\theta_0^A\eta^A = \frac{n^A c}{P} b^A . \qquad \textbf{LM(A)} \qquad (22)$$

In the skilled labor markets of both countries wages are flexible; thus, full employment prevails. In each country, demand for skilled labor comes from two sources: R&D and manufacturing. Skilled labor demand from R&D equals the aggregate intensity of R&D $I^i n^i$ [see (19) and (20)] times the difficulty-adjusted unit labor requirement of R&D $a^i X(t)$. Skilled labor demand from manufacturing equals the amount of skilled workers employed in each industry ch^i/P times n^i . The supply of skilled labor is given by (11). Equilibrium in the "skilled labor market" implies:

$$\frac{(1-(\theta_0{}^i)^2)\phi\eta^i N(t)}{2} = I^i n^i a^i X(t) + \frac{h^i c}{P} n^i \qquad \textbf{SM(i)} \quad \text{for } i = A, E. \qquad (23)$$

2.5. Steady-state equilibrium

The model has a very complex asymmetric structure which renders it unfeasible to obtain clear analytical results. To get around this problem, I consider two versions: a *basic* model with $h^A = h^E = 0$, where manufacturing uses only less-skilled labor, and a *general* model with $h^A > 0$ and $h^E > 0$ as introduced in the main text where manufacturing uses both skilled and less-skilled labor. I use the basic model to obtain analytical results and the general model to run numerical simulations.

For the basic model under certain parametric restrictions [see Appendix A], and for the general model under a wide range of parameter values [see section 4], one can show that there exists a unique steady-state equilibrium in which $w_H{}^i/w_L{}^i$, $\theta_0{}^i$, n^i, I^i , c^i, r^i and P are strictly positive and remain constant for i = A, E. The variables X(t), Π(t), $H^i(t)$ and $L^i(t)$ grow at a rate of n.[15]

I am now in a position to give a snapshot of the equilibrium which applies to both the basic and the general model. At the steady-state equilibrium, entrepreneur firms of both countries compete globally to discover higher quality products. Firms may target their research efforts at a domestic or foreign industry. The firm that discovers the next generation product in a particular line becomes the sole manufacturer of that product, sustaining temporary monopoly power in the global market. Since the arrival rate of innovations is governed by a stochastic Poisson process, the model allows for random switches in trade patterns. To see this, consider an industry in which an American entrepreneur wins the R&D race. Then, in that particular industry America claims leadership and becomes a net exporter, and Europe becomes a net importer. Further innovation by an American entrepreneur does not change this trade pattern. However, further innovation by a European entrepreneur gives rise to European leadership and leads to a switch in the trade pattern (the vertical trade dimension). The model implies that in any portion of the continuum, Europe and America can have leadership in industries right next to each other; hence, trade can take place in similar products (the horizontal trade dimension).[16]

In equilibrium, the equalization of manufacturing costs [Lemma 1] establishes the link between American and European wages (and also goods prices P). In the basic model with $h^E = h^A = 0$, Lemma 1 implies that $w_L{}^A/w_L{}^* = b^E/b^A$; thus, for a given manufacturing technology, any increase in the European minimum wage is translated into higher wages for American less-skilled workers *one for one* in percentage terms. On the other hand, in the general model with $h^E > 0$ and $h^A > 0$, the impact of an increase in w_L* on w_L^A is diluted because of the endogenous responses in skilled wages w_H^A and w_H^E.

3. Steady-state analysis: analytical results from the basic model

I start by imposing $h^A = h^E = 0$ and normalize c to one. I then work to obtain reduced form equations for each country treating P as given. First, I consider the relationship between P and n^A for America. Using $P = \lambda b^A w_L^A$ (Lemma 1) and TA(A) and LM(A), one can derive $w_H^A = w_H^A(P, n^A)$, where $\partial w_H^A/\partial P > 0$, $\partial w_H^A/\partial n^A < 0$.[17] Substituting θ_0^A from SM(A) into LM(A) using I^A from FE(A) and $w_H^A(P, n^A)$ from above gives:

$$\frac{\lambda-1}{\sigma}+\frac{\phi}{2}=\frac{\eta^A}{n^A}\left(\frac{P}{b^A}\right)^2\left((\rho-n)a^A k+\frac{\phi\eta^A}{2n^A}\right), \qquad \textbf{SS(A)}$$

which implies a positive relationship between P and n^A as captured by the SS(A) curve in Figure 1. To see the intuition, one can view SS(A) as a reduced version of LM(A). A higher final foods price P generates an excess supply of less-skilled labor via two channels. First, it lowers the demand for final goods and directly reduces the demand for less-skilled labor. Second, it raises w_H^A via $w_H^A = w_H^A(P, n^A)$ and indirectly raises the supply of less-skilled labor θ_0^A.[18] To restore equilibrium, there must be an increase in the fraction of American industries n^A. This works via two mechanisms. First, a higher n^A directly raises the demand for less-skilled labor. Second, a higher n^A reduces w_H^A via $w_H^A = w_H^A(P, n^A)$ and indirectly reduces the supply of less-skilled labor θ_0^A. For future use, note that for a given P, any excess supply (demand) of American less-skilled labor is eliminated via an increase (decrease) in n^A.

Second, I consider the relationship between P and n^E for Europe. Obviously with $w_L^E = w_L*$ and $h^E = 0$ it follows from Lemma 1 that

$$P = \lambda b^E w_L* \qquad \textbf{SS(E)}$$

Thus, P is set by the European economy (and of course by the parameter λ) independent of n^E as represented by the horizontal line in Figure 1. The intersection of the SS(A) and SS(E) curves determines the equilibrium levels of n^A and P. Henceforth, the equilibrium levels of θ_0^A, I^A, w_H^A and w_L^A can be recovered by using LM(A), SM(A), FE(A) and Lemma 1, respectively.

Using $n^E = 1 - n^A$ as illustrated in the second quadrant of Figure 1, one can determine the equilibrium level of n^E. Next, I consider the relationship between n^E and u^E for a given P. Using P =

$\lambda b^E w_L$* (Lemma 1) and TA(E) and LM(E) one can obtain $w_H^E(n^E, u^E)$, where $\partial w_H^E/\partial n^E < 0$, $\partial w_H^E/\partial u^E < 0$.[19] Substituting θ_0^E from SM(E) into LM(E) using I^E from FE(E) and $w_H^E(n^E, u^E)$ yields:

$$\frac{\lambda-1}{\sigma}+\frac{\phi}{2}=\frac{\eta^E[\lambda w^*(1-u^E)]^2}{n^E}\left((\rho-n)a^E k+\frac{\phi\eta^E}{2n^E}\right) \qquad \textbf{SS(U)}$$

which implies an inverse relationship between u^E and n^E as captured by the SS(U) curve in Figure 1. To see the intuition, one can view SS(U) as a reduced form of LM(E). An increase in the fraction of European industries n^E generates an excess demand for less-skilled labor via two channels. First, it directly raises the demand for less-skilled labor. Second, it reduces w_H^E via $w_H^E(n^E, u^E)$ and indirectly reduces the relative supply of less-skilled labor θ_0^E.[20] To restore equilibrium, there must be a fall in the unemployment rate u^E. This works via two channels. First, a lower u^E directly raises the effective supply of less-skilled labor. Second, a lower u^E increases w_H^E via $w_H^E(u^E, n^E)$ and indirectly raises the supply of less-skilled labor θ_0^E. For future use, note that for a given P and n^E, any excess demand (supply) for European less-skilled labor is eliminated via a decrease (decrease) in u^E. With the equilibrium level of n^E determined, one can obtain the equilibrium level of u^E from SS(U). Henceforth, the equilibrium levels of θ_0^E, I^E, w_H^E can be recovered by using LM(E), SM(E), and FE(E), respectively.

Figure 1 highlights the two key insights of the model. First, shocks are transmitted between America and Europe through *price* [Lemma 1] and *industry* [$n^A + n^E = 1$] channels. Second, local shocks originating from America shift the SS(A) curve and change the industry configuration. This directly affects the European economy. On the other hand, local shocks originating from Europe—as long as they are neutral on P—simply shift the SS(U) curve and exert *no* influence on the American economy. The intuition is that by supporting the minimum wage, European economy determines final goods prices P. Given this, the global distribution of industries is determined by the steady-state conditions of America. Hence, shocks to America are directly transmitted to Europe via the industry channel—which is the consequence of the zero-sum *within-industry* competition. On the other hand, shocks to Europe that are neutral on P are not transmitted to America. Europe commits to the minimum wage and bears the local consequences.

3.1. Institutional changes in European labor market

In this context, I consider a minimum wage hike and increased unemployment benefits.

Proposition 1: *An increase in the minimum wage rate in Europe* w_L*

(i) *increases the unemployment rate in Europe* u^E*,*

(ii) *decreases the relative wage of skilled labor* w_H^i/w_L^i *in both America and Europe,*

(iii) *increases the population share of less-skilled workers in America* θ_0^A*, and decreases the population share of less-skilled workers in Europe* θ_0^E*,*

(iv) *decreases the intensity of aggregate R&D in America* $I^A n^A$*, increases the intensity of aggregate R&D in Europe* $I^E n^E$*.*

I start by examining the American economy. As shown in Figure 2, a rise in w_L^* shifts the SS(E) curve up and increases both final goods prices P and the fraction of American industries n^A. In the American less-skilled labor market this generates two competing effects: the rise in n^A increases the demand for less-skilled labor, whereas the higher P works in the opposite direction. In Appendix A, it is shown that the net impact is an excess demand for less-skilled labor. To restore equilibrium, there must be an increase in the supply of less-skilled labor θ_0^A, which must be triggered by a fall in the skill premium w_H^A/w_L^A. With the rise in θ_0^A, less resources become available for R&D, and the intensity of innovative activity $I^A n^A$ decreases.

