

The Effects of Technical and Organizational Change on Labor Markets

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Table of Contents

1	Introduction	1
2	Enter Organizational Change	5
2.1	Manifestations of Recent Organizational Change	5
2.2	What Influences Organizational Choice?	6
2.2.1	Technology	7
2.2.2	The Economy's Skill-Structure	8
2.2.3	The Product Market	9
2.3	The Concept of Skill-Biased Organizational Change	10
2.4	Segregation by Skill	15
3	A Model of Endogenous Segregation by Skill	17
3.1	The Model	18
3.2	Determinants of Segregation	24
3.2.1	The Dispersion of Skills	24
3.2.2	The Sensitivity of Tasks to Skill	28
3.2.3	Some Remarks on the Extension to more Skill Types	33
3.3	Wage Formation	36
3.3.1	Changes in Worker Productivity and the Wage	39
3.3.2	Changes in Tasks' Sensitivity to Skill	43
3.4	Summary and Outlook	53
4	Conclusion	58
	References	60

1 Introduction

In most Western countries, firms these days employ a greater share of skilled workers than they did 20 or 30 years ago, despite the fact that the relative cost of skilled labor has not decreased.¹ In some countries such as the United States and Britain, the rising skill ratio in production has even been accompanied by a considerable *increase* in the gap between high- and low-skilled workers' wages. In many European countries, the move toward more skill-intensive production has been accompanied by a widespread increase in low-skilled unemployment which, according to the "Krugman hypothesis" (Krugman, 1994) is often argued to reflect the flip side of increased wage inequality within a less flexible labor market.

A variety of explanations have since been offered for these seemingly contradictory developments of the wage structure on the one hand and both the aggregate skill structure and the general skill-intensity of production on the other. These include the global integration of goods markets, changes in consumer demand, and a tendency towards deunionization in most Western countries. While all of these forces may plausibly be assumed to have influenced the demand for skills to some extent, a consensus has nevertheless emerged that technological change must have played a key role in recent labor market developments by altering the skill-demand of firms. Having become popular as the hypothesis of "skill-biased technical change" (SBTC), this strand of literature argues that recent technological change is *biased* toward certain skills or specializations, in the sense that it enhances existing differences in abilities across workers.² Technological progress is thus supposed to intrinsically favor skilled labor.

For a long time, the idea of SBTC has tended to be something of a residual concept, whose operational meaning was often "labor demand shifts with invisible causes" (Bresnahan et al., 2000, p. 1). In this definition, SBTC was not much more than a catch-all variable reflecting any changes in relative wages not readily accounted for by observable factors. Recently, the timing and magnitude of

¹See, for example, Berman et al. (1994), Autor et al. (1998), and Machin and Van Reenen (1998).

²Acemoglu (2000) provides a comprehensive review of both the empirical and theoretical literature.

labor demand shifts have led many economists to seek SBTC in the largest and most widespread technical change of the current era: the spread of new information technologies (ITs) and computers in particular. The general argument is that the introduction of IT-equipment to the workplace has enhanced high-skilled workers' productivity more strongly than that of low-skilled workers.

While such an explanation for recent labor market developments has its intuitive appeal, formal implementations of the SBTC-hypothesis generally face a number of limitations, many of which are not even overcome by including the aforementioned alternative explanations (see Acemoglu, 2000, and Snower, 1999).

First, the sheer magnitude of increases in high-skilled workers' productivity which is required by such pure technical explanations in order to generate the observed rise in wage inequality would suggest significant increases in total factor productivity. This stands in contrast to the fact that many industrial economies have experienced a substantial reduction in the rate of growth of total factor productivity since 1973.³

Second, what most simple models of SBTC cannot account for is an *absolute* decrease in the wage of low-skilled workers as observed, for instance, in the US and the UK. According to Topel (1997), for example, males in the bottom decile of the US earnings distribution experienced a staggering 20 percent drop since 1970.

Third, many empirical studies point out that increased wage inequality is less of a *within*-firm than a *between*-firm phenomenon, implying that the widening of the earnings distribution has not occurred mainly within the representative firm—as the standard modelling of SBTC would suggest—but rather between firms even within the same industry.⁴

Furthermore, on a more conceptual note, the link between technical progress and workers' productivity is still far from being fully understood. Models of SBTC (as surveyed in Acemoglu, 2000, for instance) typically assume that technical change has simply served to augment high-skilled labor as it enters into a representative production function. Casual observation suggests, however, that contemporary technological advances incorporate something of much greater complexity than a simple multiplicative effect of high-skilled workers' computer equipment on their own pro-

³Wolff (1996) provides evidence on this.

⁴See Davis and Haltiwanger (1991) and more recently Doms et al. (2000).

ductivity.

Picking up this last point, a small but growing body of literature has recently tried to take a closer look into the “black box” of the production function. Its point of departure is the idea that the production function represents something more than simply a routine physical (or “technical”) transformation process of inputs such as capital and labor into outputs. Rather, a considerable amount of resources is spent on coordination, motivation and communication within firms—activities which make up a firm’s “organization”. The production process must be set up and designed, split up into individual tasks which in turn must be grouped into jobs and assigned to certain workers. In a dynamic environment, this is not a one-time activity but a constant search for the efficient frontier. Furthermore, in a world heavily characterized by imperfect information and incomplete contractibility, various information channels must be set up within the firm, workers must be coordinated and motivated, and decision rights must be delegated.

Even though a comprehensive understanding of technology and the production function as “the methods by which inputs are combined to achieve output” may certainly be interpreted as incorporating such activities, organizational issues nevertheless have long been disregarded by economic theory. The main reason for this is that neoclassical theory is primarily a theory of markets and allocation. Thus, its main focus is on price formation rather than on the organization of production units. As a matter of fact, a wide area of literature following Coase even regards missing markets as the primary *reason* for the existence of hierarchical organizations as opposed to a completely decentralized Walrasian market structure. Thus, almost by definition, the explanatory power of competitive theory does not reach into the boundary of the firm and thus turns the firms’ internal workings into a black box.

However, as we shall argue in this essay, recent changes within this black box, that is, changes in the way firms organize to produce, have had substantial effects at the macroeconomic level, notably on the structure of labor demand and thereby wages. A look inside the black box may therefore not only deepen our understanding of *how* firms adjust their organizational structure to changing technical possibilities. Rather, by pointing out further transmission mechanisms between technology and the structure of labor demand, it may actually augment the explanatory power of

standard SBTC-theory, thus reconciling it with some of the aforementioned open questions.

With this goal in mind, the following treatment of the effects of technical and organizational change on labor markets is divided into two main sections. Section 2 begins with an overview over the various facets of organizational change, providing a stylized list of recent adjustments in firms' organizational structure. Having identified the main causes for organizational changes, we will introduce the concept of "skill-biased *organizational* change", representing the idea that contemporary reorganizations strengthen the relative demand for high-skilled labor, and provide a brief survey of justifications proposed by the literature. As these justifications are based on rather distinct ramifications of organizational change, we will focus on what seems to bear most on labor market developments: the fact that organizational change encompasses a move toward more skill-homogenous workforces, leading to an increased segregation of workers by skill.

Section 3 provides a formal framework for analyzing this trend based on the work of Kremer and Maskin (1996). In a first step, we will isolate specific causes of the observed increase in segregation, including changes in technology and changes in the economy's skill-distribution. Moreover, by means of an extension to Kremer and Maskin's model, we will show that an increased homogenization of firms' workforces may also be attributed to *other* manifestations of recent organizational change, thus uncovering a link between seemingly disparate facets of organizational change. Next, we will determine how the identified causes affect the wage structure by increasingly segregating workers. As we shall see, organizational change as captured by an increase in workforces' skill-homogeneity provides a valuable extension or even alternative to existing models of skill-biased technical change in explaining recent labor market developments. Finally, Section 4 concludes.

2 Enter Organizational Change

The fact that recent years have indeed witnessed tremendous changes in firms' internal organizational structure makes a more differentiated view of production particularly worthwhile, as it is likely that such pronounced changes have induced considerable shifts in firms' skill-requirements. Snower (1999) speaks of an "Organizational Revolution" currently underway, similar to history's two Industrial Revolutions as regards the magnitude of its impact on the division of labor and patterns of inequality.

While not every economist would consent to such an extreme view, there is nevertheless widespread agreement that the more recent past has witnessed disproportionately large changes in the way firms organize.⁵ The precise nature of the reorganizational process naturally varies from firm to firm, but the evidence is by now sufficiently detailed that it is possible to recognize some prominent central features.

2.1 Manifestations of Recent Organizational Change

The following categorization is borrowed from Aghion et al. (1999) and Caroli (2000), who summarize these changes to develop an "ID" of the typical reorganized firm:

- (a) **Decentralization of Decision Making and Control:** High hierarchical structures are rapidly being cut down by removing middle layers, resulting in flatter organizations with a wider span of control (as measured by the number of downstream agents or units being supervised by a given layer) at the remaining hierarchical layers. This trend is accompanied by a higher degree of decentralization of decision making (such as through the creation of independent profit centers with a higher degree of flexibility and independent authority) as some of the decision rights previously allotted to intermediate hierarchical layers are being transferred downstream. Overall, downstream agents are given a higher degree of both responsibility and autonomy.

⁵For overviews, see Caroli (2000), Lindbeck and Snower (2000b), OECD (1999), and Aghion et al. (1999).

- (b) **The Rise of “Organic” Firm Structures:** The shift away from extensive hierarchical structures gives rise to more “organic” organizational structures. Regarding communication within the firm, this involves the replacement of vertical communication channels by *horizontal* channels (i.e. between departments). Concerning the division of labor, organic firms no longer rely as heavily on an extreme specialization of their workforce. Workers in reorganized firms not only rotate among jobs. More importantly, in a given occupation, workers typically perform a wider variety of tasks. The more organic firm structure is further characterized by a higher degree of dynamic flexibility (possibly at the cost of static efficiency) and adaptability to more volatile product markets.
- (c) **The Introduction of Collective Work:** Again strongly related to the two above facts, reorganized firms have developed collective work in the form of work teams, involvement groups and quality circles.
- (d) **Increased Workforce-Homogenization:** Reorganized firms increasingly segregate workers by skills, leading to higher homogeneity of firms’ skill-employment structure. Traditionally, a typical firm such as General Motors relied on a good mix of both high- and low-skilled workers to carry out the various tasks associated with the production process. Recently however, it is becoming less common for workers of different skill to work in the same firm. The firm’s structure thus appears to be shifting from the General Motors prototype toward companies such as Microsoft and McDonald’s, whose workforces are much more homogeneous.

