The Double Role of Skilled Labor, New Technologies, and Wage Inequality[*]

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July 9, 2003

Abstract

This paper examines the relationship between the supply of skilled labor, technological change, and relative wages. In accounting for the role of skilled labor in both production activities and productivity-enhancing "support" activities we derive the following results. First, an increase in the supply of skilled labor raises the employment share of non-production labor within firms, without lowering relative wages. Second, new technologies raise wage inequality only insofar as they give incentives to firms to reallocate skilled labor towards non-production activities. In contrast, skill-biased technological change of the sort usually considered in the literature does not affect wage inequality.

Key words: Non-production labor; Relative wages; Skill supply; Support activities; Technological change.

JEL classification: D20; J21; J31.

1 Introduction

There is now a broad consensus that technological change has considerably contributed to the apparent shift in the labor demand structure in favor of skilled workers over the past several decades. Yet, we have just started to understand the mechanisms *how* the introduction of computing technology has changed the employment structure and wage dispersion in firms. Recently, empirical studies have investigated possible technology effects on the way workplaces are organized. A central finding is that it is the *complementarity* between technological progress and changes in the organization of work that accounts for most of the dynamics and structure in the wage-bill share of different skill groups (e.g. Bresnahan et al. (2002), Caroli and van Reenen (2001)). In contrast, technology shifts which are unrelated to internal restructuring ("raw" technical change) have a negligible impact. This strand of the literature also emphasizes the importance of training, provided by high-skilled non-production workers, for new work organization practices like autonomous problem-solving and decentralized decision-making (see OECD (1999)). Despite their salient role in modern industrial production, such non-production activities are usually not considered in the theoretical literature on technological and organizational changes.

This paper develops a model which highlights the role of high-skilled, non-production labor to provide firm-specific on-the-job training, labeled as "support activities" (Porter (1986)). Our analysis accounts for the fact that over recent years human resource policies of firms have considerably shifted from the provision of one-shot formal training courses towards informal, work-based "organizational learning" (Brown and Duguid (1991), Sumner et al. (1999)). For instance, if a worker is not regularly updated about changes in work procedures, the organizational structure, employers' goals, and so on, she loses the ability to solve problems autonomously and to bear responsibility.[1] Barron et al. (1999) find for a random sample of 3600

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[1] Batt (1999) points out that under new organizational forms, "...'learning' ... is a continuous process of using new ideas and information as sources of innovation" (p. 541f.). "[V]irtually all training and work related information (work procedures, system capabilities, product information,

US businesses from the Comprehensive Business Database in 1992 that the average time a worker is in "informal management training" is threefold the time she is in "formal training" and that off-site training programs are by far less important than on-site training in the firm. By referring to Dretske (1981), Raelin (1997, p. 563f.) comes to a similar conclusion and states that "the knowledge necessary to perform useful work cannot be a body of information to be learned, and learned once. Rather work-based learning is acquired in the midst of action and is dedicated to the task at hand." In our (static) model, these findings are reflected in the following way. We assume that training provision by high-skilled managers and supervisors induces *variable* costs (rather than fixed costs which would be appropriate in an analysis of one-shot training programs and which are usually associated with improvements in the stock of a worker's human capital), according to a linearly homogeneous "support technology". Moreover, consistent with empirical evidence (see Barron et al. (1999)), we assume that firms pay the costs of training and reap its benefits so that wages for supported and unsupported labor within the same education group are identical.

The contribution of this paper is threefold. First, by distinguishing between production and non-production labor, we provide a simple mechanism which is capable to generate the result that a rise in the relative supply of high-skilled labor does not affect relative wages. Intuitively, on the one hand, a rise in the relative skill supply depresses wage inequality between education groups as in conventional models with segmented labor markets (which do not distinguish between production-related and support activities of skilled labor). But on the other hand, declining relative wages make support/training activities relatively cheaper and induce firms to allocate a higher share of skilled labor to productivity-enhancing human resource activities. Second, we hypothesize that technological advances have made these activities more effective, e.g. by reducing communication costs through improvements in information technologies or by advances in management and human resource engineering

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legal regulations) are on-line; employees receive eight to ten e-mail messages per day advising them of any updates in any of their systems" (p. 558).

technologies. We show that these kinds of technological change unambiguously lead to higher wage inequality. Third, we examine the impact of *raw* "skill-biased" technological change of the sort usually considered in the literature (i.e. a change in the production function which raises the relative productivity of skilled labor). If a positive fraction of high-skilled labor is allocated to support activities, such a shift has no impact on wage inequality, in contrast to models which consider production tasks only. The intuition for this result again lies in the double role of skilled labor. On the one hand, raw skill-biased technological change increases relative demand for skilled production labor but, on the other hand, it reduces demand for non-production labor.

In the last few years, an extensive literature on the relationship between wage inequality, new information and communication technologies and the supply of skilled labor in industrialized countries has developed, providing important insights about technology-related changes in skill-requirements of workers.[2] The work of Acemoglu (1998, 1999) is closest in spirit to our model, also providing mechanisms which explain why an increase in the supply of skills may not lead to a decline in relative wages. According to Acemoglu (1998), an increased availability of skilled labor creates an incentive for research firms to search more intensively for technologies that complement skills. Acemoglu (1999) analyzes a labor market model with imperfect matching in which an increase in the proportion of skilled labor makes it profitable for firms to create more jobs for the skilled. In contrast, our mechanism (as outlined above) relies on an endogenous allocation of skilled labor in production-related and supporting activities. This allocation is determined by both the (relative) supply of skilled labor and technology-related gains and costs of supporting skilled and unskilled production employees, respectively.[3]

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[2]These include Lindbeck and Snower (1996, 2000), Galor and Tssidon (1997), Gregg and Manning (1997), Acemoglu (1998, 1999), Caselli (1999), Lloyd-Ellis (1999), Galor and Moav (2000), Saint-Paul (2001), among others.