I now turn to the European economy. By construction, a higher n^A implies a reduction in the fraction of European industries n^E. This reduces the demand for less-skilled workers and raises the rate of unemployment u^E. In addition, the SS(U) condition implies that for a given n^E, a higher w_L^* leads to a rise in u^E.[21] As illustrated in Figure 2, this shifts the SS(U) curve leftwards, leading to a further increase in u^E. To investigate the change in θ_0^E, I use the LM(E) equation. A higher P and a lower n^E depresses the demand for less-skilled labor whereas a higher u^E reduces the effective supply of less-skilled labor. In Appendix A, it is shown that the net impact is an excess supply of less-skilled labor. To restore equilibrium, there must be an endogenous decrease in θ_0^E, which must be triggered by a rise in the European skill premium, $w_H^E/w_L^*(1 - u^E)$. With the fall in θ_0^E, more resources become available for R&D, and the intensity of innovative activity $I^E n^E$ increases. To determine the change in the relative wage w_H^E/w_L, I use the TA(E) condition, which suggests that the change in w_H^E/w_L^* is subject to two forces. The fall in θ_0^E increases w_H^E/w_L^* whereas the rise in u^E works in the opposite direction. The net impact on w_H^E/w_L^* is negative.[22]

I now introduce unemployment benefits into the model by assuming that jobless workers are eligible to receive a fraction α of the minimum wage, where $\alpha \in (0, 1)$. In this case, the expected wage of less-skilled labor becomes $(1 - u^E)w_L^* + u^E \alpha w_L^*$. Using this, I rewrite TA(E) as:

$$\theta_0^E = \sigma \frac{[1 - u^E(1-\alpha)]w_L^*}{w_H^E}, \qquad \textbf{TA}'\textbf{(E)}$$

Note that the FE(i), LM(i) for i = A, E, and TA(A) equations remain the same.

Proposition 2: *An increase in the unemployment benefit rate* α

(i) *increases* u^E*,*

(ii) *has no effect on* w_H^A/w_L^A*, and a positive effect on* w_H^E/w_L^E*,*

(iii) *has no effect on* θ_0^A*, and a positive effect on* θ_0^E*,*

(iv) *has no effect on* $I^A n^A$*, and a negative effect on* $I^E n^E$*.*

As illustrated Figure 3, the SS(A) and SS(E) curves remain the same. Therefore, the variables pertaining to America w_H^A/w_L^A, θ_0^A, $I^A n^A$, P as well as n^A (and thus n^E) remain unchanged. In Europe, a higher α shifts the SS(U) curve leftwards and raises u^E. Intuitively, an increase in α raises the incentives to remain less skilled, causing a rise in the supply of less-skilled labor θ_0^E.[23] For a given n^E, this leads to an excess supply of less-skilled labor and hence raises u^E. With θ_0^E rising, resources for R&D shrink and thus $I^E n^E$ decreases. To determine the movement in w_H^E/w_L^*, I use the TA′(E) equation which implies that three forces govern the change in w_H^E/w_L^*. The higher levels of u^E and θ_0^E both lead to a fall in w_H^E/w_L^*, whereas the higher α causes a rise in w_H^E/w_L^*. The net impact is an increase in w_H^E/w_L^*.

3.2. Technology shocks

In the basic model, technology shocks can be classified into two groups: shocks that affect manufacturing and shocks that affect R&D. Each type of shock can take place in a local or global fashion.

Proposition 3: *Global technological change in R&D (TCRD) in the form of a simultaneous and equiproportionate reduction in the R&D unit labor requirements* a^E *and* a^A *(i.e.,* $da^A/a = da^E/a$*),*

(i) *decreases* u^E*,*

(ii) *increases both* w_H^A/w_L^A *and* w_H^E/w_L^E*,*

(iii) *decreases* θ_0^A*, and decreases* θ_0^E *if and only if* $\varepsilon(n_E, a^A) = -(\partial n^E/\partial a^A)(a^A/n^E) < 1$*,*

(iv) *increases* $I^A n^A$*, and increases* $I^E n^E$ *if and only if* $\varepsilon(n^E, a^A) < 1$ *.*

In America, a decline in a^A raises the profitability of innovative activity, motivating more firms to enter R&D races. This leads to a rise in I^A, and with $\rho - n > 0$ it follows that $I^A a^A$ also increases. The resulting increase in the demand for skilled labor and the subsequent endogenous supply response decreases θ_0^A. For a given P, the lower θ_0^A requires a fall in n^A; thus, the SS(A) curve shifts leftwards as illustrated in Figure 4. The equilibrium level of n^A goes down with no change in the equilibrium level of P. To determine the change in θ_0^A, I use the LM(A) equation. The fall in n^A reduces the demand for less-skilled labor. To restore equilibrium, there must be a fall in θ_0^A, which must be triggered by a rise in the skill premium w_H^A/w_L^A. With θ_0^A and a^E both decreasing, $I^A n^A$ increases.

In Europe, there is a direct effect due to the fall in a^E and an indirect effect due to the rise in n^E. The direct effect is analogous to that in America. A decline in a^E raises the profitability of R&D, and with $\rho - n > 0$ this leads to a rise in $I^E a^E$. The resulting increase in the demand for skilled labor and the subsequent endogenous supply response decreases θ_0^E. For a given P and n^E, this leads to an excess demand for less-skilled labor; hence, u^E must fall to restore equilibrium. Consequently, the SS(U) curve shifts to the right as shown in Figure 4. This direct effect coupled with the rise in n^E works to reduce the equilibrium level of u^E.

To investigate the change in θ_0^E, I use the LM(E) equation. The fall in u^E raises the effective supply of less-skilled labor, whereas the rise in n^E raises the demand for less-skilled labor. The net impact depends on the responsiveness of n^E to variations in a^A, as measured by the technology elasticity of European industry leadership $\varepsilon(n^E, a^A) = -(\partial n^E/\partial a^A)(a^A/n^E)$. If $\varepsilon < 1$ ($\varepsilon > 1$), then global TCRD decreases (increases) the demand for less-skilled labor, resulting in a lower (higher) level of θ_0^E.[24] To determine the change in $I^E n^E$, I use equation (23) given $h^i = 0$ for i = A, E. In the inelastic case $\varepsilon < 1$ with θ_0^E and a^E both falling, $I^E n^E$ clearly increases. In the elastic case $\varepsilon > 1$ with θ_0^E increasing and a^E falling, the direction of change in $I^E n^E$ is ambiguous. To analyze the change in w_H^E/w_L^*, I use the training arbitrage condition TA(E). The lower u^E increases w_H^E/w_L^*, whereas the effect emanating from θ_0^E depends on the value of $\varepsilon(n^E, a^A)$. In Appendix A, it is shown that the former effect always dominates the latter effect; thus, w_H^E/w_L^* unambiguously increases.

I now examine technological shocks in final goods manufacturing. Consider first a global technological progress that leads to a fall in both b^E and b^A but leaves the b^E/b^A ratio constant. Such a change exerts no distortion on the steady-state equations and therefore is totally neutral in this model. However, if the extent of technological progress in manufacturing is relatively large in one of the countries, then the neutrality result no longer holds. If the reduction in the American unit labor requirement b^E is larger (smaller) than that of Europe b^A, then the ratio b^E/b^A increases (decreases). In this case the equilibrium effects and the underlying mechanisms are identical to the case of an increase (decrease) in the European minimum wage [see proposition 1].

3.3. Demographic shocks

Temporary changes in the rate of population growth in country i can affect its world population share η^i. Such changes can stem from, for instance, a period of baby boom or immigrant influx.

Proposition 4: *An increase in America's world population share* η^A

(i) *increases* u^E *if and only if the share of American leadership in industries is higher than its share in global population* $n^A > \eta^A$,

(ii) *has no effect on* w_H^A/w_L^A, *and a negative effect on* w_H^E/w_L^E *if and only if* $n^A > \eta^A$,

(iii) *has no effect on* θ_0^A, *and a negative effect on* θ_0^E *if and only if* $n^A > \eta^A$,

(iv) *has a positive effect on* I^An^A, *and a positive effect on* I^En^E *if and only if* $n^A > \eta^A$.

In America the SS(A) condition implies that for a given P, the ratio n^A/η^A must remain constant in equilibrium. Hence, a rise in η^A must generate a proportional increase in n^A. This is captured by a rightward shift of the SS(A) curve in Figure 5. [25] With n^A/η^A constant, it follows from LM(A), TA(A) and FE(A) respectively that θ_0^A, w_H^A/w_L^A and I^A remain constant. However, with n^A rising, I^An^A increases.

For Europe, the increased levels of η^A and n^A translate into lower levels of η^E and n^E. The SS(U) condition implies that for a given n^E, a lower η^E requires a fall in u^E and entails a rightward shift of the SS(U) curve in Figure 5.[26] Hence, one observes two competing effects on u^E: the lower n^E reduces u^E, whereas the rightward shift of the SS(U) curve works in the opposite direction. The net impact depends on the movement in the n^E/η^E ratio. To facilitate the exposition let me explore the case where the n^E/η^E ratio falls. This is true if and only if in equilibrium $n^A > \eta^A$. In this case, a fall in η^E reduces the demand for less-skilled labor and raises u^E. To investigate the change in θ_0^E, I use the LM(E) equation. The fall in n^E/η^E decreases the demand for less-skilled labor, whereas the rise in u^E reduces the effective supply of less-skilled labor. The net impact is an excess supply of less-skilled labor and thus θ_0^E must fall to restore equilibrium. Equation (23) implies that the fall in θ_0^E raises $I^E n^E$, whereas the fall in η^E reduces it. The net change is ambiguous. To determine the change in w_H^E/ w_L^*, I focus on the TA(E) condition. Again, two effects are at work here: a negative effect via the higher u^E and a positive effect via the lower θ_0^E. The net impact is a decrease in w_H^E/ w_L^*.

3.4. Global skill biased technological change (SBTC) in manufacturing

To investigate SBTC in manufacturing, I use the general model in which h^E and $h^A > 0$. Figure 6 illustrates the steady-state equilibrium. The main difference from the basic model is that SS(E) line is now downward sloping in (P, n^A) space. The intuition involves two mechanisms. First, a higher P depresses the demand for less-skilled labor. Second, a higher P indirectly raises the effective supply of less-skilled labor by generating a rise in $(1 - u^E)\theta_0^E$. To restore equilibrium, there must be a rise in n^E, which translates into a fall in n^A. Observe that the equilibrium level of P now responds to changes in *any* of the model's parameters because P is no longer exclusively tied to European parameters. This response, in turn, generates additional shifts of the SS(U) curve.