Furthermore, these manifestations of organizational change appear to be complementary and mutually reinforcing since, as Osterman (1994) and Ichniowski and Shaw (1995) show, they tend to be adopted in clusters.

2.2 What Influences Organizational Choice?

It is usually assumed that the described organizational changes do not stand as an autonomous event but rather occur as an optimal response to other exogenous

shocks. Therefore, before turning directly to the *effects* of the described organizational changes on wage inequality, it should prove instructive to develop a rough understanding of the factors *influencing* organizational choice. Which exogenous factors make a certain organizational regime more efficient relative to another?

2.2.1 Technology

The first obvious influence is of course *technology* as understood in a more narrow sense. Milgrom and Roberts (1990) were among the first to point out that technological and organizational changes will typically be adapted in clusters due to complementarities among the two. Intuitively, technological possibilities certainly influence the productivity of different types of organization. Such influences may consist of direct technical innovations in production technology. For instance, manufacturing inventions beginning at the end of the 18th century are generally held responsible for the move from artisan production toward a higher division of labor in firms (see Snower, 1999). However, technological innovations may also affect activities not as directly related to production, such as communication and delegation. For example, hierarchical structures are frequently seen as an attempt to minimize on communication costs because they minimize the number of communications links required to connect multiple economic actors (see Aghion et al., 1999). Technical innovations which lead to a reduction in the costs of communication may thus reduce the attractiveness of hierarchical organizational forms.

Thinking of particular technological advances, the dominant development of the recent past has certainly been the widespread diffusion of computers into the workplace, as the quality-adjusted real price of computers has been declining at a compound rate of about 20 percent per year throughout the mid-1990s, while the share of computers in US real capital stock has displayed a hundredfold increase since 1970 (see Brynjolfsson and Hitt, 1998, and Bresnahan et al., 2000). If the efficient use of computer equipment merely implied that workers dealing with computers needed higher skills, the reader could simply be referred to the mainstream literature on plain SBTC, which assumes that computer technology is a stronger direct complement to high-skilled than to low-skilled labor. However, the consensus reached in the literature which more closely investigates the introduction of computers to the

workplace is that computers affect labor demand not only directly, but (possibly to a much larger extent) indirectly through other firm-level changes, as Bresnahan et al. (2000) point out in their study of the interaction between ITs and labor demand:

“[...] *IT is embedded in a cluster of related innovations, notably organizational changes and product innovation, which, taken together are the SBTC that calls for a higher-skilled labor mix.*” (p. 2, underline in original)

For instance, ITs are assumed to have reduced the costs of communication and monitoring. Consequently, networks increasingly replace bosses with direct interactions between workers (Bolton and Dewatripont, 1994). In an empirical study, Brynjolfsson and Hitt (1998) demonstrate that the use of ITs indeed strongly correlates with a number of organizational features, such as the removal of hierarchical layers and the breakdown of occupational barriers, even when controlling for firm size and industry. All this points to the fact that in recent years, organizational change has been called for and made possible by the development of new technologies.

2.2.2 The Economy’s Skill-Structure

However, the actual performance and implementation of new work practices and organizational forms is far from being entirely determined by technological considerations. Another important influence comes in through the prevailing quantitative and qualitative availability of skills in the economy. Not only do certain organizational forms such as multi-tasking necessitate entirely new dimensions of worker qualifications. Changes in the skill distribution may differently affect the efficiency of various organizational arrangements (and worker-task assignments in particular) more subtly through changes in the wages paid to workers of certain characteristics.

For instance, Caroli et al. (2001) suggest that extensive decentralized structures have only recently become profitable as a result of an increase in the average educational level. Similarly, Lindbeck and Snower (1996) hypothesize that the increased overall level of education has at least in part raised the profitability of multitasking organizational forms. They further speculate that a shift in workers’ *tastes* toward higher versatility may have raised the profitability of multitasking work forms

by making monotonous work relatively more expensive. Finally, Acemoglu (1999) claims that the increased availability of skill has led firms to choose organizational forms more specifically tailored to the high-skilled concerning the firm's level of capital.

This direction of causality of course presupposes that, concerning organizational choice, the qualitative and quantitative accumulation of human capital may be treated parametrically: at least in the medium to long run, organizational types are assumed to constitute a response to the skill-composition of the labor market and not vice versa. In the context of our main theme, the effects which arise between organizational change and the labor market then take on a two-way relationship, in which the supply of skills feeds back into firms' labor demand by changes in the organizational form, possibly even changing the demand structure for skills *independent* of any explicit technological changes.⁶

2.2.3 The Product Market

A final major influence on the performance of various organizational forms lies in the nature of the product market. The importance of the product market in determining the optimal organization of work was first noted by Piore and Sabel (1984), who argued that stable product markets were a prerequisite for the mass production economy which characterized markets for a long time after the Industrial Revolution. Recent changes in consumer tastes accompanied by newer methods of production seem to have transformed many product markets from a market for mass produced, standardized goods (classically exemplified by Ford's Model T) into markets for "mass customized" goods.⁷ Shifts in consumer demand have both increased the number of varieties available and made the demand faced by individual firms less predictable as the economy has moved from a supply-push to a demand-pull structure of product markets. In order to survive in a highly volatile market environment, it is argued that firms have had to make massive changes to their internal organi-

⁶See Caroli et al. (2001), for instance, who present a model of pure organizational change attributing the recent move from centralized toward more decentralized firm structures entirely to an increase in the supply of high-skilled labor.

⁷The Economist, Juli 13th, 2001, provides a nice overview of the rise of mass customization on various product markets.

zational structure toward a higher degree of flexibility. This pertains not only to changes in the immediate production process such as the use of more flexible production equipment (along with a workforce capable of operating this equipment) and more versatile production workers. For instance, a central feature of a more diversified product market is that firms must compete in matching varieties of products with consumers who have particular tastes. When products are highly differentiated and information is imperfect, a large amount of resources will thus be funnelled into improving mechanisms for matching, such as by an expansion of marketing and research departments.

Empirically, the influence of the state of the product market on organizational form receives empirical support by Osterman (1994), who finds that the best predictors for the adoption of innovative work systems are the intensity of product market competition and a company's decision to compete on the basis of quality and product variety rather than price.

For completeness' sake, it should be noted that technical change, shifts in the skill-structure of the economy, and changes in market volatility are by far not the only factors determining the relative advantage of different organizational solutions. Further influences which have received attention in the literature include various dimensions of labor management relations such as the wage bargaining mechanism, the power of labor unions as well as the firm's cultural and institutional environment.⁸

2.3 The Concept of Skill-Biased Organizational Change

Having a rough map of the factors which may have induced changes in firms' internal organizational structure over the recent past, the next step for our purpose is to ask how these changes affect the pattern of labor demand and wage inequality. A small but vastly growing literature has recently tried to tackle this question both empirically and theoretically.

Systematic empirical studies, though still scarce, suggest that firms' reorganization is typically associated with an upgrading of the workforce's level of skill. Bresnahan et al. (2000) show that decentralization in workplace organization has

⁸See Stole and Zwiebel (1996) on wage bargaining; see Caroli (2000) on unions and the firm's cultural setting.

a positive impact on firms' investments in human capital, independent of investments in ITs. Cappelli (1996) displays a positive impact of organizational changes on rising skill requirements for production jobs. Caroli and Van Reenen (1999) show that both organizational and technical change reduce the share of unskilled manuals inside firms, with the strongest impact coming from organizational change. Though still exploratory, these studies support the idea that organizational change might actually be even more strongly skill-biased than technical change.

Theoretical explanations of this "skill-biased organizational change" have focused around the idea that, as changes in the organizational structure take place, the productivity gap between individuals of different skill increases. Reorganizations in firms' production, it is argued, have primarily served to increase high-skilled workers' productivity and thereby their wage. However, as reorganization is a highly multifaceted phenomenon, these contributions generally hold quite different manifestations of organizational change responsible for the widening productivity gap.

Lindbeck and Snower (1996, 2000a), for instance, focus on the fact that reorganized firms rely more strongly on multitasking workers. According to the authors, this trend may be traced back mainly to three related exogenous developments corresponding to the three main causes of organizational change developed above: (i) technological advances, particularly ITs, that have increased the extent of complementarities arising between tasks, particularly when these tasks are performed by the same individual, relative to the gains from specialization when each worker is assigned only a single task; (ii) changes in the skill-structure of the economy (possibly due to individuals' tastes) that make workers more versatile and less specialized at particular tasks, thus also raising the benefits of assigning workers to multiple tasks rather than only a single one; (iii) a higher volatility of the product market which forces firms to adopt more flexible modes of organization involving more versatile, multi-skilled and multi-tasking agents. Lindbeck and Snower's conjecture is that, as a consequence, recent organizational change has increased firms' demand for more *versatile* workers. Now, if workers' degree of versatility is positively correlated with their educational achievement (i.e. their level of skill in the traditional sense), then the move towards multi-tasking organizational structures may indeed exhibit a shift in labor demand toward workers of higher skill, and organizational change in the

form of increased multi-tasking may hence be seen as a cause for increased wage inequality between skill groups.

Möbius (2000) interprets recent organizational changes as a move toward more *flexible* production units. The author speculates that both the reduction in the cost of more flexible production equipment and the shift in consumer demand toward more highly customized products have induced firms to produce a higher degree of varieties. A higher degree of product customization, however, also increases the likelihood that certain varieties “flop” in the sense that they are not well-received by customers. Therefore, at the same time as firms introduce more customized features to their product, they need to become more flexible in order to be able to quickly respond to a flopping product variety. Thus, both flexible machines and flexible workers can enhance the efficiency of a firm engaging in mass customization by making it less costly for the firm to respond to unpredictable and increasingly volatile tastes for product varieties. This time around, if we throw in the assumption that skilled workers are more *flexible* than unskilled workers, then a firm’s move toward a more customized range of products will be accompanied by a shift in labor demand towards high-skilled workers.

