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Skilled Labor Reallocation, Wage Inequality, and Unskilled Unemployment

by

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This paper analyzes the labor market effects of an increase in incentives in raising total factor productivity and, thus, reallocating high-skilled labor from production to non-production (i.e., R&D) activities. Within an endogenous growth framework, it is shown that such a reallocation of skilled labor depresses the demand for low-skilled labor. Contrary to the standard view of skill-biased technological change, the relative marginal productivity of labor changes only because of relative employment effects. Moreover, the impact of social comparisons between high-skilled and low-skilled workers and within the group of low-skilled workers are examined. (JEL: J 31, 0 31, 0 41)

1. Introduction

Unemployment rates of low-skilled labor in the OECD are nowadays much higher (in absolute terms as well as relative to high-skilled labor) than in the 1970s (e.g., NICKELL AND BELL [1997, tab. 10.2], OECD [1997, tab. 4.1b]). In addition, despite a rising relative supply of high-skilled labor, wage inequality has not fallen or has even risen (e.g., in the US and UK) in the last two decades (e.g., GOTTSCHALK AND SMEEDING [1997]).

These facts strongly indicate that relative labor demand has shifted towards high-skilled labor, thus worsening the labor market situation for low-skilled workers. According to the standard view, this shift has been due to "a change in the production function that raises the marginal product of the skilled relative to the un-

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skilled" (KRUGMAN [1994, 37]),[1] a hypothesis which is commonly referred to as *skill-biased technological change* (SBTC).[2]

This paper suggests another technology-related channel to explain the observed labor market developments. It is argued that a reallocation of skilled labor from production to skill-intensive non-production activities changes relative labor demand if skilled and unskilled labor are technological complements in production. Non-production activities are assumed to increase total factor productivity and are specified as R&D. The model reflects the notion that technological shocks such as the wide-spread adoption of personal computers and new information technologies lead to productivity gains only if skilled labor is shifted towards the search for new ways to organize and coordinate work. Thus, contrary to the standard view, *SBTC does not have to be reflected in changes of the relative productivity of different types of labor.* This different notion of SBTC is of considerable importance for theoretical as well as empirical reasons. First, if technological change were skilled labor-saving, i.e., made skilled workers more efficient in *production* activities already performed by skilled workers (sometimes called "intensive" SBTC),[3] then the effect on relative labor demand would be ambiguous. This is because, with technology reflected by a neoclassical production function with skilled and unskilled labor, skilled-labor-augmenting technical progress raises the relative demand for skilled workers *only if* the elasticity of substitution between skilled and unskilled labor exceeds unity (JOHNSON [1997]). In contrast, if technological change leads to a reallocation of skilled workers towards skilled-labor-intensive *non-production* activities, the relative demand for skilled labor in production rises *unambiguously* (at given wages). Second, a reallocation of (mainly) skilled workers to non-production activities is exactly in line with the empirical evidence on the skill-bias hypothesis (e.g., BERMAN, BOUND, AND GRICHILIS [1994], MACHIN, RYAN, AND VAN REENEN [1996], BERMAN, BOUND, AND MACHIN [1998]). However, this kind of evidence has been commonly interpreted as a relative labor productivity shift for *given* production employment levels, a theoretical view which has been criticized since it is not directly testable (e.g., BLANCHARD [1997], THUROW [1998]). In contrast, our model is not only empirically supported but also

[1] See ACEMOGLU [1998] for a model, in which the relative labor productivity is endogenously determined by the relative supply of skilled labor.

[2] Another explanation is that increased import competition of low-skilled labor intensive products mainly contributed to relative labor demand shifts (e.g., FREEMAN [1995]). However, according to tests based on the Heckscher-Ohlin-Samuelson model (e.g., HANSON AND HARRISON [1995], NEVEN AND WYPLOSZ [1996]) and factor content studies (e.g., KATZ AND MURPHY [1992]) the evidence for the trade hypothesis is rather weak. Moreover, contrary to a trade-based explanation of skill-upgrading or rising wage dispersion, these shifts have taken place *within* rather than *between* industries (see, e.g., BERMAN, BOUND, AND GRICHILIS [1994], MACHIN AND VAN REENEN [1998]). However, this fact may be consistent with increasing trade in intermediate rather than in final products (for a discussion, see, e.g., AGHION, CAROLI, AND GARCÍA-PEÑALOSA [1999]).

[3] See JOHNSON [1997] who in contrast views "extensive" SBTC as making the skilled more efficient in tasks formerly performed by the unskilled.

provides a more differentiated view as to *why* skilled labor has shifted into non-production activities.

In order to fix ideas, a segmented labor market for high-skilled and low-skilled workers is introduced in the endogenous growth framework of AGHION AND HOWITT [1992]. In this framework, production efficiency rises in a Hicks-neutral way, i.e., it leaves the relative productivity parameters of skilled and unskilled labor unchanged. There are two production-related activities and one non-production-related activity in the economy. The non-production activity is specified as the search for new intermediate products. For simplicity, only the latest blue-print for an intermediate good (which is associated with the highest total factor productivity) is produced and used as input for the production of a homogenous consumption good. Concerning technologies, two crucial assumptions drive the results of the paper. First, the non-production (i.e., research) activity is assumed to be skill-intensive (for simplicity, *only* high-skilled labor is used). Second, in the production of final goods, skilled and unskilled labor are technological complements. The special framework of AGHION AND HOWITT [1992] provides an appropriate structure for the general idea of the paper. However, as will be argued later, it is not necessary for the results obtained here and is chosen mainly for its familiarity.

The basic mechanism of the model is as follows. If the expected gains from the non-production activity (i.e., research incentives) increase, skilled labor is reallocated from production towards non-production (i.e., R&D).[4] Because of the decline in the employment of skilled labor in production, the relative marginal productivity of unskilled labor declines. Hence, if relative wages are fully flexible, wage inequality rises due to the resulting shift in relative labor demand.

If, however, relative wages are sticky, unskilled employment may be declining as well. *Relative wage stickiness* arises from efficiency wage payments due to social comparisons between high-skilled and low-skilled workers in final goods production.[5] Following AKERLOF AND YELLEN [1990], workers adjust their effort level downward whenever they feel treated unfairly. Thus, firms can improve work effort by paying higher wages. As a new feature of the model, *within-group* social comparisons of workers are also considered. As a result, if the wage rate of unskilled workers in final goods production exceeds its marginal productivity, the wage rate of unskilled workers in the intermediate goods production may not adjust sufficiently downward to imply full employment. That is, within-group social comparisons give rise to absolute wage stickiness.

Recent studies provide overwhelming empirical evidence for sociological efficiency wage models and their implications for wage stickiness. These include surveys on the motivating forces of decision-makers within firms behind the payment structure (e.g., LEVINE [1993], AGELL AND LUNDBORG [1995], BEWLEY [2000]) as well as experimental results about fairness considerations in experimental stud-

[4] In the framework adopted by of AGHION AND HOWITT [1992], intermediate goods production is monopolized due to patent rights. Thus, increasing research incentives stimulate the demand for skilled labor in R&D by raising the profits of the incumbent monopolist.

[5] These social comparisons may be made for envy, status, or equity considerations.

ies (e.g., FEHR, KIRCHSTEIGER, AND RIEDL [1993], FEHR, GÄCHTER, AND KIRCHSTEIGER [1996]). Moreover, there is evidence that the wages of low-skilled workers vary positively with the wages of better qualified workers within industries (e.g., SLICHTER [1950], KRUEGER AND SUMMERS [1987], [1988]).

The analysis suggests three kinds of relationships: (i) between technological change (or growth) and employment of low-skilled workers, (ii) between technological change and wage inequality, and (iii) between low-skilled employment and wage inequality.[6] Unlike in SAINT-PAUL [1996], AGÈNOR AND AIZENMAN [1997] and GREGG AND MANNING [1997] the relationships derived between technological change, wage inequality, and unemployment do not rest on changes in relative labor productivity parameters.

The paper is organized as follows: Section 2 sets up an efficiency wage model with production and non-production activities performed by low-skilled and high-skilled workers, respectively. Section 3 defines the steady-state equilibrium and derives important mechanisms underlying the comparative static results presented in section 4. Section 5 discusses the basic idea of the model and relates it to the empirical evidence. The last section summarizes. All proofs as well as transitional dynamics are given in the appendix.