Global SBTC in the form of a decline in b^E and b^A depresses the demand for less-skilled labor directly in both America and Europe. Moreover, global SBTC produces indirect effects (an increase in θ_0^A and an increase in $\theta_0^E(1 - u^E)$) that raise the effective supply of less-skilled labor in both regions. For a given P, restoring equilibrium in America requires an increase in n^A, hence the SS(A) curve shifts to the right. Similarly, in Europe there must be an increase in n^E; hence, the SS(E) curve shifts to the left. As illustrated in Figure 6, the equilibrium level of P goes down whereas the change in n^A remains ambiguous. With respect to the SS(U) relationship, one can show that the fall in P raises the demand for less-skilled labor whereas the fall in b^E reduces it. In addition, the fall in P indirectly reduces θ_0^E and the fall in b^E indirectly raises θ_0^E. Consequently, the SS(U) curve may shift in either direction. Given this and the ambiguous change in n^E, the change in u^E also remains indeterminate. Using the above results, one can investigate the changes in other endogenous variables; however, there are a large number of competing effects and the net impacts on almost all variables remain ambiguous.[27]

4. Steady-state analysis: simulation results from the general model

I now run numerical simulations of the general model. The objective is twofold: to test the robustness of the analytical results established under the basic model and to identify shocks and institutional response combinations that can generate the stylized trends. With simulations, one can also analyze the movements in more readily observed variables. The first such variable is the aggregate unemployment rate u^E_{AG}, defined as the number of unemployed people $u^E\theta_0^E N^E$ divided by the size of the labor force $[\theta_0^E + \phi(1 - \theta_0^E)]N^E$. The second variable is RD^i, defined as the share of R&D expenditure in aggregate value added, which equals $RD^i = I^i a^i k w_H^i/(1 + n a^i k w_H^i)$ for i = A, E.[28] The third variable is the wage bill share of skilled workers measured by $SH^i = w_H^i\,\phi(1 - (\theta_0^i)^2)/\,[w_H^i\,\phi(1 - (\theta_0^i)^2) + 2w_L^i\theta_0^i]$.

The benchmark parameter values are borrowed from econometric studies and calibration / simulation models. Whenever applicable, average values for Europe and US for the period 1975-1995 are utilized. In these calculations, Europe is viewed as one unified economy consisting of fifteen different countries [see footnote 1]. To highlight the role of institutional differences, I assume that technology and training parameters are common to both America and Europe and that each country accounts for half of the global population, $\eta^A = \eta^E = 0.5$. These are reasonable assumptions given that the focus is on regions that are roughly at the same level of advancement and comparable in size. The rest of the benchmark parameters are as follows: $\lambda = 1.25$, $n = 0.005683$, $\sigma = 1.3514$, $\rho = 0.07$, $\phi = 0.88945$, $\alpha = 0.48$, $b^E = b^A = 1$, $a^E = a^A = 1$, $w_L^* = 0.8034$, $k = 1.583$, $h^A = h^E = 0.27$.[29]

Column 2 of Table 3 displays the resulting benchmark levels. The aggregate unemployment rate in Europe is 0.0816. The fraction of industries with European leadership is 0.4776, which is less than the population share of Europe 0.5. Thus, labor market rigidities adversely affect a country's relative leadership position in the global economy. The relative wage of skilled labor in America is 1.9165, which is higher than that in Europe, 1.7612. Obviously, wage inequality is more pronounced in the country with the flexible wage structure. The population share of less-skilled labor in America is 0.7052, which is slightly lower than that in Europe, 0.7237. This is because the European skill premium, which is adjusted for unemployment, is lower than that of America; therefore, a larger fraction of the European labor force chooses to remain less skilled despite facing unemployment. Even though Europe is relatively less-skilled abundant, its contribution to innovation-driven growth is higher than that of America ($I^E n^E > I^A n^A$). The reason is that Europe accounts for a smaller mass of industries ($n^E < n^A$) and hence can allocate a larger portion of its skilled labor force to innovative activity. For each country, the share of R&D expenditure in aggregate value added RD^i is in the neighborhood of 5 percent, which is consistent with data from OECD countries [see Table 1].

4.1. Simulation results

I present the simulation results in Table 3. The first column under each parameter change displays the equilibrium levels subsequent to the exogenous event, and the second column shows the percentage changes in the equilibrium levels with respect to the benchmark levels. A comparison of Table 2, which outlines the results from the basic model, and Table 3 suggests that the qualitative results are identical except for two aspects. First as expected, America is now affected by all local shocks originating in Europe. However, the newly observed effects are of extremely small magnitude.[30] Second, whenever u^E and w_H^E/w_L^* move in opposite directions, the signs of $d\theta_0^E$ in Table 3 and Table 2 may differ.[31]

Numerical simulations indicate that global SBTC leads to higher European unemployment, lower relative wages and lower R&D intensities in both regions. The intuition is as follows. Global SBTC reduces manufacturing costs and thereby lowers final goods prices P (Figure 6). In America, this raises the demand for less-skilled labor, whereas the fall in b^E directly reduces it. The net impact is a decrease in the demand for less-skilled labor. To restore equilibrium, there must be an endogenous decrease in θ_0^A which must be triggered by a rise in w_H^A/w_L^A. Even though SBTC is proportionally the same in both regions, the flexible-wage America enjoys a rise in its measure of industries n^A. In Europe, the fall in b^E and n^E depresses the demand for less-skilled labor whereas the fall in P works in the opposite direction. The net impact is again a decrease in the demand for less-skilled labor. To restore equilibrium, u^E must increase and θ_0^E must fall. The fall in θ_0^E must be triggered by a rise in the European skill premium $w_H^E/w_L^*(1 - u^E)$. The puzzle is then: why do R&D intensities go down despite skill upgrading? It follows from Table 3 that demand for skilled labor coming from manufacturing, which equals $n^i h^i/P$, increases in both regions. This manufacturing demand is sufficiently strong to draw away a larger portion of the expanded skilled labor force, leaving fewer workers to perform R&D.

To explain the observed trends, I now search for shocks and institutional adjustments that generate sizeable increases in unemployment, wage inequality and R&D intensity.[32] With respect to unemployment, Table 3 points to four possible events. An 8.5 percent increase in the European minimum wage w_L^* raises u^E_{AG} by 120.05 percent. A skill-neutral improvement in American manufacturing productivity in the form of a 15 percent decrease in both b^A and h^A raises u^E_{AG} by 143.67 percent. Local SBTC in America captured by a 15 percent decline in b^A raises u^E_{AG} by 98.26 percent. Global SBTC in manufacturing captured by a 15 percent decline in both b^E and b^A raises u^E_{AG} by 29.62 percent. Observe that local SBTC in Europe actually works to *reduce* u^E_{AG} by 49.39 percent. It is the cross-border effect coming from America that creates the surge in u^E_{AG} in the case of global SBTC.[33] On the other hand, higher levels of α and η^A appear to generate relatively smaller increases in u^E_{AG}.

With respect to sources of rising wage inequality, Table 3 shows that technology shocks appear to be the culprits. First, I examine the effects of TCRD. Local TCRD in America in the form of a 20 percent decline in a^A raises w_H^A/w_L^A by 2.78 percent, producing also a cross-border effect that raises w_H^E/w_L^E by 1.59 percent. Local TCRD in Europe in the form of a 20 percent decline in a^E raises w_H^E/w_L^E by 2.83 percent, producing also a cross-border effect that reduces w_H^A/w_L^A by 0.13 percent. For the rigid-wage Europe, the cross-border effect originating from America is relatively large and works to *reinforce* the rise in European wage inequality, whereas for the flexible-wage America, the cross-border effect originating from Europe is relatively modest and works to *mitigate* the rise in American wage inequality. When TCRD is global, that is when both a^E and a^A decline by 20 percent, w_H^E/w_L^E increases by 4.58 percent and w_H^A/w_L^A increases by 2.67 percent. Observe that global TCRD implies rising wage inequality but lower European unemployment and hence cannot account for all of the stylized changes.

Second, I examine the effects of SBTC. Local SBTC in America in the form of a 15 percent fall in b^A raises w_H^A/w_L^A by 3.53 percent, producing also a cross-border effect that reduces w_H^E/w_L^* by 7.81 percent. On the other hand, local SBTC in Europe in the form of a 15 percent fall in b^E raises w_H^E/w_L^* by 8.41 percent, producing a cross-border effect that raises w_H^A/w_L^A by 1.05 percent. Once again the cross-border effects are relatively larger for Europe, but the qualitative effects differ starkly from those observed under TCRD. For the rigid-wage Europe, the cross-border effect originating from America works to *mitigate* the rise in European wage inequality, whereas for the flexible-wage America, the cross-border effect originating from Europe works to *reinforce* the rise in American wage inequality. When SBTC is global, that is when b^E and b^A fall by 20 percent simultaneously, w_H^A/w_L^A increases by 4.77 percent and w_H^E/w_L^* increases by 1.12 percent. Observe that global SBTC implies rising wage inequality but reduced levels of R&D intensity for both regions and hence is not consistent with all observed trends.

Table 3 shows that global TCRD appears to be the only event that can generate a substantial surge in R&D intensities. A 20 percent decline in a^E and a^A increases RD^A by 56.13 percent and RD^E by 42.46 percent, roughly consistent with the observed trends (see Table 2).[34]

4.2. Technology-shock-institutional response combinations

The above findings suggest that a combination of factors is needed to account for all of the stylized changes. Table 4 presents the effects of four possible combinations. The first case considered is global TCRD in the form of a 20 percent decline in both a^E and a^A coupled with an institutional response from Europe aimed at fully restoring the initial relative wage. In Europe, such a shock increases w_H^E/w_L* by 4.58 percent and reduces the aggregate unemployment rate u^E_{AG} by 25.77 percent. To neutralize the change in w_H^E/w_L* the European policy makers must implement a 3.45 percent rise in the minimum wage w_L*, which comes at the expense of a 49.82 percent increase in u^E_{AG}. The net impact is a 22.45 percent increase in u^E_{AG}. The larger the initial disturbance, the more drastic the policy response and the larger the increase in the unemployment rate. In America, global TCRD initially raises the relative wage w_H^A/w_L^A by 2.67 percent. However, the increased minimum wage in Europe creates a cross-border effect and suppresses the rise in the American skill premium. In the end, w_H^A/w_L^A increases by 2.44 percent. Under this scenario RD^A and RD^E increase by 51.32 percent and 44.80 percent, respectively; and the wage bill shares of skilled workers, SH^A and SH^E, increase by 13.42 percent and 13.01 percent, respectively.

The second case considered is global SBTC in the form of a 15 percent decline in both b^E and b^A coupled with an institutional response from Europe aimed at maintaining the initial relative wage. In Europe, such a shock increases w_H^E/w_L* by 1.12 percent and raises u^E_{AG} by 29.62 percent. To neutralize the change in w_H^E/w_L*, there must be a 0.86 percent rise in w_L*. This increases u^E_{AG} by an additional 12.56 percent and therefore raises the total change in u^E_{AG} to 41.16 percent. In America, global SBTC initially increases w_H^A/w_L^A by 4.77 percent. The European institutional response once again produces a cross-border effect and works to suppress the rise in the American skill premium. However, this effect turns out to be marginal, and in the end w_H^A/w_L^A increases by 4.70 percent. This shock-response combination raises SH^A and SH^E by 18.72 percent and 17.86 percent, respectively. However it reduces RD^A and RD^E by 23.39 percent and by 3.71 percent, respectively.