[3]Also Das (2001) explicitly accounts for a twin function of skilled labor. Analyzing a shirking model, he considers the role of skilled labor in supervisory activities, in addition to production activities. Whereas we focus on changes in skilled labor supply and technological factors, Das

This paper is organized as follows. Section 2 proposes the basic model. In section 3, the equilibrium is analyzed and comparative-static results are derived. Section 4 considers an extension to our static framework by setting up a simple growth model to investigate the robustness of our findings in a dynamic context. In section 5, the main theoretical hypotheses are summarized and confronted with empirical evidence reported in the literature. The last section concludes.

2   Basic Model

Consider a model with n identical firms, which produce a homogeneous good. There is a segmented labor market for high-skilled and low-skilled workers, who differ in formal education levels or innate abilities, respectively. The supply of high-skilled and low-skilled labor is inelastic and denoted by H and L, respectively. Output y of any firm is given by the linear homogeneous production function F (as firms are identical, an index for firms is omitted):

$$y = F\left(\widetilde{h}, \widetilde{l}\right) \equiv \widetilde{l} f\left(\kappa\right), \tag{1}$$

where $\widetilde{h}$ and $\widetilde{l}$ are the *efficiency* units of high-skilled and low-skilled labor in production. $\kappa \equiv \widetilde{h}/\widetilde{l}$ is the *skill-intensity of production labor* in efficiency terms. $f(\kappa)$ is a strictly increasing and strictly concave function.

As specified below, firms can allocate high-skilled labor towards *support* activities, i.e. informal training by managers and supervisors like information-sharing, the provision of knowledge about the organizational structure, advising, counseling, and motivating commitment to employers' goals. (Support activities differ from "traditional" training, since they do not provide workers with a stock of human capital.) Whereas high-skilled labor in production (e.g. technicans) enter the production function (1) in the usual way, supporting tasks of *non-production* labor are productivity-augmenting and thus enter the production function by raising efficiency units of *both* types of labor. The efficiency units of high-skilled and low-skilled

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(2001) examines the impact of free trade on relative wages.

production labor can then be written as

$$\widetilde{h} = h^1 + \alpha h^2 \text{ and } \widetilde{l} = l^1 + \beta l^2, \tag{2}$$

respectively. h^2 and l^2 denote the amounts of supported high-skilled and low-skilled labor, respectively, which are assumed to be more productive than non-supported labor, h^1 and l^1, employed in a firm. This is captured by $\alpha > 1$ and $\beta > 1$. The support activity may be time-consuming for employees. Implicitly, we assume that workers receive wages during that time, i.e. firms bear the entire cost of supporting workers, consistent with the findings by Barron et al. (1999). That is, the productivity differentials $\alpha - 1$ and $\beta - 1$ of supported high-skilled and low-skilled labor, respectively, are net of workers' own learning time.

One can argue that the significant reduction in communication costs induced by new technologies or advances in human resource management techniques have made information-sharing and other knowledge-based organizational forms attractive in the first place. For instance, supported labor is capable to engage in autonomous problem-solving and decision-making. Hence, we hypothesize that both α and β and thus, the gains from supporting employees have recently increased.

To support h^2 and l^2 skilled and unskilled units of labor, respectively,

$$m = \gamma G \left(h^2, l^2 \right) \equiv \gamma l^2 g \left(\chi \right) \tag{3}$$

high-skilled non-production labor is required. Equation (3) specifies the *support technology* of each firm.[4] $\gamma > 0$ is a shift parameter which indicates the efficiency

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[4] An alternative formulation of (2) and (3) would be the following. Replace (2) by $\widetilde{h} = ah$ and $\widetilde{l} = bl$, where h and l are the amounts of high-skilled and low-skilled labor with respective productivity parameters a and b. Analogously to (3), high-skilled non-production labor m could then be allowed to affect a and b (for given levels of h and l), respectively. This would necessarily imply that all workers are supported, to an endogenous degree. Our formulation (2) and (3) includes, but is not restricted to this case. More generally, any worker could be fully, partially or not at all supported. For any given employment levels $h = h^1 + h^2$ and $l = l^1 + l^2$, only the degree of support for the workforce, h^2/h^1 and l^2/l^1, matters. Letting α and β be fixed parameters just means that any non-production unit m is used most effectively, observing the support technology

of the support technology.[5] The function G is linearly homogeneous and strictly increasing in (h^2, l^2). Thus, $g'(\chi) > 0$, where $\chi \equiv h^2/l^2$ may be called the *skill-intensity of supported labor*. G can be viewed as a "joint production function" (e.g. Nadiri, 1987) with two outputs (h^2 and l^2) and one input (m). We assume a strictly concave "transformation curve". That is, the support technology exhibits complementarities among both types of labor, in analogy to the standard assumption that skilled and unskilled labor are complements in the production technology. Formally, this is reflected by the assumption $G_{12} < 0$ which is equivalent to $g''(\cdot) > 0$ under linear homogeneity of G.