2. The Model

There is a segmented labor market for high-skilled ("skilled") and low-skilled ("unskilled") labor. Unskilled labor can be allocated to produce an intermediate good which is an input for the production of a homogenous consumption good. Skilled labor used in non-production raises efficiency (i.e., total factor productivity) in final goods production. This non-production activity can be interpreted as research for new intermediate products. Besides the latest (most productive) intermediate good, both skilled and unskilled labor are inputs for the production of the consumption good. The supply of both skilled and unskilled labor is inelastic and denoted by H and L, respectively. However, the supply of *effort* by workers (rather than the supply of working hours) is a function of actual wages *relative to reference wages*. Reference wages are determined by social comparisons. Labor mar-

[6] That is, besides suggesting an alternative view about relative labor demand shifts, the model also offers an additional channel through which the rate of growth and unemployment are related. This should be compared to the earlier literature. Taking the rate of productivity growth as exogenous, PISSARIDES [1990, ch. 2] and HOON AND PHELPS [1997] derive a positive impact of growth on employment. In these models, higher expected productivity growth raises future opportunity costs of firms to invest in training of workers. In a model with endogenous investment-driven growth and matching frictions, BEAN AND PISSARIDES [1993] find an ambiguous growth-employment relationship. AGHION AND HOWITT [1994] show that, due to the creative destruction (i.e., "business stealing") effects of innovations, faster technical progress can lower employment in the presence of matching frictions. Also FALKINGER AND ZWEIMÜLLER [2000] obtain a negative relationship as their main case. In our model, there is a trade-off between endogenous technological change and employment due to social comparisons among workers rather than to imperfect matching.

kets are perfectly competitive in the sense that firms take marginal costs per unit of *effective* labor services as given. The economy is closed and agents are assumed to have perfect foresight. Both final goods production and research take place in perfect competition, whereas intermediate goods production can be monopolized by a successful innovator. Time is continuous and the length between two innovations is random. Each monopoly lasts only until the next innovation is made, whereas each patent for an intermediate product lasts forever. The price for each patent is equal to the expected present value of the flow of monopoly profits.

2.1 Final Goods Production

Output Y of the consumption good (which is the numeraire commodity) is produced using skilled and unskilled labor as well as an intermediate product of quantity x. The technology of a representative firm exhibits constant returns to scale and is, at each instant, given by the following production function:

$$(1) \qquad Y = A\,(e^{HY} H^Y)^{\alpha}\,(e^{LY} L^Y)^{\beta}\,x^{1-\alpha-\beta}, \quad \alpha > 0, \quad \beta > 0, \quad \alpha + \beta < 1\,.$$

H^Y and L^Y denote the amounts of skilled and unskilled labor with corresponding effort levels e^{HY} and e^{LY}, respectively. Denote t as the number of innovations which have occurred up to the present time. Following AGHION AND HOWITT [1992], the productivity parameter,

$$(2) \qquad A_t = A_0\,\gamma^t,$$

increases with a constant factor $\gamma > 1$ each time an innovation occurs. $A_0 > 0$ is assumed to be historically given.

2.2 Intermediate Goods Production

As will be shown below, all variables remain at the same level during the random time interval for which the monopolized production of patent t lasts. Let H_t^Y, L_t^Y, e_t^{HY}, and e_t^{LY} denote the levels of skilled and unskilled employment and effort provision, respectively, in final goods production within time interval t. According to (1), the tth monopolist of an intermediate product faces an inverse demand function:

$$(3) \qquad p_t(x) = (1-\alpha-\beta)\,A_t\,(e_t^{HY} H_t^Y)^{\alpha}\,(e_t^{LY} L_t^Y)^{\beta}\,x^{-(\alpha+\beta)}\,.$$

Intermediate goods are produced according to a constant returns to scale technology

$$(4) \qquad x = e^{LX} L^X,$$

where $(e^{LX} L^X)$ are efficiency units of unskilled labor used by the incumbent monopolist. Maximization of profits $\pi_t \equiv \max\limits_{x \geq 0} \{p_t(x)\,x - (w_t^{LX}/e_t^{LX})\,x\}$ of the tth monopolist implies

$$(5) \qquad x_t = \left(\frac{A_t (1-\alpha-\beta)^2 (e_t^{HY} H_t^Y)^\alpha (e_t^{LY} L_t^Y)^\beta}{(w_t^{LX} / e_t^{LX})} \right)^{\frac{1}{\alpha+\beta}},$$

where w_t^{LX} is the wage rate of unskilled labor in intermediate goods production. Hence, the incumbent monopolist sets a price $p = (w^{LX}/e^{LX})/(1-\alpha-\beta)$ as a fixed mark-up over marginal costs per unit of effective labor. (For notational convenience, the variable index t is suppressed whenever this does not lead to confusion.) Moreover, as long as the intermediate product has not yet become obsolete, instantaneous profits are given by

$$(6) \qquad \pi = (\alpha+\beta)\, p\, x = A \left(\frac{a\, (e^{HY} H^Y)^\alpha (e^{LY} L^Y)^\beta}{((w^{LX} / e^{LX})/A)^{1-\alpha-\beta}} \right)^{\frac{1}{\alpha+\beta}},$$

where $a \equiv (\alpha+\beta)^{\alpha+\beta} (1-\alpha-\beta)^{2-\alpha-\beta} > 0$ is an unessential constant.

2.3 Research

The waiting time for a new patent is exponentially distributed with parameter $f(e^{HR} H^R)$, where H^R is the amount of skilled labor used in research, e^{HR} is the corresponding effort level, and $f(\cdot)$ is an increasing and concave function with $f(0) = 0$. Note that the exponential distribution of the waiting implies that innovations are governed by a Poisson process, and that, approximately, $f(\cdot)$ is the instantaneous probability for an innovation to occur (see, e.g., AGHION AND HOWITT [1998]).

Let w_t^{HR} denote the wage rate of skilled labor in research after t innovations and V_{t+1} the expected discounted payoff to the $(t+1)$st innovator. The representative research unit maximizes the flow of expected profits at any point in time. Hence, in an interior solution, the labor input is chosen such that the expected marginal product of one efficiency unit of skilled labor equals its wage per unit of effort:[7]

$$(7) \qquad (w_t^{HR}/e_t^{HR}) = f'(e_t^{HR} H_t^R)\, V_{t+1}.$$

Since innovations are governed by a Poisson process with parameter $f(e^{HR} H^R)$, $\exp(-f(e^{HR} H^R)\, d\tau)$ is the probability that no innovations occur in the time interval $d\tau$, when $(e^{HR} H^R)$ efficiency units of skilled labor are used in research. Hence, if the $(t+1)$st innovator discounts instantaneous monopoly profits π_{t+1} at a constant (exogenous) rate r, the value of the $(t+1)$st innovation is given by

$$(8) \qquad V_{t+1} = \int_{\tau_{t+1}}^{\infty} \pi_{t+1} \exp(-(r + f(e_{t+1}^{HR} H_{t+1}^R))(\tau - \tau_{t+1})\, d\tau = \frac{\pi_{t+1}}{r + f(e_{t+1}^{HR} H_{t+1}^R)},$$

[7] A sufficient condition for an interior solution of the allocation of skilled labor in production and research in perfect foresight equilibrium derived below is given in the appendix.

where τ_{t+1} denotes the point in time at which innovation $t+1$ has arrived. The denominator in (8) can be interpreted as the interest rate faced by the $(t+1)$st innovator incorporating the risk of being replaced by the next innovation.[8]

2.4 *Effort Supply and Fair Wages*

Effort supply in either group is assumed to be an increasing and concave function of the actual wage w paid by firms relative to a reference wage $\tilde{w}$; that is:

$$e^i = \tilde{e}\,(w^i/\tilde{w}^i), \quad i = HY, LY, LX, HR. \tag{9}$$

Reference wages are to be interpreted as wage rates workers perceive as fair. (These fair wages will be specified below.) If actual wages are equal to fair wages, workers supply a normalized effort equal to unity; i.e., $\tilde{e}\,(1) = 1$. Wages and labor inputs are chosen in order to maximize profits subject to the respective effort supply functions (9), taking fair wages $\tilde{w}$ as given. It is easy to show that wages are set according to the following rule:

$$\frac{\tilde{e}'(w^i/\tilde{w}^i)\,(w^i/\tilde{w}^i)}{\tilde{e}(w^i/\tilde{w}^i)} = 1, \quad i = HY, LY, LX, HR. \tag{10}$$

(10) states that it is optimal for firms to pay wages such that the elasticity of effort supply with respect to the ratio between actual and fair wages equals unity. This is similar to the "Solow condition" (Solow [1979], Schlicht [1978]), and is explicitly stated in Schlicht [1992]. (10) implies that wages are set proportionally to their reference levels.