Thesmar and Thoenig (2000) also stress the move toward more flexible firms, but in the context of a product market characterized by creative destruction à la Aghion and Howitt (1992). As product market volatility increases (i.e., as creative destruction intensifies)—be it due to shifts in consumers’ tastes or technology—the expected lifespan of a given product innovation decreases. If there are fixed costs associated with achieving low marginal production costs, then firms will find it profitable to adopt production technologies with higher marginal costs but lower fixed costs, since fixed costs must be amortized over ever short product lifespans. This change toward higher marginal costs of production and lower fixed costs associated with the introduction of a particular product is what Thesmar and Thoenig deem as characteristic of a move from rigid, “mechanistic” organizational forms to newer, “organic” forms of work organization: trading in efficiency (low marginal costs) for adaptability (low fixed costs associated with the current product innovation). While the advantage of the former lies in low marginal production costs by streamlining the organizational form specifically to the currently produced innovation, making it

statically efficient, the latter relies less on such specialization and instead is more cheaply adaptable to new innovations, thus making it more efficient in a dynamic world. At the same time as product lifespans become shorter, the sunk cost component associated with the production of a new product innovation decreases, which in turn raises the total value of new product innovations to the firm. As the value of product innovation to the firm rises, R&D activities intensify. If research relies primarily on high-skilled labor, then the shift toward a higher rate of creative destruction and more flexible firm structure will hence increase the marginal value product of high-skilled labor.

Finally, Egger and Grossmann (2001) draw attention to the increased delegation of decision rights toward lower levels of the hierarchy. This process of “empowering” production workers, so the argument goes, has recently become more worthwhile through drastic reductions in communication costs both among production workers and from non-production to production workers. Worker empowerment, however, is assumed to not only consist of the administrative act of simply *granting* decision rights to production workers. Rather, it requires constant communication of both the structure and goals of the firm from managers down to production workers in order to *enable* production workers to solve problems autonomously in the face of unforeseen shocks. If, as the authors assume, such empowerment activities are to be carried out by high-skilled workers, then the rising effectiveness of empowerment (induced by new ITs) will disproportionately increase high-skilled workers’ marginal contribution to output.

Diverse as these explanations may be in their interpretation of reorganization and its causes, they all argue that recent organizational changes—whether having been caused by technical innovations, a changing skill-structure of the economy, or changing product market conditions—have increased the productivity gap between high- and low-skilled workers. By looking at production in a more differentiated manner, by splitting it up into different tasks and jobs, they all provide more elaborate reasons of why high-skilled workers may have been favored by recent changes in organization. At the same time however, these theories of skill-biased organizational change are not much more than a refinement of the idea of skill-biased *technical* change, at least if technology is understood in a broader sense as the methods by

which inputs are efficiently combined to achieve output.

Granted, if the insights won from the above interpretations of skill-biased organizational change lead to a better understanding of the nature of forces which are changing the skill structure of labor demand then it is rather meaningless to become entangled in a debate on whether the idea of skill-biased organizational change is indeed a novel concept, as proclaimed by Snower (1999), or whether it simply serves to flesh out the idea proposed by the hypothesis of skill-biased technical change, as Lawrence (2000) argues. In any case, these theories certainly serve to develop a better understanding of how SBTC may arise through structural reorganizations at the level of the firm and thus fill the usual modelling of SBTC as a form of labor-augmenting technical change targeted primarily at high-skilled labor with some life. At the same time, however, neither of them highlights any new transmission channels at the level of the *aggregate* labor market not already captured by the standard SBTC-hypothesis. As a result also, none of them is able to convincingly overcome the aforementioned empirical reservations associated with the SBTC-hypothesis, above all (i) its inability to explain the *absolute* decrease in low-skilled workers' productivity and wages, and (ii) the fact that, even within industries, wage inequality is a phenomenon which appears to have developed mostly *between* firms and not, as the more elaborate theories of skill-bias in labor demand described above generally also suggest, within the representative firm.

The most promising studies of the effects which organizational changes may have on wage inequality at the aggregate level therefore appear to come from investigations of the fact that firms increasingly segregate workers by skill. Even though the description of organization and production in these models is still at a very abstract level, theories investigating the stratification of productive resources over firms contribute something more to the understanding of recent changes in organizational structure and wage inequality than simply a more elaborate microfoundation of SBTC. Their basic message is that by increasingly segregating workers into firms according to skill, organizational change, is destroying the kinds of jobs that—due to productivity-spillovers from other, more productive factors of production—offer low-skilled workers a high level of productivity, and thus higher wages.

2.4 Segregation by Skill

The simple idea underlying models of segregation by skill is that, in order to determine a worker's productivity and thereby his wage, it can be misleading to boil and economy's production activities down to an aggregate or representative production function defined directly over the space of homogenous factor inputs. Rather, a crucial determinant of both firms' and workers' productivity lies in how workers and capital are sorted into heterogeneous firms.

Empirical support for this view on recent labor market developments comes from three sides. First, even within industries, firms typically differ in many dimensions such as size, technology, capital intensity, workforce composition, and productivity (e.g. Bayard and Troske, 1999). Second, as a part of recent organizational changes, firms have become increasingly heterogeneous in many of these dimensions. Particularly, capital-labor ratios have come to vary more strongly across firms, the composition of workforces by skill have become more heterogeneous, and firms differ more strongly in their productivity. Third, preliminary evidence suggests that these changes are associated with an increase in wage inequality, primarily *between* firms. Hence, workers' wages seem to depend not only on their *own* characteristics, but also on those of the firm they are employed in (see Dunne et al., 2000).

Now, if recent organizational changes have led low-skilled workers to increasingly be sorted into less productive firms and high-skilled workers into more productive ones, and if wages depend on such firm characteristics, then worker stratification will result in an increase in the skill-premium. In this sense, the concept of segregation by skill formalizes the idea that "organizational change often destroys the kinds of jobs that pay high wages to low-skill workers" (Acemoglu, 2000, p. 40).

In what follows, we will restrict our attention to the interaction between workers' wages and their coworkers' level of skill as captured by a model of segregation developed by Kremer and Maskin (1996).⁹ The underlying idea is that, as low-skilled workers are increasingly matched with other workers of lower skill, they

⁹Other theoretical contributions concerning the effects of segregation by skill on wage inequality include Saint-Paul (2001), Duranton (2001), and Legros and Newman (1998). Acemoglu (1999) presents a model of organizational change involving increased segregation of workers by *capital* and analyzes the effects on wages.

are no longer able to benefit from high-skilled workers' spillovers onto their own productivity, and hence their wages fall. In line with Kremer and Maskin's analysis, our initial focus is thus primarily on organizational change as described by a move toward more homogeneous workforces. However, in an extension of their model, we will show that increased segregation by skill is most likely a direct consequence of the other components of recent organizational changes discussed above in Section 2.1.

3 A Model of Endogenous Segregation by Skill

The aim of the ensuing analysis is twofold. First, we wish to identify sources which may lead firms to hire workers from an ever smaller subinterval of the available skill space, i.e. to increasingly segregate workers by skill. Second, we shall determine the influence of these forces on workers' wages. On the technical side, our focus shall furthermore be restricted to an *endogenous* determination of worker stratification across firms. That is, we will assume that firms are *ex ante* identical in their production possibilities, and seek out reasons why, *ex post*, firms may nevertheless differ in the composition of their workforce. This approach constitutes an improvement over traditional models of worker/job-matching (see Sattinger, 1993, for an overview), as firms' heterogeneity is not assumed but derived from their hiring decisions.¹⁰

Clearly, an endogenous derivation of worker stratification within a competitive framework requires some sort of non-convexities in the production function. Models of endogenous segregation by skill generally achieve this by making use of the insight that the labor market is a market for *individuals*, not for homogenous worker characteristics that could be employed independently of people (see Saint-Paul, 2001). This indivisibility in agents' characteristics makes a matching problem relevant, as it creates imperfect substitutability between workers' quality (i.e. their skill) and quantity.

To keep things tractable, it is convenient to *fix* the firms' number of workers, thus focusing entirely on qualitative substitution. An intuitive interpretation of this assumption is that employed workers make use of a firm's scarce resource—namely *jobs*.¹¹ In this case, the value of employing a worker in a firm is determined not only by his immediate contribution to output. Rather, it must be adjusted by the opportunity costs of letting this particular worker occupy a job which may alternatively be given to another worker. Under these circumstances, the production function will exhibit non-convexities and thus open the possibility for heterogeneous workforce compositions in equilibrium.

¹⁰Similarly, Acemoglu (1999) presents a model in which *ex ante* identical firms create different jobs through different investment decisions.

¹¹In a more general framework involving imperfect substitutability between skills and quantity, this scarce resource might be considered to be the firm owners' limited span of attention (see Aghion and Tirole, 1995).

In what follows, we will build upon a model of segregation developed by Kremer and Maskin (1996) which makes use of this mechanism. We will start by laying out the foundation of Kremer and Maskin's model, namely the concept of a production function defined over a fixed number of jobs. After having justified the underlying crucial assumptions regarding such a function, we will proceed with a somewhat more general production function than the one used by Kremer and Maskin. In a next step, we shall discuss reasons within this framework which may have led to the increased segregation of workers across firms and analyze their impacts on the wage structure. Here, our more general production function not only allows us to demonstrate the wider range of applicability of Kremer and Maskin's results. While their analysis is restricted to effects of exogenous changes in workers' productivity (be it through education or biased technical progress) on segregation and wages, our extension will enable us to incorporate the possibility of structural changes in the within-firm interaction between workers of varying skill-levels. As we will argue, such changes are likely to have been caused by other features of organizational restructuring pointed out above, particularly the delayering of hierarchical structures and decentralization of decision making. Consequently, we will be able to put forward a theory incorporating such organizational changes which is able to parsimoniously explain the increased segregation of workers and recent wage developments *without* relying on hard to observe changes in the labor force's productivity structure.

3.1 The Model

Assume an economy in which all firms produce a single good being sold on a competitive market. Firms consist of two workers and may freely enter and exit the market. To produce, firms hire these two workers from a labor market composed of heterogeneous individuals. Each individual may be characterized by his level of effective productivity or skill, e_i . Labor markets are competitive, so that there is a single competitive wage w_i associated with each level of skill e_i . In order to focus on the complementarities between workers' skill, we shall furthermore abstract from capital input.