The third and fourth cases involve combinations of TCRD and SBTC coupled with institutional response from Europe. In the third case, European institutions fully restore the initial relative wage, whereas in the fourth case European institutions partially restore the initial relative wage such that the resulting increase in w_H^E/w_L* roughly complies with the observed changes. Observe that even if institutions partially maintain the relative wage, European unemployment rate can still rise substantially. The comparison of numerical simulations with observed trends (as shown in Table 4) suggests that technological-shock-institutional-response combinations can indeed explain a sizeable portion of the observed trends.

4.3. The role of trade

In terms of qualitative effects, a movement from autarky to free trade is identical to an increase in the European minimum wage (conditional on the reasonable assumption that in autarky $w_L^E = w_L^* > w_L^A$). Hence, opening up of trade alone cannot explain all of the observed trends. However, as highlighted in the analytical model and numerical simulations, in an integrated world economy, local shocks generate cross-border effects and thus expose the global economy—especially the rigid wage economy—to more volatility. In addition, numerical simulations (available from the author upon request) show that moving from autarky to free trade magnifies the quantitative effects of exogenous events. The intuition is straightforward. Under autarky, R&D races take place in a local fashion and domestic firms claim leadership in *all* industries. In this case, an increase in w_L^*, for instance, simply reduces the demand for less-skilled labor and raises unemployment. Under free trade though the industry channel is at work: an increase in w_L^* reduces the relative competitiveness of Europe and leads to a decline in n^E, further depressing the demand for less-skilled labor. For shocks and institutional adjustments that directly affect final goods prices, this additional effect turns out to be quite large.

5. Discussion

The preceding analysis implies that two shock-response scenarios can account for the recent labor market and industry trends in the US and Europe. The first is a positive shock to R&D technology coupled with an institutional response from Europe that works to maintain wage equality. Its implications are consistent with the observed trends across the board: rising unemployment in Europe, rising relative wage for skilled labor (with a larger increase in America), skill-upgrading, and rising R&D intensities. The second is global SBTC in manufacturing coupled with an institutional response from Europe again driven by wage equality concerns. This combination generates the same results except for one caveat: it leads to a reduction in R&D intensities in both regions. Hence, a positive shock to R&D technology appears to be a necessary condition to explain the recent trends. The emphasis on TCRD is the main departure of the model from the recent SBTC literature. In my model, I differentiate between manufacturing and research activities and draw attention to the "activity bias" of technological change *within* industries. [35]

Do the technology shocks of the past two decades and the institutional set-up of European institutions support the above scenarios? A vast amount of research has focused on investigating the prevalence of SBTC in advanced countries. Among others, Berman et al. (1998), Machin and Van Reenen (1998), and Hollanders and Weel (2002) make a convincing argument that SBTC was a pervasive phenomenon in high-income OECD countries in the past two decades. On the other hand, the issue of TCRD has received relatively sparse attention in the empirical literature. One exception is a series of papers by Kortum and Lerner (1998, 1999) which investigate the causes of the unprecedented surge in US patenting since the mid 1980s. Testing various hypotheses using industry, firm, and country level data, they conclude that much of the increase in US patenting is due to "improvements in management or automation of the innovation process itself."[36] To the best of my knowledge, there is no study that investigates research productivity in such detail for the high income European countries. Nevertheless, two arguments can be made for TCRD. First, cross-country studies focusing on SBTC stress the high degree of financial and commercial integration among advanced countries as the major reason for the rapid diffusion of technology and thus the pervasive nature of SBTC. It is plausible to use the same reasoning, at least to some extent, to argue for pervasive TCRD. Second, data from OECD (2002b) suggests that the number of patent applications from the EU countries to the European Patent Office has increased dramatically from 15,026 to 30,620 between 1975-1995, showing a clear upward trend in the 1980s followed by some stabilization in the 1990s. This evidence is, of course, highly stylized and simply suggestive. A more rigorous empirical analysis would certainly shed further light on this issue.

With regards to the institutional structure of the European labor markets, in his overview, Siebert (1997, p.39-40), argues that in the 1960s and 1970s "equity considerations gained prominence in all European countries" and shaped the new institutional framework. He adds that in the 1980s and 1990s, these institutions prevailed, and only marginal changes have been made in the 1990s. Blanchard and Wolfers (2000, p.16) also share a similar view stating that "there clearly was an increase in the employment-unfriendly institutions in the late 1960s and early 1970s. Since then there appears to be a small but a steady decline." The establishment of such institutions and their persistence since the 1970s are consistent with the particular wage equality driven response mechanisms identified above.

In explaining the European unemployment puzzle, recent empirical work have focused on the role of labor market institutions, shocks, and the interactions between the two. Blanchard and Wolfers (2000) argue that interactions between shocks and institutions can explain a large portion of the long-term rise in the European unemployment.[37] On the other hand, Nickel, Nunziata and Ochel (2005) and Nunziata (2002) suggest direct effects of institutions dominate the interaction effects in accounting for the rise in European unemployment. My theoretical model does not lend direct support to either of the hypotheses but it helps clarify the underlying mechanisms. It is possible to interpret the institutional response aimed at maintaining wage equality, which plays a crucial role in my model, as a built-in response stemming from *existing* institutions. Alternatively, one can argue that the institutional response needs to materialize through *changing* institutions. In any case, my model formalizes the mechanisms through which shocks and institutions influence unemployment. In the papers that emphasize interactions, the focus is on adverse shocks that raise unemployment. In my model, the focus is on technology shocks that distort the relative demand between skilled and less-skilled labor.[38]

6. Conclusion

In this paper, I constructed a dynamic two-country model of trade with endogenous R&D. The model considered the institutional differences between Europe and the US in a unified framework. The paper has three main results. First, it proposes TCRD as an alternative explanation to SBTC in the trade/wages/unemployment debate. Second, the paper implies that an economy with a flexible labor market can more easily pass on the effects of shocks to an economy with a rigid labor market. Third, the model uncovers the role of international trade and the related mechanisms in transmitting local shocks.

The model can help identify the forces that can generate the stylized trends; however, many extensions can be suggested to improve the match between observed trends and numerical simulations. Incorporating heterogeneities across Europe (as advocated by Nickell 1997) and also adding a North-South dimension to the model (as recently done by Grieben 2004) can be the first steps along these lines. In addition, one can incorporate search frictions into the asymmetric labor markets setting and study wage inequality and unemployment puzzles (see for instance Acemoglu, 2003b, Arnold 2002, Sener 2001 for models with search unemployment). Finally, considering indicators of R&D productivity and economic integration as explanatory variables in the empirical framework of Blanchard and Wolfers (2000) can be a fruitful avenue for empirical research.

Endnotes

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[1] The unemployment figures, which are non-weighted averages, are based on data from Nickell and Nunziata (2001). The fifteen OECD Europe countries included are: Austria, Belgium, Denmark, Finland, France, Germany, Ireland, Italy, Netherlands, Norway, Spain, Sweden, Switzerland, United Kingdom and Portugal.

[2] See Slaughter (2000) for a comprehensive overview of empirical studies on product price movements. See, among others, Berman et al. (1994) and (1998), Machin and Van Reenen (1998) for evidence on SBTC.

[3] In particular, Neary (2002a) criticizes the exclusive focus on competitive general equilibrium models on the grounds that "it precludes any discussion of the impact of trade or technology shocks on mark-ups or profits". In the same paper, Neary (2002a) also provides an overview of the arguments against the H-O based explanations on wage inequality.

[4] Nickell (1997, 2003) and Siebert (1997) provide extensive overviews on the diverse labor market experiences of U.S. and Europe, focusing on the role of institutional differences.

[5] Building on Brecher's (1974) work, Davis (1998, 1999) and Davis and Reeve (2002) analyzed the effects of exogenous shocks on labor markets using a two-country H-O model of trade with a rigid-wage Europe and a flexible-wage America.

[6] Using manufacturing industry data from five major industrial countries (US, Japan, Germany, France and UK) Magnier and Toujas-Bernate (1994) investigate the effects of R&D expenditures on trade flows. At the national level, they find a strong correlation between the evolution of R&D expenditures and export market share. Moreover, at the industry level they find that R&D expenditures appear to be important for both high-tech and low-tech industries. In a similar spirit, Ioannidis and Schreyer (1997) examine the export shares of 10 OECD countries for three distinct periods 1977-80, 1980-85 and 1985-90. They conclude that "technology-related factors, proxied by different R&D measures, play an important role as determinants of export competitiveness; most visibly as product innovation in high technology industries but also as process innovation that reduces unit labor costs relative to competitor." This literature also includes a number of single country studies. For instance, Anderton (1999) examines the effects of innovation on the trade performance of UK and Germany, reporting a significant negative relationship between domestic innovative activity—being measured by either R&D expenditure or patenting—and import penetration. Using industry level time series data for UK manufacturing and service activities, Greenhalgh et. al (1994) document the positive role of innovation on UK trade performance through increased average quality and variety.

[7] See Machin and Van Reenen (1998), Hollanders and Weel (2002) and Berman et al (1994).

[8] For empirical evidence on the role of international trade in transmitting business cycles see Canova and Dellas (1993), Gross (2001) and Frankel and Rose (1998).

[9] The autarky to free trade exercise makes the results comparable with the recent models such as Davis (1998) and Thoenig and Verdier (2003) but obviously does not fully capture the Europe-US trade relations for the past three decades. A complete analysis of other trade policies (such as tariffs, quotas and etc.) is beyond the scope of the present paper and is left for future research. See Dinopoulos and Segerstrom (1999a) and Sener (2001) for similar models but with *identical* countries where the effects of bilateral tariff reductions are analyzed.

[10] See also Davis (1998) for this particular insight in the context of a H-O model. Empirical studies using structural VAR methods provide support for the hypothesis of the locomotive character of the US in the global economy. Employing a two-country framework—US and a sample of OECD countries grouped together: Canada, France, Germany, Italy, Japan and UK—Kwark (1999) finds that "the transmission of US shocks to foreign countries is strong but the reverse is not true" (p. 369). Studying the transmission of shocks from US to Germany and US to Canada, Gross (2002) finds that supply side shocks to the US exert a sizeable influence on the output levels in Canada and Germany. Lastly focusing on the US, Germany and Japan, Canova and Marrinan (1998) conclude that US output shocks is the major driving force of the international business cycle.