There are no market imperfections. That is, when maximizing profits, firms take wages w_h^1, w_h^2, w_l^1, w_l^2 and w_m paid for h^1, h^2, l^1, l^2 and m, respectively, as given. The decision problem of each firm can be written as[6]

$$\max_{h^1 \geq 0,\ h^2 \geq 0,\ l^1 \geq 0,\ l^2 \geq 0} F\left(h^1 + \alpha h^2, l^1 + \beta l^2\right) - w_h^1 h^1 - w_h^2 h^2 - w_l^1 l^1 - w_l^2 l^2 - w_m \gamma G\left(h^2, l^2\right).$$
(4)

The first-order conditions for the profit-maximizing employment levels h^1, h^2, l^1 and l^2, respectively (where h^2 and l^2 determine m, according to (3)), are given by

$$f'(\kappa) \leq w_h^1, \tag{5}$$

$$\alpha f'(\kappa) \leq w_h^2 + w_m \gamma g'(\chi), \tag{6}$$

$$f(\kappa) - \kappa f'(\kappa) \leq w_l^1, \tag{7}$$

$$\beta\left(f(\kappa) - \kappa f'(\kappa)\right) \leq w_l^2 + w_m \gamma\left(g(\chi) - \chi g'(\chi)\right). \tag{8}$$

The left-hand sides of (5)-(8) are the marginal products of the respective types

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(3).

[5]We hypothesize that new information and communication technologies reduce the non-production requirement for supporting workers. For instance, information about organizational changes and employers' goals can be dissipated among workers at lower costs (e.g. newsletters distributed via e-mail). This and other changes that reduce the costs to support workers can be captured by a lower γ.

[6]Remember $m = \gamma G\left(h^2, l^2\right)$, according to (3).

of labor, whereas the right-hand sides are marginal costs. The marginal costs for supported labor h^2 and l^2 equal the sum of their (hourly) wage rate (w_h^2 and w_l^2, respectively) and the marginal wage costs for the supporting staff. The latter are given by the wage rate of non-production labor times the additional (high-skilled) non-production labor requirements necessary for a marginal increase in h^2 or l^2, respectively (see (6) and (8)). It should be noted that costs for supporting workers are reflected in marginal costs of firms, i.e. non-production labor costs do not give rise to increasing returns. This reflects our basic hypothesis that informal training by managers or supervisors is not a one-shot requirement, but systematically related to the production activities of firms.

3   Equilibrium and comparative static results

With perfect competition in the labor market and homogeneity of workers within their education group, we obtain

$$w_h^1 = w_h^2 = w_m \equiv w_h, \quad w_l^1 = w_l^2 \equiv w_l. \tag{9}$$

There is full employment of both types of labor in equilibrium, i.e.

$$h^1 + h^2 + m = \frac{H}{n}, \quad l^1 + l^2 = \frac{L}{n}. \tag{10}$$

In order to focus the analysis, we concentrate on interior solutions only (i.e. $h^1 > 0$, $h^2 > 0$, $l^1 > 0$, $l^2 > 0$).[7] Thus, (5)-(8) are supposed to be binding. It follows that

$$w_h = f'(\kappa) \tag{11}$$

and thus,

$$\alpha = 1 + \gamma g'(\chi), \tag{12}$$

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[7]Note that, if $h^2 = l^2 = 0$, we would be back to a conventional segmented labor market model with production activities only.

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according to (5), (6) and (9).[8] Note that $\alpha \left(= \frac{\partial y / \partial h^2}{\partial y / \partial h^1} \right)$ equals the productivity gain from supporting high-skilled workers, whereas the right-hand-side of (12) equals the marginal costs of h^2 relative to h^1.

Lemma 1 *We have* $\chi = (g')^{-1} \left(\frac{\alpha - 1}{\gamma} \right) \equiv \widetilde{\chi} (\alpha, \gamma)$ *with* $\frac{\partial \widetilde{\chi}}{\partial \alpha} > 0$ *and* $\frac{\partial \widetilde{\chi}}{\partial \gamma} < 0$.

Proof. Use equation (12) and $g'' (\cdot) > 0$. ∎

First, if supporting high-skilled labor becomes relatively more effective (i.e. if α increases), the skill-intensity of supported labor (χ) chosen by firms increases. Second, if γ rises, i.e. if the marginal non-production requirement to support high-skilled jobs increases,[9] χ declines. Note that χ does neither depend on $\beta \left(= \frac{\partial y / \partial l^2}{\partial y / \partial l^1} \right)$ nor on labor supply H and L, respectively, according to (12).

Using (5), (7) and (9) we find that the relative wage between high-skilled and low-skilled labor is given by

$$\omega \equiv \frac{w_h}{w_l} = \frac{f' (\kappa)}{f (\kappa) - \kappa f' (\kappa)} \left(= \frac{F_1}{F_2} \right), \tag{13}$$

where (13) defines a function $\kappa = \widetilde{\kappa} (\omega)$, which is decreasing in ω. (Remember that $\kappa = \widetilde{h} / \widetilde{l}$ is the skill intensity of production labor in efficiency terms.) Moreover, using (7), (8) and (9) we obtain

$$\beta = 1 + \omega \gamma (g (\chi) - \chi g' (\chi)). \tag{14}$$

That is, labor is optimally allocated if the marginal productivity of supported low-skilled labor l^2 relative to non-supported low-skilled labor l^1, given by β, equals the marginal costs of l^2 relative to l^1 (given by the right-hand-side of (14)). (14) gives a positive relationship between ω and χ which can be written as

$$\omega = \frac{\beta - 1}{\gamma (g (\chi) - \chi g' (\chi))} \equiv \widetilde{\omega} (\chi). \tag{15}$$

The reason for $\widetilde{\omega}' (\chi) > 0$ is the following. A higher skill intensity of supported labor χ implies a lower marginal non-production labor requirement to support an

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[8]Note that $h^2 > 0$ (or $\chi > 0$, respectively) if and only if $(\alpha - 1) / \gamma > g' (0)$, according to (12) and $g'' (\cdot) > 0$.