Reference wages are assumed to be based on social comparisons among workers and are specified as follows. In final goods production, fair wages are given by[9]

$$\tilde{w}^{LY} = \eta\, w^{HY} + (1-\eta)\, w^{L*}, \quad 0 \le \eta \le 1, \tag{11}$$

$$\tilde{w}^{HY} = \nu\, w^{LY} + (1-\nu)\, w^{H*}, \quad 0 \le \nu \le 1, \tag{12}$$

where w^{L*} and w^{H*} denote the market clearing wages of unskilled and skilled labor, respectively. That is, the fair wage of unskilled (skilled) workers in final goods production is the weighted average of the wage received by skilled (unskilled) co-workers and the market clearing wage of unskilled (skilled) workers. If

[8] Treating the interest rate as exogenous in an intertemporal model may seem peculiar. As is argued in Aghion and Howitt [1992, 331], this can be theoretically founded by assuming that the intertemporal utility equals the discounted life-time consumption (with discount rate r) and there is either a frictionless Walrasian credit market or no credit market at all. Either way, with linear utility, agents do not have a motive to use capital markets for risk-sharing in this framework.

[9] See Akerlof and Yellen [1990] for a similar specification in a model with one representative firm.

there were not any social comparisons among workers, w^{L*} and w^{H*} would be the economy's full employment equilibrium wages.[10] However, as will be seen below, due to fairness considerations of unskilled workers, there may neither be full employment among the unskilled nor may wages of unskilled labor in final and intermediate goods production be equal. Note that, according to (11) and (12), if $\eta < 1$ and $\nu < 1$, wage levels perceived as fair depend on labor market conditions,[11] i.e., fair wages are low when productivity and thus the market clearing wage is low.[12] However, fair wages may depart from market clearing levels because of social comparisons *across skill groups* (i.e., $\eta > 1$ and $\nu > 1$).

Concerning fair wages of both unskilled workers in intermediate goods production and skilled workers in research, it is assumed that these workers make *within-group* comparisons with workers in final goods production. This may be formalized as:

$$\tilde{w}^{LX} = \mu\, w^{LY}, \quad \mu > 0\,; \tag{13}$$

$$\tilde{w}^{HR} = w^{HY}\,. \tag{14}$$

According to (13) and (14), both reference wages are proportional to the actual wages of equally qualified workers in final goods production. As we focus on unskilled employment, fair wages of skilled workers in research are not only proportional but also equal to skilled wages in production.[13]

In order to distinguish skilled from unskilled workers in a meaningful way, it is plausible to assume the following.

Assumption 1: Skilled workers are either sufficiently more productive or sufficiently short in supply relative to unskilled workers such that $w^{H*} > w^{L*}$ holds for any allocation of skilled workers in production and non-production.

Now we specify the effort supply function (9). If the actual wage paid to workers is lower than the fair wage, effort supplied by workers is only a fraction of its normal level. Accordingly,[14]

$$e^i = \tilde{e}\,(w^i/\tilde{w}^i) = \min\{(w^i/\tilde{w}^i),\, 1\}\,, \quad i = HY, LY, LX, HR\,. \tag{15}$$

[10] That is, without social comparisons, w^{L*} and w^{H*} would be equal to the marginal productivity of unskilled and skilled workers in final goods production, respectively.

[11] For empirical evidence that labor market conditions substantially affect workers' fairness perceptions, see, e.g., KAHNEMAN, KNETSCH, AND THALER [1986].

[12] As shown in appendix A, w^{L*} positively depends on the equilibrium employment level of skilled labor in production H^Y and negatively on labor supply L.

[13] This is assumed here merely for simplicity reasons. Moreover, one would not gain any further insight if allowing reference wages in (13) and (14) to be some weighted average analogous to (11) and (12).

[14] This follows AKERLOF AND YELLEN [1990], who argue (giving a extensive list of references) that this specification formalizes a "fair wage-effort hypothesis" which is consistent with various sociological theories.

Under this specification, the wage setting rule (10) holds for any wage $w \leq \tilde{w}$, since the marginal costs per unit of effective labor in either group equals its wage per unit of effort w/e. Moreover, if $w \leq \tilde{w}$, w/e equals the fair wage $\tilde{w}$, according to (15). In order to obtain unique wages, it is sufficient to impose the following.

Assumption 2: If profits are unaffected by paying different wages including the wage workers perceive as fair, firms prefer to pay the fair wage.[15]

Note that, according to (10) and (15), all firms are indifferent in paying any wage rate $w^i \in (0, \tilde{w}^i]$, $i = HY, LY, LX, HR$. Thus, assumption 2 implies that firms do not pay less than fair wages, i.e., workers supply normal effort $e^i = 1$, $i = HY, LY, LX, HR$.

Lemma 1: We have $w^{LY} = \eta\, w^{H*} + (1 - \eta)\, w^{L*}$ and $w^{HR} = w^{HY} = w^{H*}$, i.e., skilled labor is fully employed.

All lemmas are proved in appendix A.

Regarding skilled labor, $w^{H*} > w^{L*}$ (according to assumption 1) and lemma 1 imply that $w^{H*} > w^{LY}$ if $\eta < 1$. Thus, if $\eta < 1$ and $v > 0$, (12) implies that $\tilde{w}^{HY} = w^{H*}$, i.e., fair wages of skilled workers are below the market clearing level. Thus, equilibrium wages may exceed fair wages if paying exactly fair wages would lead to excess labor demand. If $\eta = 1$, then $\tilde{w}^{HY} = w^{H*}(= w^{LY})$. In any case, the fairness parameter v does not affect equilibrium wages. Regarding unskilled labor, $w^{H*} > w^{L*}$ and lemma 1 imply that wages of unskilled workers in final goods production lie above the market clearing level if and only if these workers make social comparisons, i.e.,

$$w^{LY} = w^{L*} \quad \text{if and only if } \eta = 0, \tag{16}$$

$$w^{LY} > w^{L*} \quad \text{if and only if } \eta > 0. \tag{17}$$

To deal with wage inequality, it is useful to look at relative wages. Note that, according to lemma 1, the relative wage of skilled labor in final goods production is given by

$$\frac{w^{H*}}{w^{LY}} = \left(\eta + (1-\eta)\frac{w^{L*}}{w^{H*}} \right)^{-1} \geq 1, \tag{18}$$

[15] Alternatively to assumption 2, one may assume a strictly concave effort supply function to obtain unique optimal wages. For example, using $\tilde{e}(w/\tilde{w}) = 1 + \log(w/\tilde{w})$ rather than (15) would leave all results unaffected.

where the latter inequality is due to assumption 1 ((18) holds with equality if and only if $\eta = 1$). Moreover, since firms take wages per unit of effort as given and $e^{HY} = e^{LY} = 1$, (1) implies that

$$\frac{w^{H*}}{w^{LY}} = \frac{\alpha L^Y}{\beta H^Y}. \tag{19}$$

From (18), it becomes clear that the higher is η, the less are relative wages determined by market forces, and the more by fairness considerations. Thus, if $\eta > 0$, relative wages in final goods production are *sticky*, i.e., compressed, in the sense that relative wages of skilled workers are below relative marginal productivity. However, relative wage stickiness is not sufficient for unemployment of unskilled workers. This is because unskilled workers who are not employed in final goods production could also be employed in intermediate goods production. Remember that $w^{LX} \geq \tilde{w}^{LX} = \mu w^{LY}$, according to (13) and the fact that firms do not pay less than fair wages. Thus, if within-group social comparisons are sufficiently strong, i.e., μ is sufficiently high, there is excess supply and thus unemployment of unskilled labor. In order to focus the analysis, the following assumption ensures that this is always the case if relative wages are sticky.

Assumption 3: If relative wages are sticky (i.e., if $\eta > 0$), then $\mu > \mu^*$, where μ^* is defined as the largest value of μ at which all unskilled workers not employed in final goods production would find employment in intermediate goods production if $w^{LX} = \tilde{w}^{LX} = \mu w^{LY}$.