Specifically, suppose that production of the good can be broken down into two

tasks: a management task and a production task, each to be performed by one of the two workers.¹² If e_m denotes the skill-level of the worker employed at the management task, and e_p describes the skill-level of the production worker, then the generic production function of an individual firm in task space takes on the form

$$Y = F(e_m, e_p), \quad (1)$$

where Y denotes the individual firm's output.¹³

The following two assumptions regarding this production function defined over the level of skill assigned to each task will be crucial to the following analysis and its results:

- (a) **Tasks are complementary**—This implies that the amount by which raising the skill-level of the worker performing one task raises output depends positively on the skill-level of the worker executing the other task. Formally, this implies that the cross-partial derivatives of the production function, $\partial^2 F(e_m, e_p)/(\partial e_m \partial e_p)$ and $\partial^2 F(e_m, e_p)/(\partial e_p \partial e_m)$ are both strictly positive.
- (b) **Tasks are unequally sensitive to skill**—Improving the skill-level of the worker performing one of the two tasks increases output by more than if this same skill-upgrading were alternatively realized at the other task. In what follows, we will specifically assume that the management task is more sensitive to skill than the production worker's task. Hence, for any two levels of skill e_1 and e_2 such that $e_1 > e_2$, $F(e_1, e_2)$ strictly exceeds $F(e_2, e_1)$.

Since these two assumptions are the driving forces behind what follows, they require justification. First, why should the skill (or effort) going into one of the tasks positively influence the productivity of the worker responsible for the other

¹²The description of the two arguments of the production function as “tasks” to be carried out by workers follows Kremer and Maskin. More comprehensively, however, they might be thought of as “job-descriptions” for both the manager's post and for the production job, which may in turn consist of a number of tasks, thus paying tribute to the fact that managers' and workers' job-description may change over time. Keeping this in mind for later considerations, we shall nevertheless continue using Kremer and Maskin's terminology.

¹³Even though, for the sake of transparency, we will generally refer to e as a measure of skill, it should more generally be understood to represent a worker's productivity or effective effort at the task. This productivity is in turn a result of both the worker's inherent and acquired abilities, but may also be affected by technical changes.

task? Remember that we are considering qualitative as opposed to quantitative complementarities, so that the usual justification for positive cross-partials in the production function does not carry over. Kremer (1993) works out a first possible explanation for positive complementarities in his O-Ring theory. He notes that production processes typically consist of a number of tasks, mistakes in any of which may reduce the product's value dramatically. If the number of mistakes made by a worker at his assigned task depends positively on his level of skill, then a higher-skilled worker at one task (which implies less mistakes made at this task) has a larger impact on the value of the final good if the skill with which the other task is executed is higher.¹⁴ In our manager-worker setting this implies that mistakes made at the management level reduce the value created by the production worker and vice versa. Indeed, companies may fail due to bad marketing, even if their product design, manufacturing, and accounting are excellent. Likewise, an excellent marketing department will be of little use as long as low-skilled workers cause a high level of defects in the product.

Saint-Paul (2001) traces complementarities between workers' skill back to the exchange of ideas within firms. He notes that skills typically consist of both "production skills" and "conception skills". While production skills only influence the worker's individual productivity, conception skills give the ability to produce ideas leading to fundamental innovations in the organization of production, thereby making all workers more productive at their respective tasks and enhancing the overall efficiency of the firm. In a similar vein, Barth (2000) speculates that education gives "organizing skills that affect the overall production". Finally, since education gives both learning and teaching skills, it may be the case that there are spillover-effects from education since more educated workers improve upon the amount of on-the-job learning for other workers and thereby enhances the productivity of the firm as a whole.

Next, why should different tasks be unequally sensitive to skill? While it is easy to imagine anecdotal cases in point of why a higher-skilled employee may improve the

¹⁴The unfortunate event which gave the O-Ring theory its name was the explosion of the space shuttle *Challenger*. The shuttle consisted of thousands of high-quality components. However, it exploded because it was launched at a temperature that caused one of those components, the O-Rings, to malfunction.

firm's productivity more when assigned to certain tasks than to others (for instance, try to imagine whether it would be more profitable for the Ford Motor Company to employ a Harvard graduate in its management or behind the conveyor belt), theoretical explanations are scarce. It is highly conceivable that managers generally assume more responsibility within firms than production workers. A higher degree of responsibility derives from the fact that—even though, in order to simplify the analysis, our model strips the organizational structure down to two workers—managers generally coordinate and supervise a *number* of subordinate workers. Thus, managers' decisions are likely to have more far-reaching consequences on the organization's overall performance. In the context of Kremer's O-Ring theory, managers' tasks would then reduce the value of output more drastically, in effect making output more sensitive to the manager's skill. Similarly, as managers overlook and coordinate the entire production process, they are likely to be more able to develop and spread innovative ideas raising the productivity of the entire firm. Within Saint-Paul's framework of the firm as a network of ideas, this would translate into the management task being more sensitive to creativity (and thereby skill) than production tasks.

The full-fledged model which best captures the idea of differential sensitivity of tasks to skill within hierarchical structures dates back to Calvo and Wellisz (1979), who formalize the concept of higher "responsibility" of jobs within higher ranks of the hierarchy.¹⁵ The authors assume that production is only carried out on the lowest level of a hierarchy. In a world of imperfect information, the job of workers on higher hierarchical levels is simply to monitor subordinate workers on the next level to prevent them from shirking. Now, if a worker on a higher hierarchical level is less productive at his monitoring activity (be it because of a lower level of skill, or because the worker is not exerting his full effort), this reduces the likelihood of being caught shirking for all downstream workers, thus reducing their incentive, their level of effort, and thereby the firm's output. In sum, tasks within higher levels of the hierarchy will therefore be more sensitive to both skill and effort because they are associated with a larger span of control and therefore a larger impact on the firm's aggregate output.

Having established and justified these two characteristics of a production function

¹⁵Their idea has recently been picked up again by Garicano (2000).

in task space, it comes to pinning down a concrete functional form for $F(e_M, e_p)$. In the context of his O-Ring theory, Kremer offers an example of a production function over task-space involving *only* the complementarity assumption but no asymmetry in skill-sensitivity by writing

$$F(e_m, e_p) = e_m e_p.$$

Clearly then, for two distinct levels of skill $e_1 > e_2$, $F(e_1, e_2) = F(e_2, e_1)$. Hence, tasks display the *same* elasticity between output and skill. It is easy to see that such a choice of $F(\cdot, \cdot)$ always leads to complete segregation regardless of the underlying skill-structure of the economy. We will return to this result further along as Kremer's O-Ring specification presents a special case of our more general specification used below.

Thus, to make the trade-off between cross- and self-matching less trivial, Kremer and Maskin (1996) suggest a production function of the type

$$F(e_m, e_p) = (e_m)^2 e_p,$$

which, as is easily seen, displays both intra-firm complementarities between workers' skill and a higher elasticity of output in the manager's skill. In what follows, we will instead work with the class of Cobb-Douglas forms with constant returns to skills described by

$$F(e_m, e_p) = (e_m)^\alpha (e_p)^{1-\alpha} \tag{2}$$

and choose α greater than $1/2$ to capture the assumption that the managerial task is more sensitive to skill than the production task. First, this introduces an additional degree of freedom to the analysis by allowing for changes in the unevenness of tasks' sensitivity to skill by varying α . As we shall see, recent changes in the way firms organize to produce are likely to result in such changes. Second, restricting ourselves to constant returns to skills permits a more transparent analysis without any loss of generality.¹⁶

¹⁶Observe that scale effects cannot materialize due to the assumption of fixed firm size, as it is impossible for a firm to take advantage of increasing returns by simply replicating itself. Therefore, our qualitative results carry over to the more general set of constant elasticity production functions $F(e_m, e_p) = (e_m)^\alpha (e_p)^\beta$, $\alpha > \beta$, particularly Kremer and Maskin's with $\alpha = 2$ and $\beta = 1$.

The reason why, in contrast to Kremer and Maskin, we focus on the "constant returns to skills"-

Concerning the exogenous supply of skills, assume that there are only two levels of skill: high- and low-skilled workers with respective skill levels of e_H and e_L .¹⁷ This distribution is taken to be exogenous: even though ultimately it, too, will be determined endogenously by individual talents and education-choices, it is likely to change more slowly than wages and the organizational matching patterns of interest to us.

Given the two-worker production process and the two-point skill-distribution, we are left with four possible organizational types: A firm may either match identical workers in the sense that it employs only high-skilled workers (the HH-organization, i.e. the Microsoft type) or only low-skilled labor (the LL-organization, i.e. the McDonald's type). We will refer to this type of segregational hiring strategy as “self-matching”. Alternatively, a firm may match heterogeneous workers by either employing the high-skilled worker at the management task and the low-skilled worker at the production task (the HL-organization), or vice versa (the LH-organization), which we shall refer to as “cross-matching”. However it is straightforward to show that if firms decide to cross-match, the former constellation always outperforms the latter, thus reducing the set of feasible organizational types to three. To see this, note that the output of the HL-organization is $Y_{HL} = (e_H)^\alpha (e_L)^{1-\alpha}$, that of the LH-organization $Y_{LH} = (e_L)^\alpha (e_H)^{1-\alpha}$. Then, letting $\eta := \frac{e_H}{e_L} > 1$ denote the skill-ratio,

$$\frac{Y_{HL} - Y_{LH}}{e_L} = \eta^\alpha (1 - \eta^{1-2\alpha}) > 0, \quad \forall \alpha > \frac{1}{2}.$$

Thus, the HL-organization is always more efficient than the LH-organization. This comes as no surprise, however, as it simply proves that our Cobb-Douglas specification of the production function conforms to the assumption that the managerial task is more sensitive to skill, and hence it is always optimal to employ the more

case in what follows is twofold. First, when we analyze the effects of changes in the organization of production as captured by changes in α and β , holding $\alpha + \beta$ constant allows us to focus on those types of changes that affect firms' output only if workers of different skill are concerned, thus rendering the effects more tractable. Second, letting $\alpha + \beta = 1$ permits us to develop more illustrative graphical representations of both Kremer and Maskin's and our own results without any loss of generality.