[9]Note that $\frac{\partial m}{\partial h^2} = \gamma g' (\chi)$.

additional unit of low-skilled labor (due to complementarities in the support technology).[10] This raises the incentives of firms to support workers and thus raises both relative demand for high-skilled (non-production) workers and relative wages, all other things equal. Equations (12)-(14) are depicted in figure 1.

Figure 1

Equilibrium wage inequality ω^* is determined by the intersection point of the $\widetilde{\omega}(\chi)$-curve and the vertical line $\widetilde{\chi}$ in the $\chi - \omega-$ space. In turn, this determines the skill-intensity in production $\widetilde{\kappa}(\omega^*)$, according to (13). Formally, according to lemma 1 and (15), the equilibrium wage differential is given by

$$\omega^* = \frac{\beta - 1}{\gamma\left(g\left(\widetilde{\chi}(\alpha, \gamma)\right) - \widetilde{\chi}(\alpha, \gamma)\frac{\alpha-1}{\gamma}\right)}, \tag{16}$$

where $\chi = \widetilde{\chi}(\alpha, \gamma)$ and $g'(\chi) = \frac{\alpha-1}{\gamma}$ from lemma 1 has been used.

Proposition 1 *The relative wage of high-skilled labor ω^* is (i) increasing in α, (ii) increasing in β, (iii) decreasing in γ, and (iv) does not depend on H and L.*

Proof. Use equation (16) as well as $g'(\widetilde{\chi}) = \frac{\alpha-1}{\gamma}$, according to lemma 1, to obtain

$$\frac{\partial \omega^*}{\partial \alpha} = \frac{(\beta - 1)\,\widetilde{\chi}(\alpha, \gamma)}{\left[\gamma\left(g\left(\widetilde{\chi}(\alpha, \gamma)\right) - \widetilde{\chi}(\alpha, \gamma)\frac{\alpha-1}{\gamma}\right)\right]^2} > 0,$$

$\frac{\partial \omega^*}{\partial \beta} > 0,$

$$\frac{\partial \omega^*}{\partial \gamma} = -\frac{(\beta - 1)\,g\left(\widetilde{\chi}(\alpha, \gamma)\right)}{\left[\gamma\left(g\left(\widetilde{\chi}(\alpha, \gamma)\right) - \widetilde{\chi}(\alpha, \gamma)\frac{\alpha-1}{\gamma}\right)\right]^2} < 0$$

and $\frac{\partial \omega^*}{\partial H} = \frac{\partial \omega^*}{\partial L} = 0.$ ∎

Corollary 1 *The skill-intensity in production κ is (i) decreasing in α, (ii) decreasing in β, (iii) increasing in γ, and (iv) does not depend on H and L.*

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[10]Remember that $\frac{\partial m}{\partial l^2} = \gamma\left(g(\chi) - \chi g'(\chi)\right)$ and $g''(\chi) > 0$.

Proof. Directly follows from proposition 1 and $\kappa = \widetilde{\kappa}(\omega)$ with $\widetilde{\kappa}'(\omega) < 0$, according to (13). ∎

The intuition for proposition 1 (and thus, for corollary 1) is the following. If α increases, supporting *high*-skilled labor becomes more attractive, implying an increase in the skill-intensity of supported labor χ. Consequently, for a given wage differential ω, the marginal cost of supporting low-skilled labor declines (as $g''(\cdot) > 0$). This increases relative demand for high-skilled non-production labor and thus, raises equilibrium wage dispersion ω^*.[11] In figure 1, an increase in α induces a shift of the $\widetilde{\chi}$-curve to the right. (Note that the $\widetilde{\omega}(\chi)$-curve is not affected by α, as it reflects the trade-off between benefits and costs of supporting *low*-skilled labor).

For a given allocation of labor (h^1, h^2, l^1, l^2) an increase in β makes support of both low-skilled and (due to $g''(\cdot) > 0$) high-skilled labor more attractive. This results in higher demand for high-skilled non-production activities. In addition, an increase in β leads, ceteris paribus, to a decline in κ and therefore to higher demand for high-skilled production labor. The latter effect arises due to the complementarity of $\widetilde{h}$ and $\widetilde{l}$ in production technology $F(\cdot)$. Both effects raise demand for high-skilled labor so that equilibrium wage inequality ω^* increases. In figure 1, an increase in β is reflected by an upward shift in the $\widetilde{\omega}(\chi)$-curve (whereas the $\widetilde{\chi}$-curve, which reflects the trade-off between benefits and costs of supporting *high*-skilled labor, remains unaffected).

An increase in γ has two effects on the relative wage. First, it raises marginal costs of supporting high-skilled labor, which induces a decline in χ, according to lemma 1. Thus, as skilled and unskilled labor are complements in the support technology (i.e. $g''(\cdot) > 0$), supporting low-skilled labor becomes more expensive in terms of non-production labor. Second, an increase in γ also raises marginal costs of supporting low-skilled labor directly, for a given relative wage ω (see (14)). The resulting decrease in the demand for non-production workers leads to a decline in ω^*.

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[11]There is a second opposing effect. For a given allocation of labor (h^1, h^2, l^1, l^2) an increase in α raises κ, and, thus, lowers ω, according to (13). However, this effect is dominated by the incentive of firms to allocate high-skilled labor towards non-production support activities so that the equilibrium level of κ declines if α increases (see part (i) of corollary 1).

In figure 1, an increase in γ induces a leftward shift of the $\widetilde{\chi}$-curve and a downward shift of the $\widetilde{\omega}(\chi)$-curve, respectively.