[11] Observe that the evolution of wages and unemployment rates in question stretches over decades. Endogenizing human capital formation captures the long-run feedback effects of unemployment and relative wages on factor supplies and thus can provide a better framework to explore long-run changes. In a recent study, Katz et al. (1995)

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argue that cross-country differences in the evolution of relative factor supplies (skilled to less-skilled labor) can account for the observed changes in wage income inequality. Their study treats factor supplies as exogenously given. However, as Davis and Reeve (2002) point out, ignoring the endogeneity of skill accumulation can lead to an upward bias in the estimated effects.

[12] Grossman and Helpman (1991, p.193) provide this argument in a similar model with flexible wages and fixed skill distribution.

[13] This specification suggests that the difficulty of conducting innovative activity is proportional to the size of the global market. In the literature, two distinct mechanisms have been proposed to justify equation (15). The first, proposed by Dinopoulos and Thompson (1996), focuses on the distributional and organizational costs associated with new products. It is suggested that due to such costs introducing new products and replacing old ones become more difficult as the number of consumers grow in the market. The second mechanism, proposed by Dinopoulos and Syropoulos (2001), refers to the rent protection efforts of innovator firms. It is argued that firms spend more resources to protect their intangible assets in larger markets due to the relatively large number of imitators and innovators in such markets. Among others, Dinopoulos and Segerstrom (1999a) and Sener (2001) have used equation (15) in the context of two-country endogenous growth models.

[14] At each instant in time *a typical* R&D firm j in country i targeting an industry ω chooses the level of R&D intensity according to the production function $I_j^i(\omega,t) = H_j^i(\omega,t)/X(\omega,t)a^i$, where $I_j^i(\omega,t)$ denotes the probability of discovering the next higher quality product, and $H_j^i(\omega,t)$ shows the level of skilled labor employed. The *typical* firm in an R&D race maximizes the expected discounted profits $\Pi^i(\omega,t)\ I_j^i(\omega,t)dt - w_H^i(\omega,t)\ H_j^i(\omega,t)dt$, where $\Pi^i(\omega,t)$ represents the expected discounted profits of a *successful* innovator in country i. Firm j enjoys Π^i with probability $I_j^i(\omega,t)dt$ and incurs the cost $w_H^i(\omega,t)H_j^i(\omega,t)dt$. Free entry into R&D races implies that the above expression must be equal to zero. The ω terms drop out in a symmetric equilibrium in which the intensity of R&D targeted at the industries of country i is the same.

[15] Throughout the paper, I only focus on steady-states because the transitional dynamics appear to be analytically intractable. It should be noted that the relevant literature that uses R&D-based growth models mostly focus on steady-state changes. See, among others, Dinopoulos and Segerstrom (1999a), Sener (2001) and Arnold (2002). On the other hand, a number of papers have stressed the importance of medium-run dynamics in explaining the labor markets trends. See, for instance, Beaudry and Green (2003), Blanchard (1997) and Acemoglu (1998). However, there appears to be a consensus among researchers that the rise in European unemployment and US wage inequality are secular changes and hence can be properly analyzed by comparing steady-states [see for instance Acemoglu (1998) and Nickell (2003, pp. 4-8)]. To study the transitional dynamics in a similar R&D-based growth setting, a simplified model with exogenous steady-state growth and fixed factor supplies (for instance a two-country version of Segerstrom (1998)) can be more appropriate. For a recent paper that considers the impact of transitory changes on steady-state unemployment through endogenous policy response see Den Haan (2003).

[16] For models that consider this particular North-North trade structure see Thoenig and Verdier (2003), Dinopoulos and Segerstrom (1999a and 1999b) and Grossman and Helpman (1991, chapter 7). For an extensive discussion of shifts in comparative advantage using real world evidence see Dinopoulos and Segerstrom (1999b).

[17] More specifically, $w_H^A(P, n^A) = \sigma P^2\eta^A/\lambda(b_A)^2n^A$. The intuition for $\partial w_H^A/\partial P > 0$ is as follows. First, a higher P implies that firms can pay higher wages to their manufacturing workers and thus w_L^A increases (Lemma 1). For a given θ_0^A, neutralizing the increase in w_L^A requires a rise in w_H^A (TA(A) equation). Second, letting θ_0^A change, one can see that a higher P decreases the demand for final goods and hence the demand for less-skilled labor. Restoring equilibrium entails a decrease in θ_0^A (LM(A) equation). To generate the endogenous supply response, there must be increased incentives to acquire skills and thus a rise in w_H^A (TA(A) equation). The intuition for $\partial w_H^A/\partial n^A < 0$ is more straightforward. A higher n^A increases the demand for American less-skilled labor. Restoring equilibrium requires a rise in θ_0^A (LM(A) equation). To generate the endogenous supply response, there must be reduced incentives to acquire skills and thus a fall in w_H^A (TA(A) equation).

[18] In particular, an increase in w_H^A reduces the profitability of R&D and thereby leads to a fall in I^A (FE(A) equation). This lowers the demand for skilled labor and causes an endogenous decrease in the supply of skilled labor, which translates into a rise in θ_0^A (SM(A) equation).

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[19] More specifically, $w_H^E(n^E, u^E) = \sigma(w_L^*)^2(1 - u^E)^2\eta^E\lambda/n^E$. The intuition for $\partial w_H^E/\partial n^E < 0$ is as follows. A higher n^E raises the demand for less-skilled labor. For a given u^E, restoring equilibrium calls for a rise in θ_0^E (LM(E) equation). To generate the endogenous supply response, there must be reduced incentives to acquire skills and thus a reduction in w_H^E (TA(E) equation). The intuition for $\partial w_H^E/\partial u^E < 0$ is as follows. First, holding θ_0^E constant, a higher u^E requires a fall in the relative wage of skilled labor and thus a *reduction* in w_H^E (TA(E) equation). Second, allowing for θ_0^E to change, one can observe that a higher u^E reduces the effective supply of less-skilled labor, and thus restoring equilibrium requires an increase in θ_0^E (LM(E) equation). To generate the endogenous supply response, there must be reduced incentives to acquire skills and thus a *reduction* in w_H^E (TA(E) equation).

[20] In particular, a lower w_H^E renders R&D more profitable and leads to a rise in I^E (FE(E) equation). This raises the demand for skilled labor and causes an endogenous increase in the supply of skilled labor, which translates into a fall in θ_0^E (SM(E) equation).

[21] To see the this, first note that $w_H^E(n^E, u^E) = \sigma(w_L^*)^2(1 - u^E)^2\eta^E\lambda/n^E$ hence $\partial w_H^E/\partial w_L^* > 0$. Thus, a higher w_L^* raises $w_H^E(n^E, u^E)$ which in turn increases the supply of less-skilled θ_0^E via the reverse of the mechanism outlined in endnote (20). Second, a higher w_L^* raises P and reduces the demand for less-skilled labor. Consequently, with θ_0^E and P both rising, an excess supply of less-skilled labor emerges. For a given n^E, this leads to a rise in u^E, implying a leftward shift of the SS(U) curve. As a side note, the intuition for $\partial w_H^E/\partial w_L^* > 0$ is as follows. First, holding θ_0^E constant, one can observe that a higher w_L^* requires a rise in the relative wage of skilled labor and thus a higher w_H^E (TA(E) equation). Second, allowing for θ_0^E to change, one can see that a higher w_L^* reduces the demand for less-skilled labor, and thus requires a decrease in θ_0^E (LM(E) equation). To generate the endogenous supply response, there must be increased incentives to acquire skills and thus a rise in w_H^E (TA(E) equation).

[22] Alternatively, one can investigate the changes in the *observed* relative wage of the skilled worker with average ability level, $(1 + \theta_0)w_H^i/2w_L^i$. In all comparative statics considered, the *observed* average relative wage moves in the same direction as the relative wage measured in *efficiency* units w_H^i/w_L^i.

[23] To see the complete mechanism one can first derive a modified version of the $w_H^E(n^E, u^E)$ equation as $w_H^E(n^E, u^E) = \sigma(w_L^*)^2(1 - u^E(1 - \alpha)(^2\eta^E\lambda/n^E$. This implies that an increase in α raises the incentives to remain less skilled, putting upward pressure on w_H^E for a given skill distribution. Subsequently, a higher w_H^E renders R&D less profitable and leads to a fall in I^E. This depresses the demand for skilled labor and causes an endogenous decrease in the supply of skilled labor, which translates into a rise in θ_0^E.

[24] One can also consider global TCRD in unequal proportions. Suppose that the degree of proportionality between the technology shocks is given by k where $k = (da^E/a^E)/(da^A/a^A) > 0$. In this case, the elasticity condition implies that global TCRD reduces θ_0^E if and only if $\varepsilon(n^E, a^A) < 1/k$. Observe that if $k < 1$, the elasticity condition becomes less-stringent.

[25] The complete story is as follows. A rise in η^A increases the supply of less-skilled labor via two mechanisms. First, it directly increases $\theta_0^A\eta^A$. Second, it leads to a rise in w_H^A (note that $\partial w_H^A(n^A,P)/\partial\eta^A > 0$) which reduces R&D profitability and depresses the demand for skilled labor. This calls for an endogenous increase in the supply of less-skilled and raises θ_0^A. With P fixed, restoring equilibrium requires a rise in n^A and hence the rightward shift of the SS(A) curve.

[26] The complete story is as follows. A fall in η^E decreases the supply of less-skilled labor via two channels. First, it directly reduces $\theta_0^E\eta^E$. Second, it leads to a fall in w_H^E (note that $\partial w_H^E(n^E, u^E)/\partial\eta^E > 0$), which raises R&D profitability and boosts the demand for skilled labor. This calls for an endogenous decrease in the supply of less-skilled and reduces θ_0^E. With n^E fixed, restoring equilibrium entails a fall in u^E and hence the rightward shift of the SS(U) curve.

[27] This implication is also valid for all of the other steady-state comparative exercises under the general model. For a detailed and complete analytical discussion see Appendix B.

[28] Note that R&D expenditure in country i equals $I^i n^i w_H^i a^i X(t)$ and aggregate value added equals $cn^i N(t) + n^i \dot{V}^i$ (the sum of value added in manufacturing and R&D). Using these expressions along with the steady-state relationships $\dot{V}^i/V^i = n$, $V^i = a^i w_H^i kN$ and the normalization $c = 1$, it is straightforward to obtain the RD^i expression in the text.