¹⁷Let it be pointed out that, using their specific version of the production function, Kremer and Maskin still proceed to generalize these results to the case of many skill levels. Our conjecture here is, however, that all the relevant mechanisms are sufficiently captured by the two-point distribution of skill and that more insight is to be gained by generalizing the production function.

skilled worker at the management task.

3.2 Determinants of Segregation

The first question we will seek to answer within this framework is which factors influence the segregation of workers across firms. As mentioned earlier, recent evidence suggests that workers are increasingly sorted into firms according to their level of skill, corresponding in the model to *HL*-organizations (the General Motors type) gradually being replaced by *HH*- and *LL*-organizations (the Microsoft- and McDonald's-type). As we will see, the move toward segregation may be traced back to two categories of changes which we shall discuss in suite: an exogenous rise in the skill-dispersion of the economy's labor force or a decrease in the relative sensitivity of tasks to skill.

3.2.1 The Dispersion of Skills

The degree of skill-segregation in the economy is of course determined by the extent to which it is profitable for a firm to either cross- or self-match employees of different skills. Remember our assumption that firms make zero profits and may enter or exit the market at any time. Since the competitive equilibrium is efficient and labor supply is inelastic, output will be maximized in the competitive equilibrium.¹⁸

We can now show that, for a fixed production technology (i.e., for a given α), whether cross-matching is more profitable than self-matching (segregation) depends on the dispersion of skills $\eta = e_H/e_L$. To see this, consider two workers of type *H* (high-skill) and two of type *L* (low-skill). These may either be cross-matched, thereby producing an output of $2Y_{HL} = 2(e_H)^\alpha(e_L)^{1-\alpha}$, or self-matched, thus producing $Y_{HH} + Y_{LL} = e_H + e_L$. Because output will be maximized in equilibrium, cross-matching will be superior to self-matching if and only if

$$2(e_H)^\alpha(e_L)^{1-\alpha} > e_H + e_L. \quad (3)$$

Whether this condition holds or not depends only on the relative level of skill dispersion $\eta = \frac{e_H}{e_L}$. To see this, let Δ denote the difference in output between two

¹⁸When considering wages in the next section, we will justify this argument more transparently by showing that in a decentralized competitive equilibrium, wages give workers the incentive to choose their coworkers such that aggregate output is maximized.

cross-matching firms and two self-matching firms in terms of efficiency units of low-skill labor e_L . Then (3) is equivalent to

$$\begin{aligned}\Delta &\equiv \frac{1}{e_L} \left[2(e_H)^\alpha (e_L)^{1-\alpha} - e_H - e_L \right] \\ &= 2\eta^\alpha - (\eta + 1) > 0.\end{aligned}\tag{3'}$$

We can now show that for any $\alpha \in (\frac{1}{2}, 1)$, there exists a nontrivial level of skill-dispersion $\eta^* > 1$ such that both self- and cross-matching yield the same output, i.e. $\Delta|_{\eta=\eta^*} = 0$. Furthermore, for lower levels of skill-dispersion $\eta < \eta^*$, cross-matching is superior to self-matching, and vice versa for $\eta > \eta^*$. Formally, this implies $\Delta|_{\eta < \eta^*} > 0$ and $\Delta|_{\eta > \eta^*} < 0$.

Reference to Figure 1, which plots the linear component of Δ , $\eta + 1$, and the strictly concave component $2\eta^\alpha$, may help visualize the following proof. For $\eta = 1$, cross- and self-matching obviously yield the same output, i.e. $\Delta|_{\eta=1} = 0$. Now consider how Δ develops as η rises by means of the derivative $\frac{\partial \Delta}{\partial \eta} = 2\alpha\eta^{\alpha-1} - 1$. For $\eta = 1$, this derivative is positive (remember that $\alpha > \frac{1}{2}$). Hence, within some vicinity of $\eta = 1$, Δ will be positive and rising, and cross-matching will therefore outperform self-matching. As η increases, however, $\frac{\partial \Delta}{\partial \eta}$ decreases monotonously and approaches -1 as $\eta \rightarrow \infty$. Therefore, $\frac{\partial \Delta}{\partial \eta}$ eventually becomes negative, and Δ monotonously decreases in η thereafter. This in turn implies that there exists an $\eta^* > 1$ such that $\Delta|_{\eta=\eta^*} = 0$, and hence cross-matching and self-matching are equally efficient. Moreover, since $\frac{\partial \Delta}{\partial \eta}|_{\eta \geq \eta^*} < 0$, we know that $\Delta|_{\eta > \eta^*} < 0$, and hence self-matching will be superior for $\eta > \eta^*$.¹⁹

¹⁹Since in their paper, Kremer and Maskin (1996) exclusively consider the special case of $F(\tilde{e}_m, \tilde{e}_p) = (\tilde{e}_m)^2 \tilde{e}_p$, they are able to explicitly solve their pendant to our cross-matching condition (3') for the critical relative skill distribution, yielding a value of

$$\tilde{\eta}^* = \frac{1 + \sqrt{5}}{2}.$$

As outlined in Footnote 16, their discussion (and critical value for $\frac{e_H}{e_L}$) can be shown to be qualitatively equivalent to a value of $\alpha = 2/3$ in our Cobb-Douglas case, if we subject their measure of skill to a positively monotonous transformation such that $e_i = (\tilde{e}_i)^3$, $i = L, H$, thus simply redefining the measure of skill. Accordingly, the reader may easily verify that

$$\eta^* = \left(\frac{1 + \sqrt{5}}{2} \right)^3$$

describes the critical value in our Cobb-Douglas case with $\alpha = 2/3$.

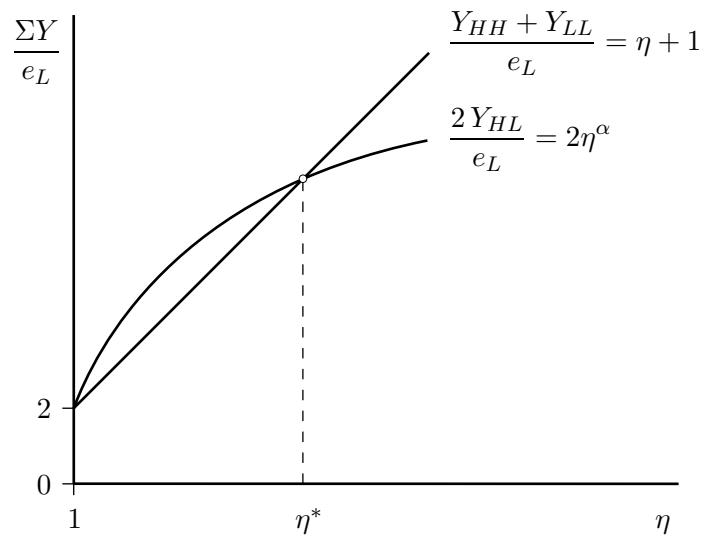


Figure 1: The Benefits of Cross- and Self-Matching.

Therefore, when the dispersion of skills is sufficiently tight, firms will find it profitable to compose their labor force of workers from different skill-groups, yielding organizational forms which build upon a heterogeneous labor force. If, on the other hand, skills are sufficiently dispersed, firms will switch to organizational forms with a homogeneous labor force.²⁰

The mechanism underlying this result may be found in the interplay between skill complementarity in tasks and unequal sensitivity of tasks in determining the equilibrium matching pattern. Consider Figure 1 which illustrates Kremer and Maskin's finding for our generalized production function. It plots the aggregate output of the cross- and self-matching solutions in terms of low-skilled efficiency units e_L against each other. In the trivial case of both types of workers being equally skilled ($\eta = 1$), both self- and cross-matching firms obviously produce identical amounts. Then, as skill-dispersion initially begins to rise, cross-matching firms profit more from this

²⁰It should be pointed out, though, that even when cross-matching is efficient compared to self-matching, unless the number of high- and low-skilled workers is equal, the economy will typically nevertheless comprise of some self-matching pairs. For instance, if there are more high-skilled than low-skilled workers, then all low-skilled workers will be matched up in cross-matching firms with high-skilled workers, whereas the remaining high-skilled workers will have no choice but to self-match. This will play a key role when we turn to the determination of wages in the next section.

increase because they exclusively assign the more skilled workers to the more skill-responsive tasks, which makes their output rise more than one for one compared to the rise in relative skill-dispersion. Loosely speaking, cross-matching firms don't "waste" high-skilled workers on jobs which are not as sensitive to skill. However, as the dispersion of skill-levels increases further, this first-order effect is increasingly counteracted by the second-order effect of task complementarity, as the productivity-enhancing allocation of more skilled workers to the more skill-sensitive managerial task is offset by the lower productivity of their coworkers. Eventually, the second effect overwhelms the first, so that for a sufficiently high dispersion of skills, it is more efficient for workers to be self- rather than cross-matched. Segregation by skill then dominates the entrepreneurial landscape.

Based on this mechanism, Kremer and Maskin (1996) put forward two possible causes for an exogenous increase in η which may have triggered firms to increasingly homogenize their labor forces: (i) an increase in the dispersion of skills through exogenous changes in education policies and choices, and (ii) skill-biased technological change. Regarding an increase in skill-dispersion, Juhn et al. (1995) provide evidence of a moderate increase in skill-dispersion (accompanied by an increase in the mean skill-level) in the US from 1964 to 1988. Kremer and Maskin (1996) report an increase of 20 percent in the dispersion of skills for the U.K. between 1978 and 1988. Nevertheless, these findings are still heavily debated (see Acemoglu, 1999). Hence, even though an increase in the dispersion of skills would provide an elegant explanation for the increase in segregation by skill (and, as we shall see, a rise in wage-inequality) in that it does not rely on difficult to measure changes in technology, its relevance remains open.