To sum up, technological change which raises the incentive of firms to support workers (i.e. an increase in α and β or a decrease in γ, respectively) raise equilibrium wage inequality ω^*, due to an increased demand for high-skilled non-production workers.

Finally, both an increase in H and a decline in L have the following two opposing effects. On the one hand, for given levels of supported labor h^2 and l^2, ω is reduced by an increase in the skill-intensity of production labor in efficiency terms κ. Formally this can be seen by writing κ as

$$\kappa = \frac{H/n - \gamma G\left(h^2, l^2\right) + (\alpha - 1) h^2}{L/n + (\beta - 1) l^2}, \tag{17}$$

where we used (2), (3) and (10). This effect is similar to conventional models with a segmented labor market. However, on the other hand, supporting low-skilled labor becomes more attractive since the marginal costs of l^2 relative to the marginal costs of l^1 decrease.[12] This also stimulates the use of non-production workers to support high-skilled workers, according to (12). As more high-skilled labor is allocated towards non-production activities, κ declines. This raises the relative wage ω. Both effects exactly cancel out in equilibrium due to the linear homogeneity of $G(\cdot)$ and the assumption that only high-skilled workers can be allocated to non-production activities.

Thus, once technological change has made productivity-augmenting support attractive (i.e. if $\alpha > 1$, $\beta > 1$), a higher relative supply of skills does not lower wage inequality, due to the induced restructuring process within firms. This is a novel mechanism, which provides a simple and intuitive way for understanding the recent non-negative relationship between skill supply and wage inequality.[13]

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[12]Remember that these marginal costs equal $1 + \omega\gamma\left(g\left(\chi\right) - \chi g'\left(\chi\right)\right)$, according to (14), which decrease when ω declines, all other things equal.

[13]Since the equilibrium value of κ is independent of H and L (see corollary 1), first-order conditions (5) and (7) imply that real wages w_h and w_l are also independent of labor endowments H and L (which is a non-standard result compared with existing literature).

In contrast to the technology shifts considered in Proposition 1, most of the literature on relative wages, skill supply and new technologies hypothesizes biased shifts in the production function which raise the relative marginal productivity of skilled labor, for any given skill-intensity (e.g. Gregg and Manning, 1997; Acemoglu, 1998; Galor and Moav, 2000). That is, for a given skill-intensity of production-related tasks in efficiency terms κ, the relative marginal productivity F_1/F_2 shifts up. It is interesting to examine the impact of such skill-biased technological change (SBTC) when taking into account the double role of high-skilled labor in production-related and non-production activities. The following, somewhat surprising result emerges.

Proposition 2 *An upward shift in F_1/F_2 for any given $\kappa > 0$ does not affect relative wages ω^*.*

Proof. Follows directly from (16). ∎

According to (13), SBTC implies that, for any κ, the relative wage ω increases. However, this means that SBTC makes the allocation of skilled labor towards support activities *less* attractive, since the opportunity costs of high-skilled non-production workers increase. In other words, SBTC increases relative demand for skilled production workers, but reduces demand for non-production workers. Under the linear homogeneity of both the production technology and the support technology, both effects cancel out such that equilibrium wage dispersion ω^* remains unchanged. This suggests to look more carefully on the tasks where technology-related changes in the relative demand for skills have actually occurred. Our model indicates that technology changes which change incentives of firms to support labor but not SBTC regarding production related tasks affect wage inequality in a systematic way.

What determines the degree of supporting the workforce within firms? To answer this question we have to look at comparative static results with respect to the ratio of supported to non-supported workers within an education group, h^2/h^1 and l^2/l^1, respectively.

Proposition 3 *The ratios h^2/h^1 and l^2/l^1 (i) rise with H/L and α, and (ii) decrease with γ. (iii) The impact of β on these ratios is ambiguous.*

Proof. See appendix. ∎

First, note that, due to the linear homogeneity of both the production and the support technology, the ratios h^2/h^1 and l^2/l^1 depend on the *relative* supply of high-skilled labor H/L. As already discussed after proposition 1, if high-skilled labor becomes (relatively) less scarce, firms have an increasing incentive to support workers.

Second, for given levels of supported labor, an increase in α raises the skill-intensity in production κ, according to (17). This reduces relative wages, according to (13), and thus, lowers marginal costs of supporting low-skilled labor (i.e. lowers marginal costs of l^2 relative to l^1), according to (14). Thus, the ratio l^2/l^1 increases. Moreover, an increase in α means that the marginal productivity of h^2 relative to h^1 rises (see (12)), thus raising h^2/h^1 as well.

Third, an increase in γ raises marginal non-production labor requirements to support both high-skilled and low-skilled labor, according to (12) and (14), respectively. Hence, both h^2/h^1 and l^2/l^1 are negatively related to γ.

Finally, note that, somewhat surprisingly, an increase in β has an ambiguous impact on both l^2/l^1 and h^2/h^1, respectively. On the one hand, the marginal productivity of l^2 relative to l^1 increases, according to (14). However, on the other hand, all other things equal, an increase in β lowers the skill-intensity of production labor in efficiency terms κ, according to (17). In turn, this raises ω and thus gives a disincentive to support low-skilled workers. This is an opposing effect to the first one. (Formally, this effect is due to the strict concavity of $f(\cdot)$.) In sum, the impact of β on l^2/l^1 turns out to be ambiguous. For the impact of β on h^2/h^1 note that for a given L an increase in l^2/l^1 would imply that l^2 increases and thus, the skill intensity of supported labor χ decreases, all other things equal. According to (12), a decline in χ would lower the marginal costs of h^2 relative to h^1 and thus, would raise h^2/h^1. Hence, l^2/l^1 and h^2/h^1 are positively related. Since the impact of β on l^2/l^1 is ambiguous, the impact of β on h^2/h^1 is ambiguous as well.