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[29] The size of innovations $\lambda = 1.25$ measures the gross mark up enjoyed by innovators. Basu (1996) and Norrbin (1993) estimate this mark up to be in the range of 1.05 and 1.40. The rate of population growth $n = 0.005683$ is found by calculating the rate of growth for the combined population of Europe and the US. The data is from OECD (2002a). The subjective discount rate ρ is set at 0.07 to generate an interest rate of 0.07. This value is the average real return on the US stock market for the past century as measured by Mehra and Prescott (1985). To calculate σ and ϕ, I assume that life-time of an individual spent at work D is 40 years, and the length of training T is 4 years. The benefit rate $\alpha = 0.48$ is the average benefit rate in the 15 European countries for the period 1975-1995. This data is from Nickell and Nunziata (2001). The minimum wage in Europe is set at $w_L^* = 0.8034$ to generate an aggregate unemployment rate u^E_{AG} of 0.0816, which exactly equals the average unemployment rate in Europe during the period 1975-1995. The R&D difficulty parameter k is set at 1.583 to generate a world-wide R&D intensity $I^An^A + I^En^E$ of 0.0224, which in turn implies a growth rate of 0.5 percent. Note that the growth rate in this economy equals the growth rate in consumer utility $g = (I^An^A + I^En^E)\log\lambda$ [see Grossman and Helpman, 1991, p. 97]. This figure is consistent with the recent empirical estimates of Denison (1995) and Jones (2002) who suggest that the rate of growth driven by knowledge advancement is in the neighborhood of 0.5 percent. The skilled labor requirements in manufacturing are set at $h^A = h^E = 0.27$ such that the wage bill share of skilled labor is 0.3779 for America and 0.3726 for Europe. These figures are in the neighborhood of the values reported in Table 1. The choice of parameters and the resulting values are consistent with the recent simulation models based on endogenous growth models. See for instance Jones (2000), Lundborg and Segerstrom (2002), and Dinopoulos and Segerstrom (1999). Special thanks are to Paul Segerstrom for his suggestions on the choice of parameters.

[30] More specifically, for three additional cases—an increase in α, an increase in η^A and an increase in a^E—we now observe responses in the American variables. To get a sense of the magnitudes, consider for example a substantial 15 percentage points increase in α, which reduces $w_H{}^A/w_L{}^A$ by only 0.04% and increases $\theta_0{}^A$ by only 0.04%.

[31] Note that when u^E and $w_H{}^E/w_L^*$ move in opposite directions two competing effects on $\theta_0{}^E$ are observed. A higher u^E encourages skill upgrading whereas a lower $w_H{}^E/w_L^*$ discourages it (see the TA(E) equation). In the basic model with $\alpha = 0$, it is shown that under all such situations the former effect dominates the latter. However, as α increases, unemployment becomes less important in skill acquisition decisions. Indeed, there exists a critical level of α above which the unemployment effect is dominated by the relative wage effect. The simulation results indicate that under four particular events—an increase in w_L^*, a decline in a^A, a proportional decline in both b^A and h^A, and an increase in η^A—the benchmark level of $\alpha = 0.48$ is above the critical level that sets off the sign switch in $d\theta_0{}^E$.

[32] I choose the magnitudes of benchmark perturbations based on following considerations. I increase α by 15 percentage points, reflecting the increase in the unweighted average benefit rate in Europe from 0.35 to 0.50 between 1973 and 1989. I increase η^A by 2.5 percentage points, reflecting in the increase in the population share of America from 0.3897 to 0.4153 for the period 1975-1995. I set the change in w_L^* to fully account for the increase in the aggregate unemployment rate; thus w_L^* is increased by 8.5 percent to generate a 120 percent rise in $u_E{}^{AG}$. I set the changes in b^A and b^E to fully capture the increase in the wage bill share of non-production workers; thus, b^A and b^E are decreased by 15 percent to increase SH^A and SH^E by 18 percent. I set the changes in a^E and a^A to fully account for the rise in R&D intensities; thus, a^E and a^A are decreased by 20 percent to raise RD^A by 56.13 percent and RD^E by 42.47 percent. The resulting changes in the endogenous variables are in line with the figures reported in Table 1.

[33] The intuition is that when SBTC is local in Europe, n^E increases. The rise in n^E and the fall in P raises the demand for less-skilled labor more than offsetting the adverse effect stemming from the fall in b^E. However, when SBTC is global, with its rigid wage Europe loses it competitiveness and n^E decreases. As a result, the combined impact of n^E and b^E reduces the demand for less-skilled labor more than offsetting the positive effect coming from the fall in P.

[34] To test for the robustness of the numerical results, I reran the simulations using high and low values of the parameters. In all situations considered, there existed a unique equilibrium solution with strictly positive values for the endogenous variables in the relevant ranges. I found that the qualitative and quantitative results of the benchmark model are robust to alternative parameter choices with one caveat. Whenever $\theta_0{}^E$ and w^H/w_L^* move in opposite directions, the sign of $d\theta_0{}^E$ and dI^En^E may deviate from the basic model's predictions [see Table 2] at sufficiently high values of α [see endnote (31) for details].

[35] It is worth pointing out that the notion of TCRD fits quite closely with the notion of *intensive SBTC*, a particular form of SBTC a la Johnson (1997) by which skilled workers become more productive in their already existing jobs—as opposed to *extensive SBTC* by which skilled workers become more productive at jobs previously done by

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less-skilled workers. This link between TCRD and intensive SBTC becomes more definite when one adopts a broader definition of R&D that includes all activities conducive to creation and diffusion of knowledge, such as finance, accounting, marketing and so on. Johnson (1997) argues that in order to explain the widening wage gap, extensive SBTC should be more prevalent whereas my paper suggests that TCRD—which can be viewed as a subcategory of intensive SBTC—can also play a crucial role.

[36] The positive relationship identified between the relative wage of skilled and R&D intensity also finds supports from US time series evidence. The figures provided by Lloyd-Ellis (1999, p. 49) suggest that US investment rate in R&D, measured by the amount of grants, falls in the 70s and rises in the 80s, a pattern consistent with the changes in the US skill premium.

[37] See also Den Haan et al. (2001) for a theoretical model that formalizes the interaction hypothesis of Blanchard and Wolfers (2000) in a search unemployment setting. In particular, Den Haan et al (2001) show that unemployment effects of an adverse shock are magnified in the presence of high unemployment benefit replacement rates and high tax rates on labor income.

[38] See also Mortensen and Pissarides (1999) for a closed economy search unemployment model that explores the role of unemployment insurance and employment protection in affecting the relationship between relative labor demand shifts and unemployment.

Table 1. Stylized trends in manufacturing.
(Selected European countries and the US)

	1973	1977	1981	1985	1989	Changes (1989-1973)	
Nationwide unemployment rates							
Denmark	0.010	0.054	0.072	0.070	0.075	1.266	European average: 1.1679
France	0.027	0.049	0.073	0.102	0.094	1.579	
Germany	0.008	0.036	0.044	0.072	0.056	1.909	
Sweden	0.020	0.015	0.021	0.024	0.014	0.086	
UK	0.031	0.061	0.098	0.112	0.072	1.000	
US	0.048	0.069	0.075	0.075	0.052	0.086	
Nonproduction/production wage differentials							
Denmark	1.511	1.382	1.359	1.434	1.437	-0.008	European average: 0.0229
Sweden	1.487	1.549	1.532	1.493	1.509	-0.011	
UK	1.316	1.292	1.340	1.366	1.470	0.087	
US	1.553	1.531	1.532	1.559	1.623	0.032	
Employment share of nonproduction workers							
Denmark	0.251	0.270	0.292	0.293	0.318	0.173	European average: 0.1345
Germany	--	0.292	0.306	0.318	0.327	0.079	
Sweden	0.271	0.288	0.299	0.304	0.303	0.086	
UK	0.260	0.278	0.311	0.321	0.325	0.201	
US	0.246	0.261	0.285	0.305	0.303	0.199	
R&D intensity (R&D/Value Added)							
Denmark	0.021	0.022	0.270	0.031	0.039	0.628	European average: 0.5980
France	0.035	0.037	0.046	0.056	0.060	0.611	
Germany	0.032	0.037	0.043	0.052	0.055	0.551	
Sweden	0.038	0.050	0.063	0.080	0.081	0.830	
UK	0.043	0.046	0.064	0.062	0.060	0.371	
US	0.063	0.062	0.077	0.097	0.087	0.472	
Wage-bill shares of nonproduction workers							
Denmark	0.336	0.338	0.359	0.373	0.402	0.150	European average: 0.1524
Sweden	0.356	0.385	0.395	0.395	0.396	0.067	
UK	0.317	0.333	0.377	0.392	0.414	0.240	
US	0.337	0.351	0.379	0.406	0.414	0.192	

Note: All changes are as percent changes (e.g., European average unemployment rate increased by 116.79%). To smooth the percentage change figures, percentage difference between the averages of (85-89) and (73-77) are reported. Average change figures pertaining to Europe are based on unweighted calculations.

Source: Unemployment rates are from Nickell and Nunziata (2001). The rest of the indicators are based on manufacturing data as presented in Machin and Reenen (1998). Choice of countries strictly follows Machin and Reenen who provide comparable and reliable data for a select group of OECD countries. As is common in the literature, figures pertaining to nonproduction and production workers are used to proxy values for skilled and less-skilled labor. For trends in other high income OECD countries at different time intervals see Berman et al. (1998) and Hollanders and Weel (2002) .