The other possibility suggested by Kremer and Maskin is to interpret the increase in η not as a rise in the dispersion of workers' inherent level of skill, but as the result of skill-biased technical change. Such change may be seen as increasing the productivity of high-skilled workers e_H while leaving low-skilled workers' productivity e_L unchanged. Hence, the model predicts that skill-biased technical change will increasingly induce high-skilled workers to produce with other high-skilled workers and leave the low-skilled to work together with other low-skilled workers, thus destroying the kinds of jobs that let workers of lower skill profit from complementarities

with high-skilled workers. However, Kremer and Maskin's interpretation of a rise in e_H as skill-biased technical change is not entirely satisfying as, in the context of a production function defined over task space, it postulates that SBTC has caused high-skilled workers' productivity to rise equally independent of the type of task (or job) they perform. Hence, their assumption is that technical innovations have made high-skilled workers equally more productive at *all* tasks, no matter whether they are performing conception or coordination tasks as a manager or part of the assembly line as a production worker. But having set up a model which splits the production process into distinct tasks in order to analyze the interaction of skills, it appears like one step forward and two steps back to then proceed by assuming that technical changes in the production process affect workers' productivity only according to their skill-level but regardless of the task they perform.

3.2.2 The Sensitivity of Tasks to Skill

In contrast to Kremer and Maskin's analysis, our generalized production function allows us to pinpoint another, more parsimonious kind of change in production technology leading to an increased homogeneity of firms' workforces: a decrease in the relative sensitivity of tasks to skill. This is best seen graphically by referring to Figure 2 and observing that, for any value of skill-dispersion $\eta > 1$ and for any $\alpha_0 \in (\frac{1}{2}, 1)$, a decrease in the skill-sensitivity of the managerial task relative to the production task from α_0 to $\alpha_1 > 1/2$ lowers the output of the cross-matching organizational form (expressed in efficiency units of low-skill labor) relative to that of the self-matching organizational form. Thus,

$$\frac{\partial \eta^*}{\partial \alpha} > 0, \quad (4)$$

i.e., as the relative task-sensitivity to skill decreases, the critical value of skill-dispersion η^* for cross-matching to be superior to self-matching decreases.²¹ A

²¹ To prove this formally, consider the cross-matching condition (3') and implicitly differentiate $\Delta \equiv 2(\eta^*)^\alpha - \eta^* - 1 = 0$ to obtain

$$\frac{\partial \eta^*}{\partial \alpha} = -\frac{2 \ln \eta^* (\eta^*)^\alpha}{2\alpha(\eta^*)^{\alpha-1} - 1}$$

The numerator is always positive since $\eta^* > 1$. The denominator on the other hand represents $\frac{\partial \Delta}{\partial \alpha} \Big|_{\eta=\eta^*}$, which we have argued in our above derivation of η^* to be negative. Thus, $\partial \eta^* / \partial \alpha > 0$.

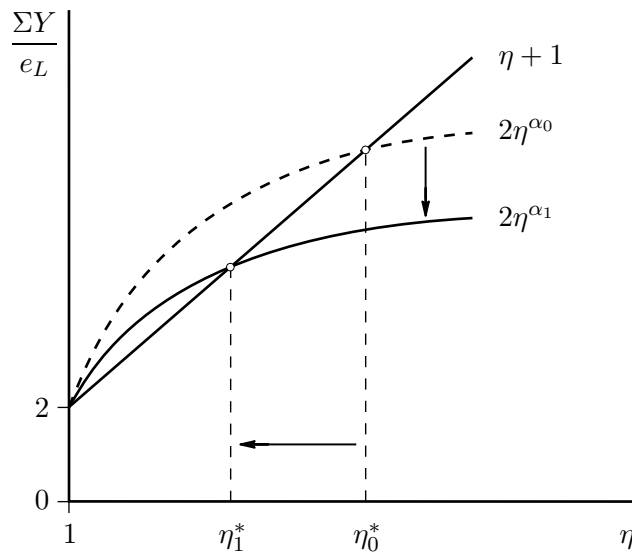


Figure 2: Segregation and a Decrease in Tasks' Relative Sensitivity to Skill.

fall in α can therefore explain the move toward a higher degree of workforce homogenization without relying on changes in workers' relative productivities. The dependence of the critical skill dispersion for cross-matching η^* on α is displayed graphically in Figure 3. South of this curve, for $\eta < \eta^*(\alpha)$, firms will cross-match workers of different skills (Region I), whereas for $\eta > \eta^*(\alpha)$ (Region II), workers will be segregated. In terms of this visualization, Kremer and Maskin's explanations for increased segregation concern a move “up” from the cross-matching Region I into the segregating equilibrium of Region II by means of an increased dispersion in worker productivity η . Our generalization adds that a rise in segregation may alternatively (or additionally) have been caused by a decrease in α . In this case, the switch from cross- to self-matching arises from changes taking place within the firm as opposed to changes in the skill-structure of the economy. As management and production tasks' sensitivity to skill become more equal, firms prefer to hire workers of equal skill as complementarities between management and production gain in relative importance.²²

Turning back to our collection of stylized facts regarding the reorganization of

²²Note also that our more general production function also contains Kremer's O-Ring theory as a borderline case for $\alpha \rightarrow 1/2$, i.e. as tasks become equally sensitive to skill. In this case $\eta^* \rightarrow 1$, and hence complete segregation by skill prevails for any nontrivial level of skill dispersion $\eta > 1$.

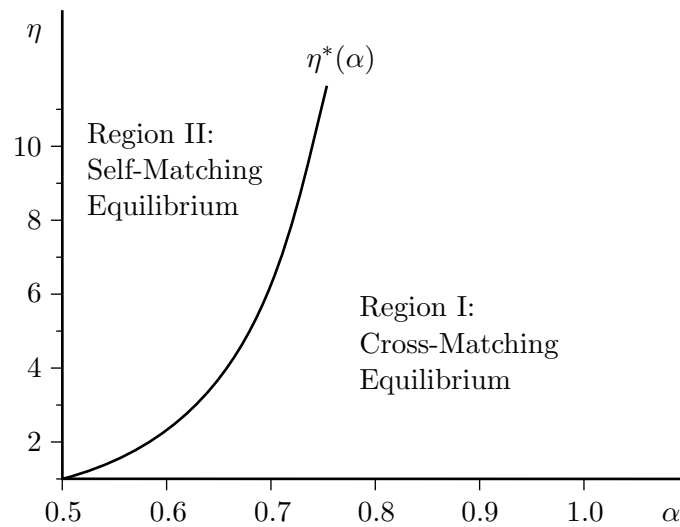


Figure 3: Cross- and Self-Matching Equilibria.

production, the assumption that output has become more sensitive to production workers' skills is supported by recent changes in firms' organization. Production workers are increasingly confronted with more complicated, programmable equipment, an ever increasing range of tasks associated with their job-description, a higher degree of autonomy in decision-making, and the rising need for them to be able to communicate either within teams or horizontally with other workers on their level. Hence it is well conceivable that, as a consequence of recent workplace reorganization, the firm's output has come to depend more strongly on the level of skill of its production workers. Loosely speaking, whereas putting a highly skilled individual to work on the production floor of Adam Smith's pin factory would presumably not have increased the firm's output by very much, newer forms of organization allow firms to reap high benefits from employing workers of higher skill at production tasks or, more generally, jobs on lower levels of the hierarchy.

Note, however, that this argument alone only suggests an increase in the elasticity of output to production workers' skill, leaving the elasticity of output to the manager's skill unaltered. While such a change would also generate a higher degree of segregation,²³ our claim here is that there has actually been a *shift* in skill-sensitivity

²³To see this, again consider the more general production function $F(e_m, e_p) = (e_m)^\alpha (e_p)^\beta$, $\alpha > \beta$ (see Footnote 16, p. 22). In this case, the cross-matching condition (3') works out to

from the management to the production task (i.e., a corresponding *decrease* in the skill-sensitivity of the management task).

First, consider the role of the manager as a coordinator of production activities. Recall our justification of skill-complementarities between management and production following Kremer's (1993) O-Ring theory, namely that mistakes made at any of the two tasks will strongly affect the value of the final good. As traditional organizational forms relied heavily on centralized coordination and decision making in the hands of the management and gave little autonomy to production workers, output was highly sensitive to mistakes made by managers (and thereby their skill) and considerably less to those made by production workers. In contemporary organizations, on the other hand, coordination and decision rights are successively transferred to lower hierarchical levels, accompanied by a replacement of vertical communication channels by horizontal coordination among production workers. Aghion and Tirole (1997) and Egger and Grossmann (2001) describe this development as a successive "empowerment" of production workers. Therefore, as responsibility is shifted from management to the production level and production workers are actually given the *opportunity* to make use of their skills, the value of output becomes less sensitive to the manager's skill and more sensitive to the production workers. As Snower (1999) summarizes:

"Through the advances in information technologies, centralization of decision making in the hands of senior executives is no longer essential to ensure coordination and consistency in business activity." (p. 29)

Similar observations hold as regards management's role as a monitor. The general need to monitor subordinate workers and ensure an efficient level of effort on the production floor (as in the aforementioned approach by Calvo and Wellisz, 1979) is likely to have decreased significantly with the move from traditional hierarchical structures to a more decentralized, market driven form of organization. The in-

$2\eta^\alpha - (\eta^{\alpha+\beta} + 1) > 0$. In analogy to our above derivation, inequality (4) can then readily be shown to generalize to

$$\frac{\partial \eta^*}{\partial [\alpha / (\alpha + \beta)]} > 0.$$

Hence, as β (the skill-sensitivity of the production task) increases for a given α , the threshold value of skill-dispersion for self-matching to occur, η^* , decreases.

creased implementation of direct pay-incentives in connection with a higher degree of autonomy given to production workers in reorganized firms should make production workers' performance, and thereby total firm output, less responsive to the skill-level of the monitor.²⁴

Finally, a shift in the elasticity of output to skill from managers to production workers may also be justified in the context of Saint-Paul's (2001) interpretation of the firm as a network of ideas. As traditional, Taylorist firms relied on thoroughly formulated, rigid sets of instructions regarding production workers' narrowly defined tasks, production workers' creativity had little effect on output. A worker responsible for attaching the rear view mirrors onto Henry Ford's Model T had little room to develop and implement innovative ideas enhancing the efficiency of the entire production process. Rather, such innovations were born centrally at the management level, and a higher degree of creativity (i.e., a higher skill) was thus much more effective when employed within the management. In contrast, newer organizational structures are much less rule based, and production workers enjoy a higher degree of autonomy and responsibility across a wider range of tasks. As firms move from relying on a strong division of labor toward more encompassing, problem oriented job-descriptions, production workers are given the opportunity to find more efficient ways to fulfill their tasks. The development and diffusion of innovative ideas among production workers is further enhanced by the introduction of collective work forms and increased horizontal communication among production workers, as well as between production workers and customers (see Lindbeck and Snower, 1996). In sum, as firms' structures become more organic, production workers' and managers' posts give skilled workers more equal opportunity to develop and spread innovative, productivity-enhancing ideas.