Above we emphasized the importance of considering firms' expenditures for organizational support activities. Thus, one would like to know how aggregate non-production employment $M \equiv nm$ as share of both high-skilled employment and total employment, respectively, depends on the parameters of the model. The impacts of α, β, γ, and H/L on both $\Gamma \equiv M/H$ and $\Psi \equiv \frac{M}{H+L}$ are analyzed in the following.

Proposition 4 *(i) Both the ratio of non-production employment to total high-skilled employment $\Gamma = M/H$ and the non-production employment share $\Psi = \frac{M}{H+L}$ rise with α and H/L. (ii) The impacts of β and γ on both Γ and Ψ are ambiguous.*

Proof. See appendix. ■

As discussed after proposition 3, an increase in the relative supply of skilled labor H/L raises incentives to support workers and thus raises the non-production employment share of both high-skilled employment and total employment, Γ and Ψ, respectively. The same holds true for an increase in α, whereas the impact of β is again ambiguous (for the same reasons as in proposition 3). The impact of γ on both Γ and Ψ remains to be argued. On the one hand (as discussed after proposition 3), an increase in γ provides a disincentive to support workers, thus depressing the non-production employment shares. However, on the other hand, for given levels of h^2 and l^2, a higher non-production labor requirement for supporting workers is needed. Hence, due to the latter effect γ also positively affects the non-production employment shares, leaving the overall impact of γ on both Γ and Ψ ambiguous.

4 A Simple Dynamic Setting

One may argue that the static nature of the model, including the absence of physical capital, is oversimplistic. This section considers an extension of our static set up to a simple AK model of endogenous growth, primarily chosen for its simplicity and familiarity.[14] It is demonstrated that the key features of the basic model do neither hinge on our two-factor set up nor on the static framework.

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[14]Recent empirical support for the AK model is provided by Li (2002).

As in the basic model, there is one homogenous consumption good. Each firm produces output $y(t)$ at date t (time is continuous) according to

$$y(t) = A(t)k(t)^\delta \widetilde{h}(t)^\varepsilon \widetilde{l}(t)^{1-\delta-\varepsilon}, \tag{18}$$

$0 < \delta < 1$, $0 < \varepsilon < 1$, $\delta + \varepsilon < 1$, where $k(t)$ denotes physical capital per firm. Efficiency units of labor $\widetilde{h}$ and $\widetilde{l}$ are still given by (2). Total factor productivity A depends on the *average* capital stock of firms, denoted $\bar{k}$, employing the familiar specification $A(t) = \bar{k}(t)^{1-\delta}$. As usual, this can be interpreted as external spillover effect from firms' investments (e.g. learning-by-doing). In equilibrium, $\bar{k}(t) = k(t)$ must hold. Thus, we have

$$y(t) = k(t)\widetilde{h}(t)^\varepsilon \widetilde{l}(t)^{1-\delta-\varepsilon}. \tag{19}$$

That is, the production technology exhibits *socially* increasing returns to scale (although constant-returns to scale prevail from the perspective of single firms), and a constant social return to capital. The support technology remains the same as in the basic model.

There is a representative household (choosing the aggregate consumption path when endowed with aggregate resources) with preferences represented by the standard intertemporal utility function[15]

$$U = \int_0^\infty e^{-\rho t} \frac{C(t)^{1-\sigma} - 1}{1 - \sigma} dt, \tag{20}$$

$0 < \rho < 1$, $\sigma > 0$, where $C(t)$ is the aggregate consumption level at time t. Let $K(t) = nk(t)$ and $Y(t) = ny(t)$ denote the aggregate capital stock and the total output level, respectively. The initial capital stock $K(0) = K_0 > 0$ is historically given. Abstracting from capital depreciation, the capital stock (which equals the stock of assets of the representative agent) evolves according to

$$dK(t)/dt = Y(t) - C(t). \tag{21}$$

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[15]For the concept of a (positive) representative consumer, see e.g., Mas-Colell et al. (1995), who show that such a consumer always exists, for instance, under homothetic preferences (e.g., like preferences considered in (20)). Recall that, in our model, individuals differ in their formal education levels or innate ability, respectively.

Denoting the interest rate by $r(t)$, utility maximization of the representative consumer leads to the well-known Euler-equation[16]

$$\frac{dC(t)/dt}{C(t)} = \frac{r(t) - \rho}{\sigma} \equiv \vartheta(t). \qquad (22)$$

In view of (9), the firms' decision problem at each point in time is to solve

$$\max_{h^1(t),h^2(t),l^1(t),l^2(t),k(t)} A(t)k(t)^\delta \left[h^1(t) + \alpha h^2(t)\right]^\varepsilon \left[l^1(t) + \beta l^2(t)\right]^{1-\delta-\varepsilon} - \qquad (23)$$
$$r(t)k(t) - w_h(t)\left[h^1(t) + h^2(t) + \gamma G\left(h^2(t), l^2(t)\right)\right] - w_l(t)\left[l^1(t) + l^2(t)\right].$$

Thus, observing that the external productivity equals $A(t) = k(t)^{1-\delta}$ in equilibrium, the equilibrium interest rate is given by

$$r(t) = \delta \widetilde{h}(t)^\varepsilon \widetilde{l}(t)^{1-\delta-\varepsilon}. \qquad (24)$$