Table 2. Comparative steady-state results: Basic model with $\alpha = 0$

Shocks and Institutional Changes	Unemployment Europe du^E	Relative skilled wage America $d(w_H^A / w_L^A)$	Relative skilled wage Europe $d(w_H^E / w_L^*)$	Share of less-skilled America $d(\theta_0)^A$	Share of less-skilled Europe $d(\theta_0)^E$	R&D intensity America $dl^A n^A$	R&D intensity Europe $dl^E n^E$
Minimum wage increase ($w_L^* \uparrow$)	+	–	–	+	–	–	+
Unemployment benefit rate increase ($\alpha \uparrow$)	+	0	+	0	+	0	–
Local technological change in R&D: American case ($a^A \downarrow$)	–	+	+	–	+	+	–
Local technological change in R&D: European case ($a^E \downarrow$)	–	0	+	0	–	0	+
Global and equiproportionate technological change in R&D ($a^E \downarrow$ and $a^A \downarrow$)	–	+	+	–	– iff $\varepsilon(n_E, a) < 1$	+	+ if $\varepsilon(n_E, a) < 1$
Relative decline in European manufacturing productivity $(b^E/b^A)\uparrow$	+	–	–	+	–	–	+
Increase in the share of America in the global population ($\eta^A \uparrow$)	+ iff $n^A > \eta^A$	0	– iff $n^A > \eta^A$	0	– iff $n^A > \eta^A$	+	+/–

Table 3. Simulation results for the general model

		8.5 % rise in w_L*		15 % points rise in α		20% fall in a^A		20% fall in a^E		20% fall in a^E and a^A	
	Benchmark	Levels	Changes	Levels	Changes	Levels	Changes	Levels	Changes	Levels	Changes
n^E	0.4776	0.4478	-0.0622	0.4759	-0.0034	0.4891	0.0241	0.4721	-0.0114	0.4836	0.0127
u^E	0.1093	0.2327	1.1281	0.1192	0.0902	0.0885	-0.1905	0.1049	-0.0404	0.0835	-0.2365
w_H^A/w_L^A	1.9165	1.9032	-0.0069	1.9157	-0.0004	1.9698	0.0278	1.9140	-0.0013	1.9677	0.0267
w_H^E/w_L^*	1.7612	1.5826	-0.1014	1.7761	0.0085	1.7892	0.0159	1.8110	0.0283	1.8418	0.0458
θ_0^A	0.7052	0.7101	0.0070	0.7054	0.0004	0.6861	-0.0271	0.7061	0.0013	0.6868	-0.0260
θ_0^E	0.7237	0.7506	0.0372	0.7273	0.0050	0.7205	-0.0044	0.7055	-0.0252	0.7019	-0.0302
l^An^A	0.0105	0.0091	-0.1334	0.0104	-0.0073	0.0198	0.8884	0.0102	-0.0245	0.0195	0.8639
l^En^E	0.0119	0.0122	0.0238	0.0115	-0.0334	0.0115	-0.0333	0.0209	0.7505	0.0205	0.7197
RD^A	0.0469	0.0402	-0.1439	0.0466	-0.0080	0.0744	0.5847	0.0457	-0.0266	0.0733	0.5613
RD^E	0.0550	0.0586	0.0649	0.0538	-0.0220	0.0527	-0.0413	0.0804	0.4611	0.0783	0.4246
u^E_{AG}	0.0816	0.1796	1.2005	0.0894	0.0951	0.0658	-0.1937	0.0765	-0.0626	0.0606	-0.2577
SH^A	0.3780	0.3992	0.0561	0.4055	0.0729	0.4318	0.1423	0.4047	0.0706	0.4308	0.1396
SH^E	0.3726	0.3880	0.0414	0.4023	0.0798	0.4075	0.0937	0.4185	0.1231	0.4260	0.1434
P	1.4818	1.5552	0.0495	1.4858	0.0027	1.4894	0.0051	1.4953	0.0091	1.5037	0.0148

		15% fall in b^A and h^A		2.5 % points rise in η^A		15% fall in b^A		15% fall in b^E		15% fall in b^E and b^A	
	Benchmark	Levels	Changes	Levels	Changes	Levels	Changes	Levels	Changes	Levels	Changes
n^E	0.4776	0.3964	-0.1699	0.4519	-0.0536	0.4213	-0.1179	0.5215	0.0921	0.4709	-0.0140
u^E	0.1093	0.2583	1.3623	0.1127	0.0303	0.2123	0.9415	0.0581	-0.4687	0.1459	0.3342
w_H^A/w_L^A	1.9165	1.8808	-0.0186	1.9167	0.0001	1.9841	0.0353	1.9366	0.0105	2.0080	0.0477
w_H^E/w_L^*	1.7612	1.5627	-0.1127	1.7567	-0.0025	1.6236	-0.0781	1.9093	0.0841	1.7809	0.0112
θ_0^A	0.7052	0.7185	0.0190	0.7051	-0.0001	0.6811	-0.0341	0.6978	-0.0104	0.6730	-0.0456
θ_0^E	0.7237	0.7486	0.0344	0.7242	0.0007	0.7405	0.0232	0.6864	-0.0515	0.7013	-0.0310
l^An^A	0.0105	0.0067	-0.3642	0.0110	0.0523	0.0070	-0.3355	0.0126	0.1975	0.0093	-0.1115
l^En^E	0.0119	0.0144	0.2069	0.0114	-0.0451	0.0137	0.1493	0.0094	-0.2108	0.0113	-0.0530
RD^A	0.0469	0.0289	-0.3847	0.0470	0.0024	0.0311	-0.3380	0.0572	0.2195	0.0424	-0.0967
RD^E	0.0550	0.0711	0.2926	0.0554	0.0065	0.0661	0.2027	0.0430	-0.2177	0.0534	-0.0290
u^E_{AG}	0.0816	0.1989	1.4367	0.0841	0.0309	0.1618	0.9826	0.0413	-0.4939	0.1058	0.2962
SH^A	0.3780	0.3876	0.0256	0.4060	0.0741	0.4385	0.1600	0.4159	0.1002	0.4494	0.1888
SH^E	0.3726	0.3919	0.0518	0.4003	0.0744	0.4060	0.0896	0.4344	0.1658	0.4405	0.1821
P	1.4818	1.4280	-0.0363	1.4806	-0.0008	1.4445	-0.0252	1.3713	-0.0746	1.3365	-0.0981

Note: All changes are in percentage terms (e.g. an 8.5% rise in w_L* increases u^E by 112.81%)

Table 4. Illustrative comparisons of observed trends with numerical simulations

		Case 1		**Case 2**		**Case 3**		**Case 4**	
		• 20 % global TCRD • w_L* increased to fully restore initial relative wage		• 15 % global SBTC • w_L* increased to fully restore initial relative wage		• 20% global TCRD • 15% global SBTC • w_L* increased to fully restore initial relative wage		• 20% global TCRD • 15% global SBTC • w_L* increased to partially restore initial relative wage	
	Observed changes	Simulated changes	Percent explained	Simulated changes	Percent explained	Simulated changes	Percent explained	Simulated changes	Percent explained
w_H^A / w_L^A	0.0318	0.0244	0.7685	0.0470	1.4790	0.0741	2.3288	0.0752	2.3633
w_H^E / w_L^*	0.0229	0.0001	0.0028	0.0000	-0.0018	-0.0001	-0.0022	0.0210	0.9190
RD^A	0.4720	0.5132	1.0873	-0.1104	-0.2339	0.4208	0.8915	0.4426	0.9376
RD^E	0.5980	0.4480	0.7492	-0.0222	-0.0371	0.4295	0.7182	0.4187	0.7002
u^E_{AG}	1.1679	0.2245	0.1922	0.4117	0.3525	0.6106	0.5229	0.4019	0.3441
SH^A	0.1919	0.1342	0.6994	0.1872	0.9755	0.2472	1.2884	0.2496	1.3007
SH^E	0.1524	0.1301	0.8540	0.1786	1.1716	0.2331	1.5294	0.2393	1.5705

Note: All changes are in percentage terms (e.g. the observed change in u^E is 116.79%). "Percent explained" is calculated by taking the ratio of "simulated change" to "observed change". Observed changes come from Table 2. Under the percent explained column, a value above (below) 1 implies over-simulating (under-simulating) the observed effect. A value below 0 implies that the simulated effect is in the wrong direction.