Together, the assembled bits of evidence paint a consistent picture suggesting that recent organizational changes have indeed made firms' output more evenly responsive to the skill-level of both production workers and managers. As we have seen, such decreases in the sensitivity of tasks to skill raise the importance of skill-

²⁴Acemoglu and Newman (1997) add that, next to decreasing costs of data-collection on production workers' performance, an increase in total factor productivity, which increases workers' incentive to exert effort, may have lowered the necessity for monitoring in organizations.

complementarity in the production process and make it more profitable for workers to be matched with other workers of similar skill. Thus, our extension of the Kremer and Maskin model is able to link these organizational changes to the observation that firms' workforces are becoming increasingly homogenous in skill.

3.2.3 Some Remarks on the Extension to more Skill Types

Before turning to the impact of the above mechanisms on wages, let us still briefly characterize the implications of extending the analysis to more skill-types. Since we have assumed that the labor force consists of only two types of workers, high- and low-skilled, the above model portrays worker stratification as a binary choice between "segregation" and "no segregation". Firms are either completely homogeneous in the skill-structure of their workforce or completely mixed, hiring workers from both extremes of the skill-distribution.

In reality of course, workers' skills are more evenly distributed over a range of skill-levels. Consequently, firms are also not restricted to a binary choice when composing their workforce, but rather a continuous one, hiring workers from a smaller or larger subinterval of the skill distribution.

To get a grasp on the concept of increased segregation in a continuous skill setting, Kremer and Maskin (1996) propose an aggregate index of segregation which measures the degree of correlation of skills across firms. Specifically, given a sample of J firms indexed by $j = 1, \dots, J$, let Z_j be the set of workers in firm j and z_j the number of workers in this firm. Given a measure of skill e , denote the mean-skill level in the entire sample by \bar{e} (i.e., $\bar{e} = \sum_{j=1}^J \sum_{i \in Z_j} e_i / N$, where N is the total number of workers in the sample). Then the index of correlation or segregation, ρ , is defined as

$$\rho = \frac{\sum_{j=1}^J \sum_{i \in Z_j} (e_i - \bar{e}) \sum_{k \in Z_j} (e_k - \bar{e}) / z_j}{\sum_{j=1}^J \sum_{k \in Z_j} (e_k - \bar{e})^2},$$

where workers are indexed by i and k . An index of $\rho = 0$ indicates that all firms have the same skill-mix of workers, whereas an index of $\rho = 1$ indicates complete segregation, in which all workers within a firm are of identical skill. This index is easily shown to equal the ratio of the variance of the skill level *between* firms, s_b^2 ,

to the variance of the skill level of the *total* population s_T^2 , so that $\rho = s_b^2/s_T^2$ (see Kremer and Maskin, 1996). Since the variance of the population's skill level s_T^2 may further be decomposed into the variance between firms, s_b^2 , and the variance within firms, s_w^2 , the segregation index may alternatively be expressed as

$$\rho = 1 - \frac{s_w^2}{s_T^2}. \quad (5)$$

Given this refined measure of segregation, how does the extension to more skill types affect the above results? Kremer and Maskin, using their specific production function with fixed elasticities to skill, proceed to analyze the effect of an increase in skill dispersion in a setting of continuous skill. Since their mathematical derivation becomes quite involved and further relies on a set of assumptions to make the equilibrium computable, we shall restrict ourselves to a brief sketch of their results.

To summarize, in the case of continuous skill space, an increase in the dispersion of skills s_T^2 (corresponding to an increase in η in the two-skill case) also leads to increased segregation as measured by the index ρ . What changes compared to the two-skill case, however, is *how* ρ increases. Unlike the two-skill case, when skills are distributed continuously the increase in ρ , as defined in (5) materializes primarily through an increase in s_T^2 , while s_w^2 is left unchanged.

To understand this, observe that in the two skill-case, the choice of an individual firm i regarding its specific level of within-firm skill dispersion, $s_{w,i}^2$, is a constrained choice between $s_{w,i}^2 = 0$ (the *HH*- or *LL*-firm type) and $s_{w,i}^2 = s_T^2$ (the *HL*-firm). Hence, as s_T changes, the set of choices available to the firm changes, and an increase in s_T may therefore lead the firm to choose $s_{w,i}^2 = 0$ instead of $s_{w,i}^2 = s_T^2$, thus leading to changes in the dispersion of skills within the firm as a consequence of changes in the total dispersion of skills s_T .

This is different if firms face a *continuous* choice of $s_{w,i}^2 \in [0, s_T^2]$. For $s_{w,i}^2$ sufficiently smaller than s_T^2 , the firm's optimal choice of within-firm skill dispersion, $s_{w,i}^2 \in [0, s_T^2]$, is then largely independent of the total dispersion of skills s_T^2 (see Kremer and Maskin, 1996).²⁵ Consequently, an increase in skill-dispersion raises the index of segregation ρ as defined in (5) only through an increase in s_T^2 , while within-

²⁵This stylized argument is somewhat complicated—but not overthrown—by the fact that quantitative restrictions on the availability of skill-types apply, so that not all firms may be able to realize their optimal choice of $s_{w,i}^2$.

firm skill dispersion s_w^2 remains constant. Rather, an increase in the dispersion of skills will simply lead some firms to hire from the tails of the skill distribution, but leave the *relative* skill-composition of their workforce unchanged.

Next, consider a decrease in tasks' relative sensitivity to skill as represented by a decrease in α . We have shown in the previous section for the two-skill case that, *given* the firms' choice set $s_{w,i}^2 \in \{0, s_T^2\}$, a decrease in α will eventually lead the firm to switch from $s_{w,i}^2 = s_T^2$ to $s_{w,i}^2 = 0$, choosing a more homogenous workforce. Similarly, in the case of discrete skill-levels (i.e., when $s_{w,i}^2 \in [0, s_T^2]$), a decrease in α will lead the firm to *continuously* adjust the composition of its workforce, reducing $s_{w,i}$. Therefore, as α decreases in the case of a continuous distribution of skills, the index of segregation, ρ , will rise by means of a decrease in within-firm skill dispersion s_w^2 , and not, as in Kremer and Maskin, through an increase in the total populations' skill-dispersion s_T^2 .

Put differently: concerning the reasons for workforce-homogenization put forward by Kremer and Maskin, the degree of segregation ρ does not increase as a result of firms hiring workers from a tighter skill-interval—as the General Motors vs. Microsoft/McDonald's example insinuates—but rather because the *relative* measure of segregation rises. In contrast, our approach of postulating decreases in the relative sensitivity of tasks to skill within the firm strikes closer to the root of this idea. As tasks become more equally sensitive to skill, the intra-firm trade off between skill-complementarity and differential skill-sensitivity is actually shifted in favor of a more homogenous workforce, thus increasing segregation more directly by lowering the optimal level of workforce skill-dispersion.

Nevertheless, we are aware of the fact the line of argument presented here is rather sketchy. In conclusion, this short digression should by no means attempt to undermine Kremer and Maskin's analysis. Rather, it seeks to motivate our approach of extending their model by means of a more general production function—in search of reasons for increased segregation other than exogenous changes in the skill- or productivity-distribution. Since by itself, this will sufficiently complicate the maths, let us again return to our two-skill case for the remainder.

3.3 Wage Formation

Having pinned down possible reasons which may have led firms to increasingly self-match rather than cross-match their employees according to skill, we will next turn to analyzing the effect of such changes on wages. As we shall see, allowing for worker stratification across firms renders some interesting insights regarding wage inequality.

Remember that we have assumed firms to make zero profits. Hence, the entire revenue from production accrues to workers. If wages are competitive, the zero-profit conditions for the three possible organizational types may thus be written as

$$\begin{aligned}\Pi_{HH} &= F(e_H, e_H) - 2w_H \\ &= e_H - 2w_H \stackrel{!}{=} 0,\end{aligned}\tag{6}$$

$$\begin{aligned}\Pi_{LL} &= F(e_L, e_L) - 2w_L \\ &= e_L - 2w_L \stackrel{!}{=} 0,\end{aligned}\tag{7}$$

$$\begin{aligned}\Pi_{HL} &= F(e_H, e_L) - w_H - w_L \\ &= (e_H)^\alpha (e_L)^{1-\alpha} - w_H - w_L \stackrel{!}{=} 0,\end{aligned}\tag{8}$$

where Π denotes the profit of the different organizational types and w_i ($i = H, L$) denotes the wage of the two skill groups. These are three equations in only two unknowns, w_H and w_L . However, in equilibrium at least one of them will not be binding because the organizational type is not efficient.

Now, starting with the simpler case, assume cross-matching is inefficient so that condition (3') is violated. Firms then find it profitable to homogenize their labor force. In this case, there are only HH - and LL -type organizations. Workers of either skill-type thus simply match with other workers of the same skill-type, produce, and share the output. Wages are then determined by equations (6) and (7) alone:

$$w_H = \frac{1}{2}e_H, \quad \text{and}\tag{9a}$$

$$w_L = \frac{1}{2}e_L.\tag{9b}$$

This describes the admittedly rather trivial case in which, since the two types of workers do not interact in production, their skill-levels do not affect each other's

wages. In conjunction with the determinants of segregation discussed in the previous subsection however, this finding may provide some insight into how SBTC affects wages when worker-stratification occurs. If we interpret e_H and e_L as workers' productivity at the two tasks and suppose that high-skilled workers' productivity e_H has risen recently due to skill-biased technological change, then the increasing segregation of workers according to skill may pose an explanation to one of the questions left open by incorporating SBTC into standard aggregate production functions, namely why SBTC has not increased the wage of the low-skilled through complementarities in the production process (see for instance Acemoglu, 2000). The simple answer proposed by Kremer and Maskin's model is that the countervailing forces caused by unequal skill-sensitivity of tasks have successively led high-skilled workers to choose organizational types in which they work mostly with other high-skilled workers, thereby increasingly de-linking high-skilled workers' productivity and wages from those of the low-skilled.