Since $r(t)$ is independent of physical capital, there exists a steady state equilibrium without any transitional dynamics, i.e., for all $t \geq 0$, $r(t) \equiv r$ (e.g. Bertola, 1993). Existence of such an equilibrium can be seen as follows. First, note from (19) and the first-order conditions to maximization problem (23) that both output $y(= Y/n)$ and wage rates w_h and w_l grow at the same rate as the capital stock $k(= K/n)$, if the employment allocation (h^1, h^2, l^1, l^2) is constant over time.[17] As supply for skilled and unskilled labor, H and L, is time-invariant, the latter is consistent with an equilibrium. Moreover, a constant allocation of labor implies that the interest rate is time-invariant, according to (24). Finally, note that both the aggregate capital stock K and output Y (which have the same growth rate, as argued above) must grow at the same rate as consumption, according to (21). According to (22), using $r(t) = r$, this growth rate is given by[18]

$$\vartheta(t) = \frac{r - \rho}{\sigma} \equiv \vartheta. \qquad (25)$$

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[16]Besides budget constraint (21), also the standard 'No Ponzi Game' condition $\lim_{T \to \infty} e^{-rT} K(T) \geq 0$ (NPG) has to be observed in the utility maximization problem of the representative agent.

[17]With respect to the optimal choices of labor inputs, again, we focus on an interior solution.

[18]Irreversibility of investments requires non-negative growth, i.e. $r \geq \rho$, according to (25). Moreover, note that NPG (see footnote 16) together with utility maximization implies the transversality condition (TVC) $\lim_{T \to \infty} C(T)^{-\sigma} e^{-\rho T} K(T) = 0$ (e.g. Barro and Sala-i-Martin, 1995). Under the bal-

From the first-order conditions to maximization problem (23) with respect to the optimal labor inputs (h^1, h^2, l^1, l^2), it is easy to see that

$$\omega(t) = \frac{\varepsilon}{1 - \delta - \varepsilon} \frac{1}{\kappa} \equiv \omega, \tag{26}$$

in analogy to (13), where $\kappa(t) = \widetilde{h}(t) / \widetilde{l}(t) = \widetilde{h}/\widetilde{l} \equiv \kappa$ with a time-invariant allocation of labor. Most important, it is easy to check that the key equations (12), (14) and (15) for the equilibrium of the basic model remain valid in the present intertemporal context. Thus, equilibrium wage dispersion ω^* is still given by (16). In fact, all results stated in propositions 1-4 remain valid in this intertemporal context with physical capital and investment-driven growth.

5   Testable Hypotheses and Empirical Evidence

The goal of this subsection is to summarize the main theoretical hypotheses and to confront them with empirical evidence. However, a rigorous econometric test of our hypotheses is beyond the scope of this paper. Instead, we present some empirical results that support the predictions of our comparative-static analysis in section 3.

First, according to propositions 3 and 4, an increase in the relative skill supply induces firms to allocate a higher share of skilled labor to productivity-enhancing human resource activities, thereby allowing for more knowledge-based organizational forms. This prediction corresponds to a strong positive effect of changes in the relative supply of skilled labor (proxied by regional skill price differentials) on organizational change identified in Caroli and van Reenen (2001) by use of survey data for France and the UK.

A second hypothesis of our model is that improvements of information technologies or management techniques result in higher support/training provision and therefore in a more flexible work organization (reflected by higher ratios h^2/h^1 and

anced growth path, TVC holds if $\rho > \vartheta(1-\sigma)$ (for instance, $\sigma \geq 1$ is sufficient, according to (25)). To see this, substitute $K(T) = K_0 e^{\vartheta T}$ and $C(T) = C(0)e^{\vartheta T}$ (note that the initial consumption level $C(0)$ is endogenous) into TVC. From this, it is easy to check that TVC holds if and only if $\rho > \vartheta(1-\sigma)$.

l^2/l^1, respectively, according to proposition 3).[19] The empirical literature on organizational change emphasizes the complementarity of investment in information technology and organizational change but often avoids conclusion on causal effects. However, in a recent study Autor et al. (2001) use time series observations for the US and find that computerization alters the composition of job tasks. Moreover, Caroli and van Reenen (2001) identify technical change as an important determinant of organizational change, which gives first insights into the causal relationship between these two phenomena. Brynjolfsson et al. (2000) and Bresnahan et al. (2002) find a positive relationship between computerization and training provision which is robust with respect to different measures of computerization.[20]

Finally, propositions 1 and 2 show that technological change has an impact on relative wages only insofar as it results in a higher effectiveness or reduced costs of support activities, thereby inducing an incentive for changes in the organization of work. This is in line with the empirical finding that "[s]kill-biased organizational changes, induced by technical change may have a much larger effect on skills than raw technical change" (see Bresnahan et al. (2002, p. 371)).

In sum, empirical evidence gives some support to our theoretical hypotheses. However, due to our focus on a theoretical analysis, a rigorous econometric test of our predictions is left open for future research.

6   Conclusion

This paper has analyzed the relationship between skill supply, technological change, and wage inequality across skill groups. Based on a distinction between production-related and non-production activities we have shown that an increase in the relative skill supply creates incentives for firms to allocate a higher share of skilled labor to

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[19]This refers to an increase in α or a decrease in γ, respectively. However, the impact of an increase in β on h^2/h^1 and l^2/l^1 turns out to be ambiguous, according to proposition 3.

[20]OECD (1999) summarizes findings of several empirical studies and concludes that flexible (new) work organization practices, combined with technical change, lead to demands for higher levels of training.

productivity-augmenting support activities. In our framework, the resulting increase in the non-production employment share is strong enough to offset any labor supply changes so that equilibrium wage inequality is not affected. Moreover, technological changes, which increase the effectiveness or reduce the costs of support activities (in terms of high-skilled non-production requirements), unambiguously raise wage inequality, whereas the impact on the non-production employment share is ambiguous. In contrast, skill-biased technological change of the sort usually considered in the literature has no impact on the relative return to skills in our model.