Figure 1. Steady-state equilibrium in the global economy

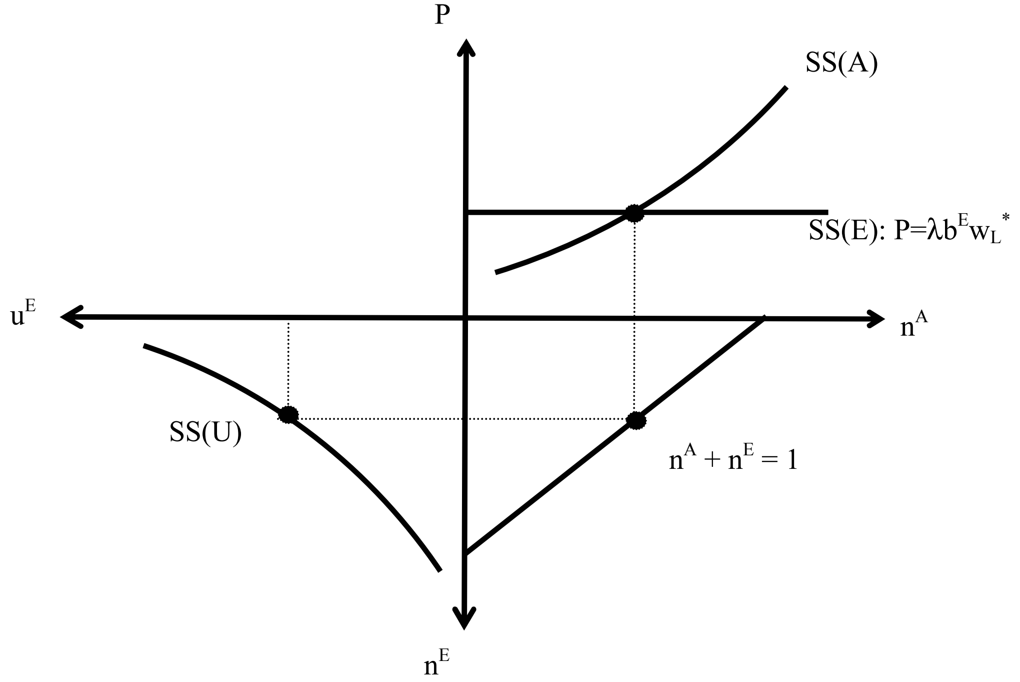


Figure 2. An increase in the European minimum wage: $w_L{}^*\uparrow$

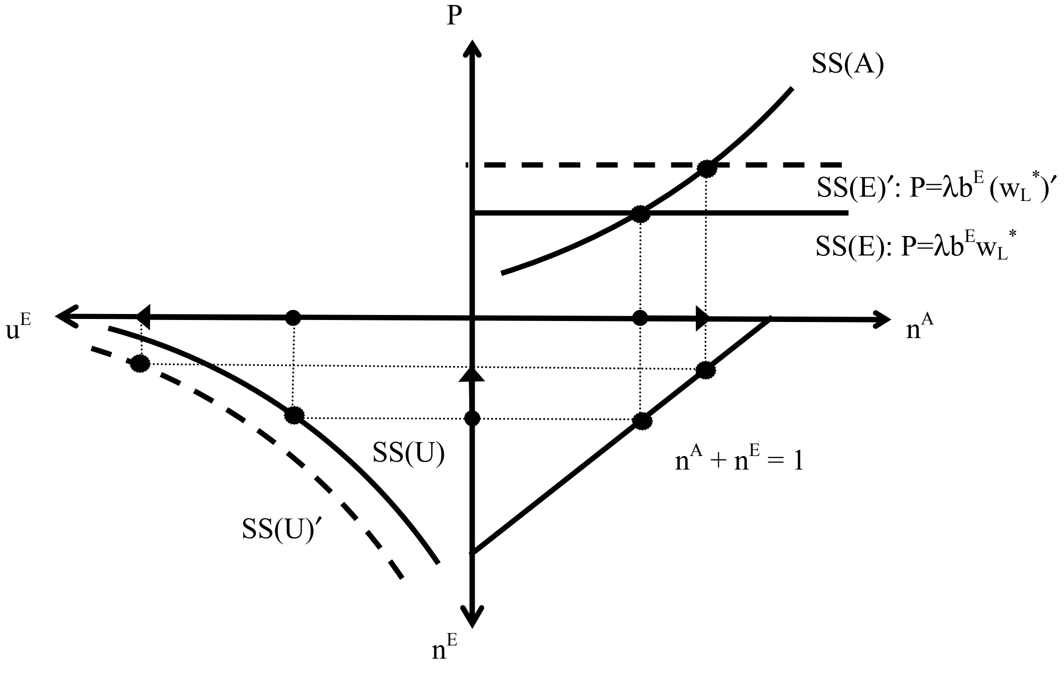


Figure 3. An increase in unemployment benefit rate: α↑

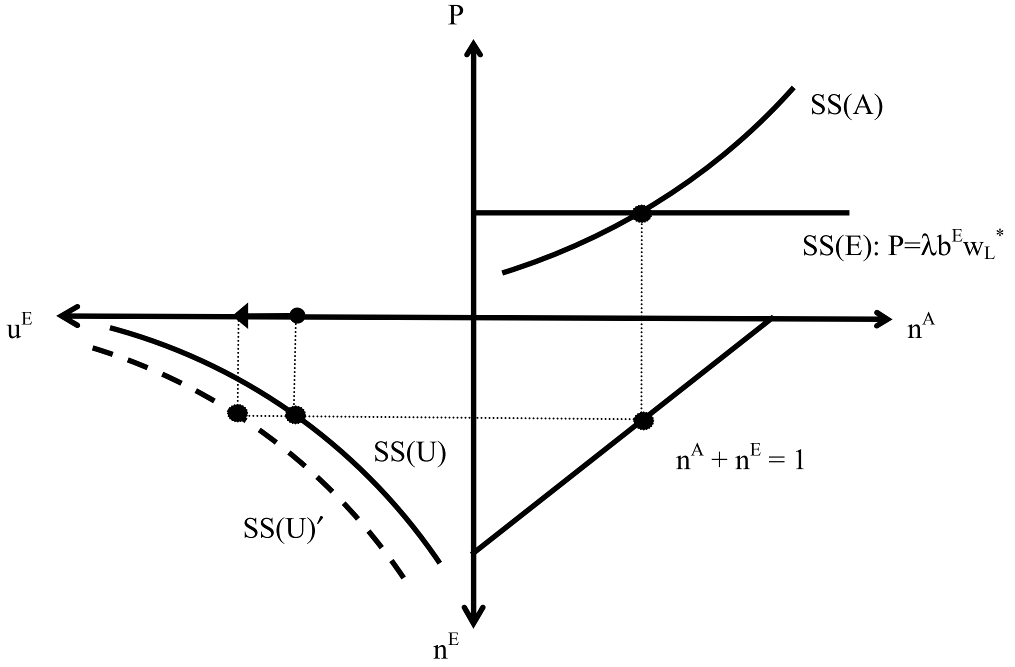


Figure 4. Global technological change in R&D: a^E and a^A both ↓

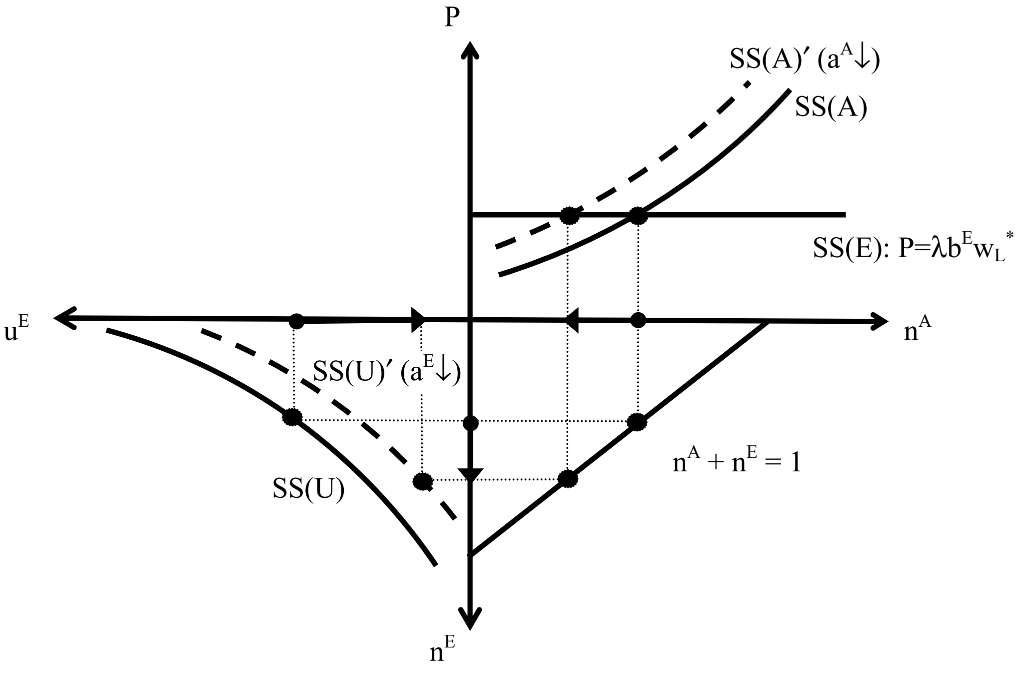


Figure 5. An increase in the world population share of America: $\eta^A\uparrow$
(the case when $n^A > \eta^A$)

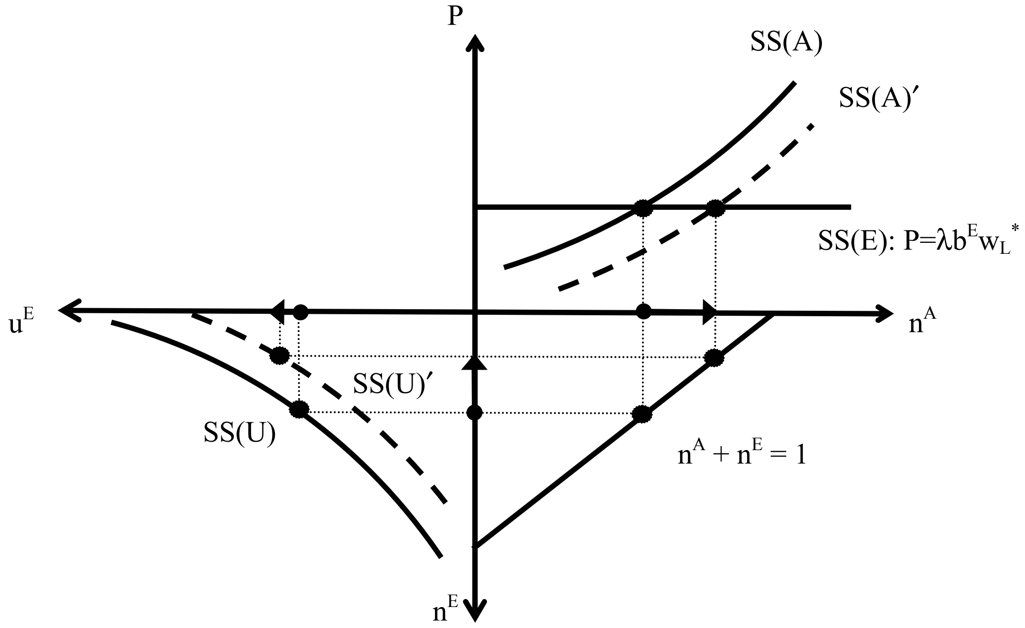
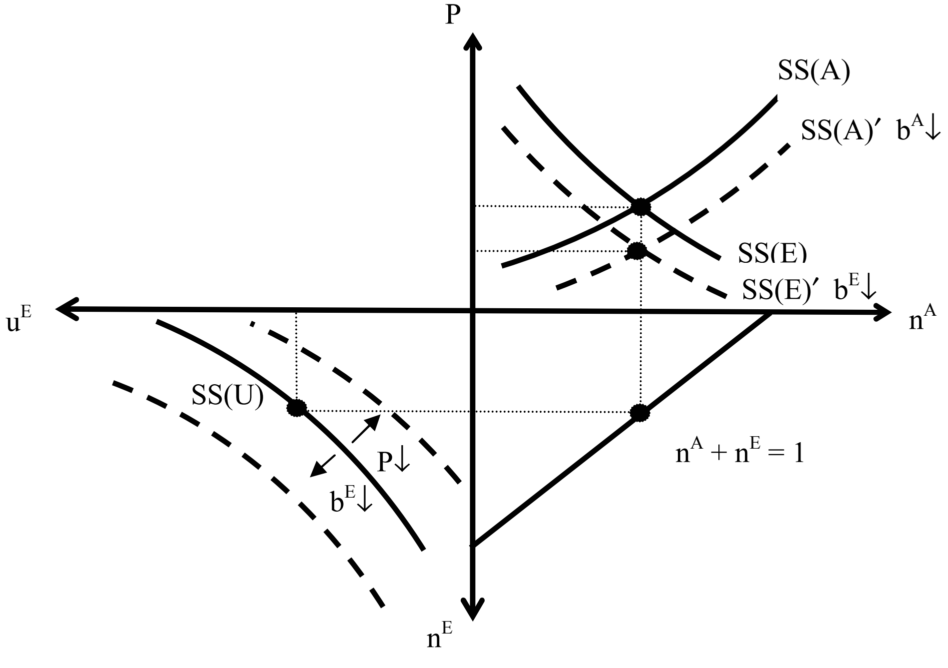


Figure 6. Global skill-biased technological change in manufacturing: b^A and b^E both ↓



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