Lemma 2: If $\eta > 0$ or $\mu > 1$, we have $w^{LX} = \mu w^{LY}$. If $\eta > 0$ or $\mu > 1$, there is unemployment among the unskilled. If $\eta = 0$ and $\mu \leq 1$, we have $w^{LX} = w^{L*} = w^{LY}$ and thus full employment of unskilled labor.

Note that if $\eta = 0$ and $\mu < 1$, equilibrium wages of unskilled workers in intermediate goods production exceed their fair wages since otherwise there would be excess demand for unskilled labor. In the following, the analysis is focused on the case $\eta > 0$, i.e., relative wages are sticky and there is unemployment of unskilled labor.[16]

Remark: Note that $w^{HR} = w^{HY} = w^{H*}$ and, if $\eta = 0$ and $\mu \leq 1$, then $w^{LY} = w^{LX} = w^{L*}$, according to lemma 1 and lemma 2, respectively. Thus, if $\eta = 0$ and $\mu \leq 1$, all results of our model would be the same as if there were no social comparisons (or efficiency wage considerations, respectively) in the model. Of course, since there would not be unemployment of unskilled workers in this case, only the relation-

[16] Note that μ^* is endogenous and we have $\mu^* < 1$ if $\eta > 0$, according to the definition of μ^*. As will be directly implied by the results in section 4, in steady-state equilibrium μ^* rises with r and H, falls with γ, L, and η, and does not depend on v. Note that if $\eta > 0$ and $\mu \geq 1$, assumption 3 is not necessary for unemployment.

ship between wage inequality and technological change could be analyzed. But *qualitatively*, all results with respect to relative wages would be the same as in the case with social comparisons, as long as $\eta < 1$ (i.e., relative wages are not fully rigid).

3. Perfect Foresight Equilibrium and Balanced Growth

In perfect foresight, equilibrium wage rates of skilled labor in research and production are equal and always adjust until the market for skilled labor is cleared (i.e., $w_t^{HY} = w_t^{HR} = w_t^{H*}$, according to lemma 1). This defines a sequence $(H_0^Y, H_1^Y, H_2^Y, \ldots)$, where $H_t^Y = H - H_t^R$ for all $t \geq 0$. (Recall that the variable index t denotes the period of random length in which the tth innovation is monopolized.) The allocation of skilled labor in production and research simultaneously determines all wage levels, the employment levels of unskilled labor in intermediate and final goods production as well as the economy's rate of growth. In this section, the way in which unskilled employment and relative wages are affected by the allocation of skilled labor in production and research is derived. Moreover, the balanced growth equilibrium is defined. As derived in section 4, the impacts of the parameters H, γ, and r on the steady-state allocation of skilled labor then imply how H, γ, and r affect relative wages, employment levels, and growth in steady state. As is also shown in section 4, the parameters L, η, and μ affect employment and relative wages through a channel which differs from that of the impact on the skilled labor allocation.

3.1 How the Allocation of Skilled Labor Affects Relative Wages and Unskilled Employment

Denote the unemployment rate of unskilled labor as

$$u^L = 1 - \frac{L^X}{L} - \frac{L^Y}{L}. \tag{20}$$

Lemma 3: (i) If $\eta < 1$, relative wages of skilled workers decline as the amount of skilled labor used in production increases, i.e.,

$$\frac{\partial(w^H/w^{LY})}{\partial H^Y} < 0 \quad \text{and} \quad \frac{\partial(w^H/w^{LX})}{\partial H^Y} < 0.$$

(ii) If $\eta > 0$, the employment level of unskilled labor in final goods production increases with the amount of skilled labor used in production, i.e.,

$$\frac{\partial L^Y}{\partial H^Y} > 0.$$

(iii) If $\eta > 0$, the unemployment rate of unskilled labor decreases with the amount of skilled labor used in production, i.e.,

$$\frac{\partial u^L}{\partial H^Y} < 0.$$ [17]

The intuition of lemma 3 is the following. A higher amount of skilled labor devoted to production raises the relative marginal product of unskilled labor since skilled and unskilled labor are technological complements in final goods production, according to (1). Hence, if $\eta < 1$, relative wages decline unambiguously with H^Y (part (i) of lemma 3). (If $\eta = 1$, relative wages are solely determined by fairness considerations and thus are *totally* rigid.) If $\eta > 0$, relative wages are sticky due to social comparisons made by unskilled workers in final goods production. This implies that an increase in skilled labor allocated to production unambiguously reduces the unemployment rate of the unskilled (part (iii) of lemma 3). The reason for this is as follows. First, employment of unskilled workers in final goods production L^Y rises due to their increased marginal productivity (part (ii) of lemma 3). Second, as shown in the proof of lemma 3 (see appendix A), the labor demand of the incumbent monopolist and thus employment in intermediate goods production L^X is unambiguously positively related to the employment level of unskilled labor in final goods production. Intuitively, if a higher amount of unskilled labor is employed in final goods production, the inverse demand function (3) faced by the incumbent monopolist shifts upwards. Hence, the marginal revenue of the incumbent monopolist increases. Moreover, (1) implies that wages and employment in final goods production are negatively related for both skilled and unskilled labor. Thus, according to lemma 2, an increase in L^Y lowers marginal costs (i.e., wages w^{LX}) in intermediate goods production, unambiguously raising labor demand.[18]

Remark: If $\eta = 0$, then relative wages are fully flexible. Thus, in this case there are no employment effects arising from a change in the allocation of skilled labor, even if there is unemployment among the unskilled (i.e., even if $\mu > 1$, in addition to $\eta = 0$, according to lemma 2).

3.2 Balanced Growth

Define a balanced growth equilibrium as a stationary solution for the productivity-adjusted wage rate $\omega_t^{H*} = (w_t^{H*}/A_t)$ of skilled workers, productivity-adjusted wages $\omega_t^{LX} = (w_t^{LX}/A_t)$, $\omega_t^{LY} = (w_t^{LY}/A_t)$ of unskilled workers, and employment levels

[17] Note that lemma 3 (ii) implies that μ^* positively depends on H^Y if $\eta > 0$.

[18] In appendix A it is also shown that the elasticity of the unskilled employment level in the final goods production with respect to skilled labor lies between zero and unity. Moreover, it is easy to show that this elasticity increases with η, the degree to which unskilled workers socially compare themselves with skilled workers in final goods production.

H_t^R, H_t^Y ($= H - H_t^R$), L_t^X, and L_t^Y. These steady-state equilibrium values are denoted $\hat{\omega}^{H*}$, $\hat{\omega}^{LX}$, $\hat{\omega}^{LY}$, $\hat{H}^R$, $\hat{H}^Y$, $\hat{L}^X$, and $\hat{L}^Y$ (with a corresponding unemployment rate $\hat{u}^L$), respectively.[19]

The average growth rate of final output $Y_t = \gamma Y_{t-1}$ is endogenously determined by the amount of skilled labor used in research. As can be shown analogously to AGHION AND HOWITT [1992, 336], the average steady-state growth rate of the economy is given by

$$g = f(\hat{H}^R) \ln \gamma . \tag{21}$$

Thus, growth increases with both the steady-state amount of skilled labor devoted to research $\hat{H}^R$ and the factor $\gamma > 1$ by which total factor productivity increases each time an innovation occurs. Note that due to the assumption $f(0) = 0$, if the entire skilled labor force were to be used in production, there would be no output growth in this economy.

4. Comparative Static Results

Concerning the steady-state allocation of skilled labor and growth, neither the introduction of a segmented labor market for skilled and unskilled labor nor allowing for efficiency wages in the basic framework of AGHION AND HOWITT [1992] qualitatively affect their results. (See appendix C for a formal derivation.) First, a higher discount rate r reduces the expected discounted value of an innovation, making research less profitable relative to production. This causes the amount of skilled labor used in research $\hat{H}^R$ to fall, which in turn has a negative impact on the average growth rate, according to (21). Second, the size of innovations γ positively affects future profit streams in intermediate goods production and, thus, $\hat{H}^R$, unambiguously yielding faster growth. Third, a rising skilled labor supply H has a negative impact on the wages of skilled labor in both research and final goods production, yielding higher skilled labor demand for both non-production and production activities.