Our model should be viewed as complementary to the existing literature. According to the standard notion, technological change increased skill requirements and thus, provided incentives for firms to intensify training of workers. In contrast, our analysis suggests that shifts in human resource management can be understood by an increase in the supply of well-educated labor and by technical advances which make support activities more effective or less costly.

Our model is just a first step to proceed along these lines. Future research could provide a detailed understanding of the forces, processes and impacts of new management practices for the macroeconomic equilibrium regarding earnings dispersion and the employment structure.

Appendix

Proof of proposition 3

According to (3) and (10), we obtain

$$\frac{H}{L} = \frac{h^1 + h^2 + m}{l^1 + l^2} = \frac{h^1/l^2 + \chi + \gamma g\left(\chi\right)}{l^1/l^2 + 1}. \tag{A.1}$$

Moreover, we have

$$\kappa = \frac{\widetilde{h}}{\widetilde{l}} = \frac{h^1 + \alpha h^2}{l^1 + \beta l^2} = \frac{h^1/l^2 + \alpha \chi}{l^1/l^2 + \beta}. \tag{A.2}$$

(A.1) and (A.2) simultaneously give h^1/l^2 and l^1/l^2 as functions of κ, χ and the parameters α, β and γ (remember that χ and κ are also functions of these parameters only, according to lemma 1 and corollary 1). It is easy to show from (A.1) and (A.2) that

$$\frac{h^1}{l^2} = \frac{\kappa\gamma\left(g\left(\chi\right) - \frac{\alpha-1}{\gamma}\chi\right) + \kappa\left(\beta - 1\right)H/L - \alpha\chi\left(H/L - \kappa\right)}{H/L - \kappa}. \qquad (A.3)$$

Note that $H/L > \kappa$ since

$$\frac{h^1}{l^2} + \alpha\chi = \frac{\kappa\gamma\left(g\left(\chi\right) - \frac{\alpha-1}{\gamma}\chi\right) + \kappa\left(\beta - 1\right)H/L}{H/L - \kappa} > 0 \qquad (A.4)$$

and the denominator of the right-hand-side of (A.4) is positive. Note that $\frac{h^2}{h^1} = \frac{\chi}{h^1/l^2}$. Substituting (A.3) in the latter expression thus yields

$$\frac{h^2}{h^1} = \frac{\chi\left(H/L - \kappa\right)}{\kappa\gamma\left(g\left(\chi\right) - \frac{\alpha-1}{\gamma}\chi\right) + \kappa\left(\beta - 1\right)H/L - \alpha\chi\left(H/L - \kappa\right)}. \qquad (A.5)$$

Moreover, substituting (A.3) in (A.1) and (A.2) and solving for l^2/l^1 yields

$$\frac{l^2}{l^1} = \frac{H/L - \kappa}{\gamma\left(g\left(\chi\right) - \frac{\alpha-1}{\gamma}\chi\right) + \beta\kappa - H/L}. \qquad (A.6)$$

Observing the partial derivatives of χ and κ as stated in lemma 1 and corollary 1, respectively, as well as using $H/L > \kappa$ proves proposition 3 by partially differentiating (A.5) and (A.6) with respect to α, β, γ and H/L. ∎

Proof of proposition 4

Note that $\Gamma = \frac{M}{H}$ can be written as

$$\Gamma = \frac{\gamma g\left(\chi\right)}{h^1/l^2 + \chi + \gamma g\left(\chi\right)}, \qquad (A.7)$$

where $M = nm$, $H = n\left(h^1 + h^2 + m\right)$ and $m/l^2 = \gamma g\left(\chi\right)$ have been used (for the latter two equations, see (10) and (3), respectively). Substituting (A.3) into (A.7) yields

$$\Gamma = \frac{\gamma g\left(\chi\right)\left(H/L - \kappa\right)}{\left[\gamma\left(g\left(\chi\right) - \frac{\alpha - 1}{\gamma}\chi\right) + \left(\beta - 1\right)\kappa\right]H/L}. \qquad (A.8)$$

Observing the partial derivatives of χ and κ as stated in lemma 1 and corollary 1, respectively, as well as using $H/L > \kappa$ proves proposition 4 with respect to Γ by partially differentiating (A.8) with respect to α, β, γ and H/L. For the impacts on Ψ note that the non-production employment share can be written as $\Psi = \frac{M/H}{1 + L/H}$. The results for Ψ thus directly follow. ∎

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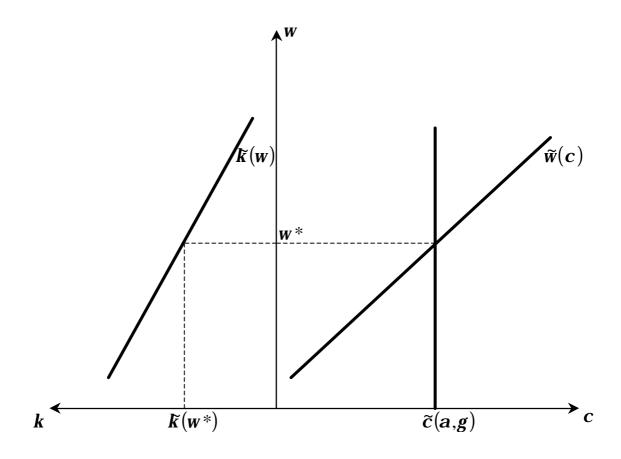
Figure 1: Skill intensities and equilibrium wage inequality.