In the following, comparative static results of an interior steady-state equilibrium, in which strictly positive amounts of skilled labor are devoted to both research

[19] A formal analysis of the transitional dynamics is given in appendix B. As in AGHION AND HOWITT [1992], in the transition to the steady state there is a negative relationship between current and future use of skilled labor in production. According to (6), (8), and $H_{t+1}^Y = H - H_{t+1}^R$, a foreseen increase in the amount of skilled labor in production next period raises the expected value of the next innovation, because of both rising monopoly profits next period and a lower risk of being displaced by a new monopolist. Hence, according to (7) and lemma 1, *current* wages of skilled workers increase, in turn depressing current demand for skilled workers in final goods production. Also note that, according to lemma 3, the model predicts both unskilled employment levels and relative wages will fluctuate during the transition to the steady state.

Table 1
Comparative Static Results of an Interior Steady State Equilibrium, if $0 < \eta < 1$

Change in: / Effect on:	r	γ	H	L	H, L^*	η	μ
$\hat{H}^Y$	+	–	+	0	+	0	0
$\hat{H}^R$	–	+	+	0	+	0	0
$\hat{u}^L$	–	+	–	+	–	+	+
$\hat{\omega}^H/\hat{\omega}^{LY}$	–	+	–	+	–	–	–
$\hat{\omega}^H/\hat{\omega}^{LX}$	–	+	–	+	–	–	–
$\hat{\omega}^{LY}/\hat{\omega}^{LX}$	0	0	0	0	0	0	–
$\hat{\omega}^H$	–	+	–	+	–	–	–
$\hat{\omega}^{LY}$	+	–	+	–	+	+	–
$\hat{\omega}^{LX}$	+	–	+	–	+	0	+
g	–	+	+	*0*	+	*0*	*0*

Key: * $\Delta H + \Delta L = 0$.

and final goods production, are derived. All results are summarized in table 1. The propositions are proven in appendix D.[20]

4.1 Change in Research Incentives

First, consider parameter changes which directly affect expected monopoly profits and, thus, future values of innovations, e.g., by lower discount rates or larger productivity gains per innovation.

Proposition 1: Consider an interior steady-state equilibrium with $0 < \eta < 1$. Both a decrease in the discount rate r and an increase in the size of innovations γ raises (i) the unskilled unemployment rate $\hat{u}^L$, (ii) relative wages $\hat{\omega}^H/\hat{\omega}^{LY}$ and $\hat{\omega}^H/\hat{\omega}^{LX}$, and (iii) the average growth rate g.

A lower discount rate r raises the average growth rate of the economy by raising the steady-state amount of skilled labor in research (see above). The same is true for an increase in the size of innovations γ, which, in addition, also has a direct impact on growth, according to (21). Concerning unemployment and relative wages, the mechanisms underlying lemma 3 apply: As a lower amount of skilled labor is devoted to production, the relative marginal productivity of unskilled labor in final goods production declines. However, due to fairness considerations between both

[20] For the interested reader, table 1 also contains the results for the absolute wage levels, which are not derived in the following in order to focus the discussion.

skill groups, relative wages of unskilled labor do not fall to the same degree. Hence, even though the wage gap between skilled and unskilled workers widens, the unskilled employment level in final goods production is reduced. For given within-group social comparisons, the resulting downward shift of the inverse demand function faced by the incumbent monopolist also lowers employment in intermediate goods production.

4.2 Change in Labor Supply

Now consider a change in the supply of both skilled and unskilled labor, e.g., through educational training programs or immigration.

Proposition 2: Consider an interior steady-state equilibrium with $0 < \eta < 1$. (i) An increase in skilled labor supply H reduces the unskilled unemployment rate $\hat{u}^L$, lowers relative wages $\hat{\omega}^H/\hat{\omega}^{LY}$ and $\hat{\omega}^H/\hat{\omega}^{LX}$, and raises the average growth rate g. (ii) An increase in unskilled labor supply L raises the unskilled unemployment rate $\hat{u}^L$, raises relative wages $\hat{\omega}^H/\hat{\omega}^{LY}$ and $\hat{\omega}^H/\hat{\omega}^{LX}$, and does not affect the growth rate g.

First, a positive share of an additional skilled labor supply will be employed in production. Hence, again lemma 3 applies; that is, both unskilled unemployment and wage inequality is reduced because of an increase in the relative marginal productivity of unskilled labor. Moreover, as a larger amount of skilled labor is devoted to research, the economy is growing faster in its steady state. Second, since unskilled workers in final goods production consider it fair to receive lower wages when the labor supplied by their group increases, wage inequality increases with L. This leads to a higher employment level of unskilled labor in final goods production. Because also fair wages in the intermediate goods production also decline due to within-group comparisons, labor demand increases here as well. However, because of wage compression due to fairness considerations, relative wages are not flexible enough to keep the unskilled unemployment rate constant.[21]

Concerning the allocation of skilled labor, an increase in unskilled labor supply is neutral in steady-state equilibrium with the technology in (1). This is because the marginal productivity of skilled labor in research and production, respectively, is equally increased by a rising unskilled employment level. Generally, the net effect of a rising supply of unskilled labor on the allocation of skilled labor and, thus, on growth is ambiguous.

The analysis suggests that educating or training unskilled workers is even more effective in reducing both unskilled unemployment and wage gaps between skilled and unskilled workers than immigration of skilled labor, since the former also re-

[21] In other words, the elasticity of unskilled employment with respect to unskilled labor supply lies between zero and unity, as can formally be derived from equations (A3) and (A6) in the appendix.

duces the unskilled labor force. However, this comparative static result may be misleading as education is costly in the real world.[22]

4.3 Change in Fairness Considerations

Fairness considerations of unskilled workers have three effects in the model. First, firms are induced to pay wages which yield unemployment of unskilled labor in order to elicit high effort. Second, social comparisons in final goods production create relative wage stickiness, preventing wages from adjusting sufficiently to keep unskilled unemployment at a constant rate, when (relative) earning prospects of unskilled workers deteriorate. Third, within-group social comparisons among the unskilled lead to absolute wage stickiness.

Proposition 3: Consider an interior steady-state equilibrium with $0 < \eta < 1$. The unskilled unemployment rate $\hat{u}^L$ rises and relative wages $\hat{\omega}^H/\hat{\omega}^{LY}$ and $\hat{\omega}^H/\hat{\omega}^{LX}$ fall with fairness parameters η and μ, respectively.

More intensive social comparisons by unskilled workers of skilled workers in final goods production (i.e., a higher η) *ceteris paribus* raise wages of the unskilled and thus reduces employment of unskilled labor in final goods production. In turn, this induces relative wages of skilled labor to fall, according to (19). Moreover, labor demand of the incumbent monopolist also declines. The reason for this is the following: First, due to within-group comparisons, wage demands in intermediate goods production are positively related to the wage of the unskilled in final goods production where the latter rises unambiguously. This raises marginal costs of the incumbent monopolist. Second, a decreasing employment level in final goods production shifts the inverse demand function of the incumbent monopolist downward, in turn reducing the marginal revenue. Hence, unskilled unemployment unambiguously increases with η. A higher μ implies lower labor demand in intermediate goods production by raising marginal costs of the incumbent monopolist. Hence, the production of intermediate goods declines. This, in turn, reduces unskilled labor demand in final goods production, since declining input of the intermediate good lowers the marginal productivity of unskilled labor. Thus, because of its decreasing employment, relative marginal productivity of unskilled labor increases, inducing relative wages to fall.

With the Cobb-Douglas technology (1), fairness parameters η and μ do not have any impact on the steady-state allocation of skilled labor. According to the discussion above, the marginal productivity of skilled labor in both final goods production and research declines with η and μ, respectively, yielding lower skilled labor demand in both units. With respect to the allocation of skilled labor, the two effects exactly cancel each other out in balanced growth equilibrium. It should be

[22] Some countries, e.g., Australia and Canada, to some extent select immigrants on basis of their education.

noted that fairness perceptions in intermediate and final goods production are mutually reinforcing because of the vertical integration of both production activities. That is, fairness considerations in one production activity affects both labor demand and wages in the other one. In contrast, social comparisons of skilled labor in final goods production (represented by the parameter ν) do not have any impact on wages or employment as skilled workers always receive market clearing wages.

5. Discussion

5.1 Skilled Labor Reallocation Versus Biased Change in Production

The model predicts that a reallocation of skilled labor away from activities which are directly related to production results in a reduction of the demand for unskilled labor, thus fostering wage inequality and unemployment. In fact, there is plenty of evidence from OECD countries for a substantial increase in the non-production employment share within most industries in the last two decades.[23] This labor reallocation towards non-production activities is highly correlated with an increase of skilled labor within industries (BERMAN, BOUND, AND GRICHILIS [1994], MACHIN, RYAN, AND VAN REENEN [1996]). Moreover, it has been shown that this kind of skill-upgrading is significantly correlated with both the R&D expenditure (e.g., MACHIN AND VAN REENEN [1998]) and computer-intensity of an industry (e.g., AUTOR, KATZ, AND KRUEGER [1998]). Also the share of the total labor force devoted to R&D has increased sharply in the developed world. For instance, in 1988 almost one million people have been employed in R&D in the US which is nearly twice as many as in the early 1970s (see JONES [1995, fig. 1]).

One may object that the special consideration of research as non-production activity in the model does not reflect either the *total* increase of the non-production employment share nor account for the fact that the shift mainly occurred *within* industries. However, the structure of the model allows a broader interpretation. The crucial part of the model is that qualified workers in non-production search for and realize more efficient ways to organize production and work (i.e., in order to raise A). This fits well with the notion that major innovations like the so-called "computer revolution" have induced firms to engage in substantial restructuring.[24] The

[23] For example, BERMAN, BOUND, AND MACHIN [1998, tab. II] find an annualized change of 0.3 percentage points for the US non-production employment share during the 1980s, where 73% of this change has been within industries according to a standard decomposition into employment changes within and between industries. Similar figures are provided for other OECD countries as well. According to MACHIN AND VAN REENEN [1998], in 1989 most countries had non-production employment shares well above 30%. Besides non-production employment shares non-production wage-bill shares have also substantially increased.

[24] See LINDBECK AND SNOWER [1996], who, however, do not distinguish between production and non-production activities. For case studies revealing substantial organizational changes, see, e.g., HAMMER AND CHAMPY [1993].

basic idea is that, for the adoption of recent information technology to become efficiency-enhancing, resources had to be shifted towards activities that increase the flow of information within a firm and new ways to be found to coordinate, supervise, and train workers in order to reap the gains from job rotation and team work.[25] In terms of our model, such an exogenous technology shock can be viewed as an increase in γ, fostering organizational changes with respect to the skilled labor allocation. Thus, although the model analyzes the interaction between *research* and total factor productivity, the mechanism underlying the reallocation effect is very likely to play an important role for other non-production activities as well.

Are the results and the structure of the model at odds with the empirical finding that the shift towards non-production employment has mainly occurred within firms and industries? In contrast to the theoretical literature on SBTC (but in line with the empirical one), the new explanation for relative labor demand shifts in the model has been derived by analytically distinguishing between production and non-production activities. Generally, non-production activities are supposed to enhance productivity rather than to produce physical output. One may imagine that there are non-production units within firms or that firms have "outsourced" those business services, e.g., to consulting or outside research firms. Although the research unit in the endogenous growth model of AGHION AND HOWITT [1992] used in this paper is usually interpreted as an outside research sector, it should be noted that AGHION AND HOWITT [1998] interpret the research activity in their model also as knowledge production *within* firms, stating that "the amount of resources devoted to the creation of knowledge is certainly underestimated by standard measures of R&D. ... Many workers ... in management or other non-research activities spend considerable amounts of their time and energy in looking for better ways of producing and selling the output of the enterprise they are employed by, and hence their compensation should be counted ... as part of the cost of creating knowledge." (p. 437) This is exactly in line with our basic hypothesis. For the results of our model it only matters that non-production units are separated from production units. If this is the case, the marginal productivity of low-skilled workers in production units is affected when skilled labor is shifted towards non-production. Thus, relative labor demand shifts in the model are consistent with both non-production employment shifts within and between firms and industries, respectively. Does the distinction of non-production units within and outside a firm matter for the role of social comparisons in the model? Since we do not consider social comparisons of similarly educated workers within the same unit, it is unessential if social comparisons among workers are made within or between firms, as long as

[25] Moreover, as SNOWER [1999] points out, new information technologies permit firms to design and manufacture products through a parallel process in which design engineers and manufacturing employees interact. Compared to an organization in which design and manufacturing is a sequential process, such an organizational structure is likely to increase both the gains from designing products and the productivity of *all* employees.

they are made *across units*. In other words, it is the analytical distinction of units rather than firms that matters for the results of the model.

5.2 *Productivity Growth and Skilled Labor Reallocation*

According to the discussion above, the model suggests that the widespread adoption of information and communication technologies has opened up new possibilities of raising productivity which, however, could only be realized by shifting high-skilled workers to non-production activities. We have shown that this, in turn, adversely affects low-skilled labor demand.

According to (2) and (21), if skilled labor is reallocated due to an increase in γ (rather than a decrease in r), both output growth and factor productivity growth is raised.[26] One may argue that this is as (yet) not supported by the data. However, since according to our basic hypothesis an increase in γ is technology-related, one may fall back on the extensive discussion about the "productivity puzzle" reported in the literature on information technologies (i.e., that productivity growth does not seem to have accelerated despite the "computer revolution"). First, it has been forcefully argued that "it takes time and resources for the potential productivity of the new technology to be fully realized." (AHN [1999, 5]) It may even be the case that "new technologies are, in fact, initially broadly inferior to older technologies they seek to replace," although they most likely will "ultimately dominate older systems of production across a wide variety of activities." (YOUNG [1993, 446]) Although these "learning costs" are, for simplicity, not reflected in the model, the notion that resources have to be provided in order to reap the benefits of these technologies is exactly in line with our basic hypothesis. In fact, recent evidence for the US suggests that productivity growth has eventually surged considerably in the second half of the 1990s (EUROPEAN COMMISSION [1999], WIFO [1999], THE EDITORS [2000, 51] of *The Economist*). From today's perspective, it seems that the "new economy" hypothesis, i.e., the notion that trend growth has increased due to the "computer revolution," is finally supported by empirical evidence.[27] Second, many authors believe that, due to the surge in the use of information equipment, the long-discussed problems of measuring the growth of output and productivity have become much more severe (e.g., GRICHILIS [1994], AGHION AND HOWITT [1998],

[26] In the model, output growth is also promoted by an increase in non-production employment, according to (21). As extensively discussed in the endogenous growth literature, this is due to a "scale effect" (i.e., an increase in R&D input raises long-run growth). However, the presence of such a "scale effect," embodied in the model of AGHION AND HOWITT [1992], which is used here for its familiarity and simplicity, is unessential for all of our results. As YOUNG [1998], SEGERSTROM [1998] and AGHION AND HOWITT [1998, ch. 12] have shown, the "scale effect" can be eliminated without affecting any other basic predictions of innovation-driven growth models. See JONES [1999] for further discussion.

[27] It should also be noted that, consistent with our analysis, LÜCKE [1999] finds evidence for a positive relationship between total factor productivity growth and the decline in the relative demand for low-skilled labor within the OECD in the 1980s.

OECD [1999]).[28] For instance, AGHION AND HOWITT [1998, ch. 12] show that, even in a steady state with balanced growth, the failure of national account statistics to reflect the substantial improvements in the quality of both capital and consumption goods contributes to a severe underestimation of the rates of productivity and output growth.[29]

5.3 *Social Comparisons and Unemployment*

According to AGELL AND LUNDBORG [1995, 302], survey evidence from manufacturing firms suggests that "*blue-collar workers apparently compare wages both within their own firm and across firms.*" The structure of our model allows us to analyze the interaction between these two types of social comparisons. If $\eta > 0$, wages are compressed in final goods production due to social comparisons of unskilled workers with skilled workers. However, the analysis has shown that this is not sufficient to create unemployment. Only if within-group social comparisons of unskilled workers in intermediate goods production are sufficiently strong (i.e., μ is sufficiently large) such that the wage of the unskilled in this production unit does not fully adjust, there is unemployment among the unskilled.[30] In other words, wage compression in final goods production creates wage pressure in intermediate goods production and within-group social comparisons imply that absolute wage levels are rigid. Moreover, a reallocation of skilled labor away from final goods production reduces labor demand in both final *and* intermediate goods production for given fairness perceptions of workers. From this one can conclude

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[28] Zvi Grilichis even devoted his presidential address at the AEA congress in 1994 to this issue, noting that "our ability to interpret changes in aggregate total factor productivity has declined, and major portions of actual technical change have eluded our measurement framework entirely. ... and thus its productivity effects, which are likely to be quite real, are largely invisible in the data. That there were gains is not really in doubt. Just observing the changes in the way banks and airlines operate, and in the ways in which information is delivered to firms and consumers, would lead one to conclude that we are in the midst of a major technological revolution." (GRICHILIS [1994, 10f.])

[29] With respect to other measurement problems such as the failure to account for output of knowledge (which, e.g., results from non-production activities) as investment (as is done for physical capital), AGHION AND HOWITT [1998, 435f.] conclude: "These measurement problems particularly distort standard measures of growth during a period of *transition* such as we are going through now when the information revolution has greatly enhanced the opportunities for knowledge creation. In particular, they imply that GNP and productivity may appear to be *slowing down* when in fact they are *surging*."

[30] In AGHION AND HOWITT [1992] only skilled labor is productive in intermediate goods production. In this case, $\eta > 0$ would be a sufficient condition for unemployment. Thus, with this specification the labor market effects of within-group social comparisons could not be addressed. Another reason behind our modification of incorporating unskilled labor in (4) is the notion that once a patent is invented, production itself only requires routine tasks. Assuming alternatively that both types of labor can be employed in intermediate goods production would not affect the main results of this paper, since it is the allocation of skilled labor between production and non-production activities which is essential in the model.

that in the case of related (e.g., vertically integrated) production activities, skilled labor reallocation towards non-production activities even affects labor demand in parts of the economy in which this kind of restructuring does not take place.

6. Summary

In this paper it has been shown that incentives to reallocate high-skilled labor from production to non-production (i.e., research) activities depresses relative demand for low-skilled workers if skilled and unskilled workers are technological complements in production. The basic idea is that, in order to reap the benefits of major technological changes, like the adoption of personal computers and information technologies, industries must restructure, which means that resources (i.e., skilled workers) have to be shifted. Since the relative marginal productivity of labor changes only because of relative employment effects, this is a different argument than the usual hypothesis of SBTC, commonly viewed as an "exogenous shift in the production function." (BERMAN, BOUND, AND MACHIN [1998, 1250]) Whereas the usual skill-bias hypothesis is not directly testable, our view is supported by the fact that there has been a substantial increase of skilled non-production workers, especially in R&D and computer-intensive industries. Moreover, whereas relative labor demand effects of skill-augmenting shifts in a neoclassical production function crucially depend on the elasticity of substitution between skilled and unskilled labor, the reallocation effect suggested in this paper reduces unskilled labor demand unambiguously. With firms paying efficiency wages based on social comparisons among workers, the resulting labor market effects depend on the interaction between relative wage stickiness, arising from social comparisons of the unskilled with skilled workers (AKERLOF AND YELLEN [1990]), and absolute wage stickiness arising from within-group social comparisons among unskilled workers. It has been shown that wage compression due to social comparisons of workers across skill groups in one production activity (or sector, respectively) results in unemployment of unskilled workers, if and only if unskilled workers cannot be fully absorbed by another production activity (or sector, respectively). In our model, within-group social comparisons of unskilled workers may prevent wages in this other sector from adjusting fully.

Some final remarks should be made. First, although it has been shown that labor reallocation can have important employment and distributional effects, the production process is still viewed as a black box. In order to examine in more detail the labor market effects of the dramatic organizational changes we are witnessing nowadays, a more differentiated model of firms is needed. Second, the development and adoption of modern technologies which imply substantial changes in the organization within firms and industries should be made endogenous.

Appendix A: Proofs of Lemmas 1–3

Proof of Lemma 1: The lemma is proven in three steps.

Step 1: According to (14) and the fact that firms do not pay less than fair wages, we have $w^{HR} \geq \tilde{w}^{HR} = w^{HY}$. Suppose $w^{HR} > w^{HY}$. Then the representative research unit could unambiguously gain by cutting wages down to $w^{HR} = w^{HY}$ since $e^{HR} = 1$, whenever $w^{HR} \geq w^{HY}$. Thus, $w^{HR} = w^{HY}$.

Step 2: Suppose $w^{HR} = w^{HY} < w^{H*}$. According to the definition of w^{H*} as market clearing wage, this would create excess demand for skilled labor. Hence, competition in the labor market implies $w^{HR} = w^{HY} \geq w^{H*}$.

Step 3: Note that $w^{LY} \geq \tilde{w}^{LY}$, according to the fact that firms do not pay less than fair wages, and $w^{HR} = w^{HY} \geq w^{H*}$, according to step 2. Using (11), this implies $w^{LY} \geq \tilde{w}^{LY} = \eta w^{HY} + (1 - \eta)\, w^{L*} \geq \eta w^{H*} + (1 - \eta)\, w^{L*}$. Now suppose $w^{HR} = w^{HY} > w^{H*}$, which would result in unemployment for skilled labor. Thus, underbidding of unemployed skilled workers in final goods production would also lower fair wages of unskilled workers in final goods production. Thus, competition would drive wages down to $w^{HY} = w^{H*}$ and skilled employment levels up to full employment. Moreover, since there is no excess demand for unskilled labor at fair wages, and full effort is provided whenever $w^{LY} \geq \tilde{w}^{LY}$, we have $w^{LY} = \tilde{w}^{LY} = \eta w^{H*} + (1 - \eta)\, w^{L*}$. *Q.E.D.*

Proof of Lemma 2: Remember that $w^{LX} \geq \tilde{w}^{LX} = \mu w^{LY}$, according to (13) and the fact that firms do not pay less than fair wages. If $\eta > 0$, then there is unemployment of unskilled labor, according to assumption 3. Moreover, if $\eta = 0$, then $w^{LY} = w^{L*}$, according to (16). Thus, if $\eta = 0$ and $\mu > 1$, then $w^{LX} \geq \tilde{w}^{LX} = \mu w^{L*} = w^{L*}$, and, thus, there is unemployment among the unskilled. If $\eta = 0$ and $\mu = 1$, there would be full employment at fair wages $\tilde{w}^{LX} = w^{LY} = w^{L*}$, and $w^{LX} \geq \tilde{w}^{LX} = w^{L*}$ must hold in labor market equilibrium. Since firms do not pay more than fair wages if there is no excess labor demand at fair wages, we have $w^{LX} = w^{LY} = w^{L*}$ and full employment if $\eta = 0$ and $\mu = 1$. Similarly, if $\eta > 0$ or $\mu \geq 1$, there is no excess labor demand which implies $\tilde{w}^{LX} = w^{LX} = \mu w^{LY}$. Only the case $\eta = 0$ and $\mu < 1$ remains to be argued. If $\eta = 0$ and $\mu < 1$, then there would be excess demand of unskilled labor at fair wages $\tilde{w}^{LX} = \mu w^{LY} = \mu w^{L*} < w^{L*}$ such that $w^{LX} > \tilde{w}^{LX}$ must hold in labor market equilibrium. Since there is no excess demand if $w^{LX} \geq w^{L*}$ and workers provide full effort if $w^{LX} = w^{L*}$, we have $w^{LX} = w^{LY} = w^{L*}$. *Q.E.D.*

Proof of Lemma 3: Using (1) and the fact that firms do not pay less than fair wages, the wage rate of the unskilled in final goods production becomes

$$\text{(A1)} \quad w^{LY} = A\beta(H^Y)^{\alpha}\,(L^Y)^{\beta-1}\,x^{1-\alpha-\beta} = A\left(\frac{b(H^Y/L^Y)^{\alpha}}{(w^{LX}/A)^{1-\alpha-\beta}}\right)^{\frac{1}{\alpha+\beta}},$$

where the latter equation is due to substitution of (5), $b \equiv \beta^{\alpha+\beta} (1-\alpha-\beta)^{2(1-\alpha-\beta)} > 0$. Substituting $w^{LX} = \mu w^{LY}$ from lemma 1 into (A1) yields

$$\text{(A2)} \qquad w^{LY} = Ab\mu^{-(1-\alpha-\beta)} (H^Y/L^Y)^\alpha, \text{ and } w^{LX} = Ab\mu^{\alpha+\beta} (H^Y/L^Y)^\alpha.$$

With (4) and the fact that firms do not pay less than fair wages, it follows that $L^X = x$. Hence, substituting (A2) into (5), one obtains a positive relationship between unskilled labor in the intermediate and the final output sector as suggested in subsection 3.1:

$$\text{(A3)} \qquad L^X = (c/\mu) \cdot L^Y,$$

$c \equiv (1-\alpha-\beta)^2/\beta > 0$. A common market clearing wage of unskilled labor is obtained if and only if $\mu \leq 1$ and $\eta = 0$, according to lemma 2. Using (A2) and (A3) and the labor market clearing condition, this market clearing wage is given by

$$\text{(A4)} \qquad w^{L*} = Ad\,(H^Y/L)^\alpha,$$

$d \equiv \beta^\beta (1-\alpha-\beta)^{2(1-\alpha-\beta)} (\beta + (1-\alpha-\beta)^2)^\alpha > b > 0$. With $w^{LY} = \eta w^{H*} + (1-\eta)\, w^{L*}$ from lemma 2 we can write

$$\text{(A5)} \qquad \frac{w^{LY}}{w^{H*}} \left(1 - (1-\eta) \frac{w^{L*}}{w^{LY}} \right) - \eta = 0 .$$

Substituting (19), (A2), and (A4) into (A5), one gets

$$\text{(A6)} \qquad \frac{\beta H^Y}{\alpha L^Y} \left(1 - (1-\eta)\, \mu^{1-\alpha-\beta} \left(\frac{\beta + (1-\alpha-\beta)^2 \; L^Y}{\beta L} \right)^\alpha \right) - \eta = 0 ,$$

which defines L^Y implicitly as function of L, η, μ, α, β, and H^Y (where the latter is endogenously determined). Applying the implicit function theorem to (A6) yields

$$\text{(A7)} \qquad \frac{\partial L^Y H^Y}{\partial H^Y L^Y} \in (0,1) \text{ if and only if } 0 < \eta < 1 ,$$

$$\text{(A8)} \qquad \frac{\partial L^Y H^Y}{\partial H^Y L^Y} = 1 \text{ if and only if } \eta = 1 ,$$

which proves lemma 3 (ii). Part (i) follows from (A7) together with (19). Finally, part (iii) follows from (A3) and part (ii). *Q.E.D.*

Appendix B: Transitional Dynamics

In this appendix, the transition path towards the balanced growth equilibrium is formally derived. Using (19) and (A2), the skilled wage rate after t innovations in terms of aggregate productivity equals

$$\omega_t^{H*} = \alpha(d/\mu)^{1-\alpha-\beta}\,(L_t^Y/H_t^Y)^{1-\alpha}. \tag{B1}$$

Rewriting (7), the expression for the marginal productivity of skilled labor in research, by using (2), (6), (8), and the fact that firms do not pay less than fair wages one obtains (after dividing by A_t)

$$\omega_t^{HR} = f'(H_t^R)\,\frac{\gamma\left(\dfrac{a(H_{t+1}^Y)^{\alpha}(L_{t+1}^Y)^{\beta}}{(\omega_{t+1}^{LX})^{1-\alpha-\beta}}\right)^{\frac{1}{\alpha+\beta}}}{r+f(H_{t+1}^R)}. \tag{B2}$$

Substituting (A2) into (B2) yields

$$\omega_t^{HR} = f'(H_t^R)\,\frac{(\alpha+\beta)(1-\alpha-\beta)(d/\mu)^{1-\alpha-\beta}\,\gamma(H_{t+1}^Y)^{\alpha}(L_{t+1}^Y)^{1-\alpha}}{r+f(H_{t+1}^R)}. \tag{B3}$$

In equilibrium the right hand sides of (B1) and (B3) must be equal if a positive amount of labor is used in research, according to lemma 1. Hence, if $H_t^Y = H - H_t^R < H$ for all $t \geq 0$, a perfect foresight equilibrium $(H_0^Y, H_1^Y, H_2^Y, \ldots)$ satisfies

$$A(H_t^Y) = B(H_{t+1}^Y), \tag{B4}$$

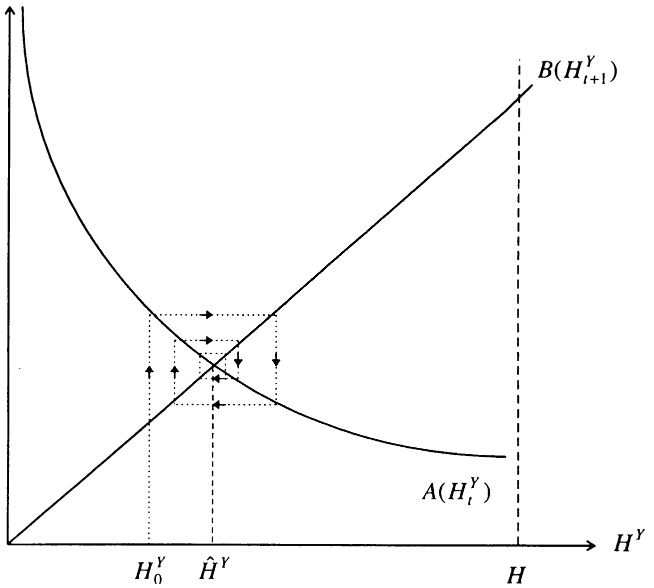
$$\text{where}\quad A(H_t^Y)\,\frac{\alpha(d/\mu)^{1-\alpha-\beta}\,(L_t^Y/H_t^Y)^{1-\alpha}}{f'(H-H_t^Y)}, \tag{B5}$$

$$B(H_{t+1}^Y) \equiv \frac{(\alpha+\beta)(1-\alpha-\beta)(d/\mu)^{1-\alpha-\beta}\,\gamma(H_{t+1}^Y)^{\alpha}(L_{t+1}^Y)^{1-\alpha}}{r+f(H-H_{t+1}^Y)}. \tag{B6}$$

Using (A7) and (A8), we obtain $A'(H_t^Y) \leq 0$ and $B'(H_{t+1}^Y) > 0$, respectively. Hence, there is a non-positive relation concerning the use of skilled labor in production between two subsequent periods t and $t+1$; that is

$$\frac{dH_{t+1}^Y}{dH_t^Y} = -\frac{A'(H_t^Y)}{B'(H_{t+1}^Y)} \leq 0, \tag{B7}$$

Figure 1
Transitional Dynamics Towards the Steady-State Equilibrium if $\eta < 1$ or $f''(\cdot) < 0$



where the latter holds with equality if and only if $\eta = 1$ and $f(\cdot)$ is a linear function in H^R. Figure 1 shows a transition path of the economy converging towards its steady state $\hat{H}^Y$ (simultaneously determining unskilled employment and wages) as a clockwise spiral starting from H^Y_0.

Appendix C: Allocation of the Skilled Labor Force in Steady State

Using (B5), (B6), and the definition of a stationary (balanced growth) equilibrium, if $A(H) < B(H) \Leftrightarrow \gamma\alpha^{-1}(\alpha+\beta)(1-\alpha-\beta)f'(0)\,H > r$ (which implies that a positive amount of labor is used in research), then the steady-state value of skilled labor in production is given by

$$\text{(C1)} \qquad A(\hat{H}^Y) = B(\hat{H}^Y) \Leftrightarrow$$

$$\text{(C2)} \qquad \gamma(\alpha+\beta)\,\alpha^{-1}(1-\alpha-\beta)f'(H-\hat{H}^Y)\,\hat{H}^Y - (r + f(H-\hat{H}^Y)) = 0.$$

Applying the implicit function theorem to (C2) yields

$$\text{(C3)} \qquad \frac{\partial \hat{H}^Y}{\partial r} > 0, \quad \frac{\partial \hat{H}^Y}{\partial H} = 1 - \frac{\partial \hat{H}^R}{\partial H} \in (0,1), \text{ and } \frac{\partial \hat{H}^Y}{\partial \gamma} < 0,$$

as stated in section 4.

Appendix D: Proofs of Propositions 1–3

Comparative static results with respect to the parameters r, γ, and H directly follow from (C3) and lemma 3. Note that the parameters η, μ, and L do not affect the allocation of skilled labor according to (C2). Results with respect to η, μ, and L thus follow from differentiating L^Y, which is implicitly defined as function of these parameters in (A6), in connection with (A3) and (19). *Q.E.D.*

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