When firms find it profitable to cross-match workers, the determination of wages is not quite as simple. High- and low-skilled workers then jointly determine the output of the cross-matching HL -firm, and the share of this revenue accruing to each type is not immediately obvious. Remember, though, that the number of high- and low-skilled workers in the economy will generally not be equal. Rather, one of the two groups will usually outnumber the other. Then, even though cross-matching is more efficient than self-matching, some workers of the larger skill-group will be left over from this matching process and be forced to organize and produce in a self-match. This larger group may be thought of as being "abundant".

Assume first that high-skilled workers are abundant. Then there are only HH - and HL -type firms, and from equations (6) and (8) wages are thus easily seen to be

$$w_H = \frac{1}{2}e_H, \quad \text{and} \quad (10a)$$

$$w_L = (e_H)^\alpha (e_L)^{1-\alpha} - \frac{1}{2}e_H. \quad (10b)$$

If, on the other hand, low-skilled labor is abundant, then wages are determined by

$$w_H = (e_H)^\alpha (e_L)^{1-\alpha} - \frac{1}{2}e_L, \quad \text{and} \quad (11a)$$

$$w_L = \frac{1}{2}e_L \quad (11b)$$

according to equations (7) and (8). The intuitive reason for this is that the labor market constellation determines the opportunities of the marginal—due to the structure of the model—*two* workers. Assume, for instance, that two high-skilled workers enter the labor market. If low-skilled labor is abundant (i.e., there is at least one *LL*-match in the economy), they have the opportunity of breaking up an *LL*-match, which decreases output by e_L , and matching up with them into two *HL*-type firms, thus increasing output by $2(e_H)^\alpha(e_L)^{1-\alpha}$. The net increase in output of one marginal *H*-worker is therefore $(e_H)^\alpha(e_L)^{1-\alpha} - \frac{1}{2}e_L$, which exactly equals the wage as determined by equation (11a). If, on the other hand, high-skilled labor is abundant, the two marginal high-skilled workers will not be able to match with any low skilled workers. Therefore, they will have to self-match, which gives an output of e_H and is split up among the two and thus yields a wage w_H as defined by equation (10a). The same rationale describes the determination of w_L .

Another way of rationalizing the distribution of earnings in this model is to interpret the benefits experienced by cross-matching firms as a kind of surplus over the output produced by the self-matching organizational form. Which group of workers is able to appropriate this surplus is then determined by their respective bargaining positions. In our competitive framework, bargaining power is in turn fully determined by the scarcity of skill-groups in the sense that the scarce group of workers is able to fully capture the surplus associated with cross-matching. If, for instance, low-skilled labor is scarce, then workers of low-skill are able to push up their wage share by threatening to alternatively produce with one of the high-skilled workers currently in a self-match, where there is no such surplus. In a purely competitive setting, low-skilled workers will be able to push up the wage share until high-skilled workers are indifferent between self- and cross-matching and, hence, low-skilled workers will claim the entire rent for themselves.²⁶

Two further points are worth noting. First, we can now show more rigorously that, as we simply assumed in the previous subsection in line with Kremer and Maskin (1996), competitive wages really do ensure output is maximized in a decentralized equilibrium. Assume first that high-skilled labor is abundant. High-skilled

²⁶This also explains intuitively why, when there are equal amounts of each skill-type and hence only cross-matching firms, wages are not uniquely determined by equation (8) alone.

workers are then indifferent between self- and cross-matching according to equations (9a) and (10a). Low-skilled workers, on the other hand, have an incentive to cross-match if and only if the wage as determined by equation (9b) exceeds that in equation (10b), which is exactly equivalent to our cross-matching condition (3') in the previous subsection. The same reasoning carries over to the case of abundant low-skilled labor, where low-skilled workers will be indifferent between cross- and self-matching. Second, the direction in which a change in the level of skill or productivity of one group of workers affects the wage of the other is ambiguous and depends on the dispersion of skills, as may be anticipated by a glance at equations (10b) and (11a). It is these comparative statics, pointed out by Kremer and Maskin, that we shall turn to next.

3.3.1 Changes in Worker Productivity and the Wage

To set the following results into perspective, let us start out by briefly reviewing the influence of worker productivity on wages in a standard neoclassical environment with a representative production function of the type $Y = G(e_H n_H, e_L n_L)$ defined over people- rather than task-space, where n_H and n_L respectively denote the number of high- and low-skilled workers employed. First, the assumption that $G(\cdot, \cdot)$ has positive first-order derivatives ensures that workers' wages rise with their own productivity, that is $\frac{\partial w_H}{\partial e_H}, \frac{\partial w_L}{\partial e_L} > 0$. This effect also obtains within the present model of self- and cross-matching. Second, the assumption of positive cross-partial derivatives has the effect that each group of workers' productivity affects the wage of the other group positively, that is $\frac{\partial w_H}{\partial e_L}, \frac{\partial w_L}{\partial e_H} > 0$. In a nutshell, this second feature is one of the difficulties faced by SBTC-theories in explaining recent wage developments: if technological changes have indeed been biased in the sense of raising only high-skilled workers' productivity e_H , so the argument goes (c.f. Acemoglu, 2000), then this higher productivity must have "trickled down" onto low-skilled workers' productivity through complementarities in the production function, thus raising their absolute wages (or employment in a less flexible labor market regime) as well. As pointed out earlier, evidence for many countries regarding trends in low-skilled workers' wages (or, in a less flexible labor market regime, employment) points in a different direction.

It can be shown within the present model that this “trickle down”-effect may actually be reversed if only the dispersion of skills η is sufficiently tight. To see this, consider the situation in which cross-matching is efficient and high-skilled workers are abundant. Competitive wages are then determined by equations (10a) and (10b). Hence, high-skilled workers’ wages w_H are only dependent on their own level of productivity e_H . Things are different with the wage of the low-skilled. Since they are the scarce factor of production, low-skilled workers are able to fully capture the surplus arising from the cross-matching organization over the self-matching solution, which in turn depends on *both* types’ productivity. Obviously, their wage w_L also rises with their own productivity e_L . To determine the effect of a change in e_H on low-skilled workers’ wages, differentiate (10b) to obtain

$$\frac{\partial w_L}{\partial e_H} = \alpha (e_H)^{\alpha-1} (e_L)^{1-\alpha} - \frac{1}{2} = \alpha \eta^{\alpha-1} - \frac{1}{2}.$$

Clearly then, there exists a critical value of skill dispersion

$$\bar{\eta} = (2\alpha)^{\frac{1}{1-\alpha}}$$

such that

$$\frac{\partial w_L}{\partial e_H} \begin{cases} > 0, & \text{for } \eta < \bar{\eta} \\ = 0, & \text{for } \eta = \bar{\eta} \\ < 0, & \text{for } \eta > \bar{\eta}. \end{cases}$$

That is, for a sufficiently tight dispersion of skills $\eta < \bar{\eta}$, an increase in the skill-level of high-skilled workers raises low-skilled workers’ wages. This is the familiar spillover effect which also obtains in standard SBTC-models. The more interesting effect obtains when the distribution of skills is sufficiently dispersed such that $\eta > \bar{\eta}$. In this case, the effect is reversed. An increase in the productivity of high-skilled workers depresses low-skilled workers’ wages.²⁷

²⁷Although, of course, for this effect to occur, the distribution of skills must still be sufficiently tight to ensure the occurrence of cross-matching, i.e. condition (3’) must still be satisfied. In fact, in order to rigorously prove that the inequality-aggravating effect is even relevant, it must still be shown that it is even *possible* for both inequalities to be met simultaneously for any value of α . This is somewhat tedious since, unlike Kremer and Maskin, we are not able to explicitly solve (3’) for η^* and show that $\eta^* > \bar{\eta}$, $\forall \alpha \in (\frac{1}{2}, 1)$. Observe however that if condition (3’) were to hold with strict inequality for $\eta = \bar{\eta}$, we could still increase η by an infinitesimal amount above $\bar{\eta}$, thus satisfying both $\eta > \bar{\eta}$ and condition (3’). Substituting $\bar{\eta} = (2\alpha)^{\frac{1}{1-\alpha}}$ into condition (3’) yields

$$2[2(1-\alpha)]^{-1} - [2(1-\alpha)]^{-\frac{1}{\alpha}} - 1 > 0,$$

Again, the informal explanation for this result may be found in the counteracting forces of task complementarity and unequal sensitivity of tasks to skill. To illustrate, let us normalize efficiency-units of low-skilled labor e_L to 1, so that $\eta \equiv e_H$. Now consider Figure 4, which redraws Figure 1 for $e_L = 1$. Here, $e_H + 1$ describes the output from segregating two high-skilled and two low-skilled workers into self-matching firms, $2(e_H)^\alpha$ describes the output yielded by cross-matching workers. When segregation occurs, output may be decomposed into the output of the high-skilled pair, e_H , and that of the low-skilled couple, $e_L = 1$. Wages are then unambiguously determined simply by splitting the respective firms' output among the workers, i.e. $2w_H = e_H$ and $2w_L = e_L = 1$. Hence, in the segregating state, $w_H = \frac{1}{2}e_H$ and $w_L = \frac{1}{2}e_L = \frac{1}{2}$. However, as seen in the previous section, when the dispersion of skills is sufficiently tight (when $e_H < \eta^*$), it is more efficient to cross-match workers into pairs consisting of a high-skilled manager and a low-skilled production worker. Since wages are competitive and high-skilled workers are abundant, their wage is nevertheless tied down to their outside opportunity, which is determined by the output of the HH -firm. Hence, no matter whether firms cross- or self-match, the wage share accruing to the two high-skilled workers in total is always $2w_H = e_H$. The total wage share of the two low-skilled workers is therefore the difference between the cross-matching output $2(e_H)^\alpha$, and the high-skilled workers' outside opportunity e_H .

Now, the outside opportunity of the two high-skilled workers always rises one for one with a rise in their skill-level e_H , whereas the output of the two cross-matching firms, $2(e_H)^\alpha$, is nonlinear in e_H . For low values of skill-dispersion ($e_H < \bar{\eta}$), it rises more strongly than e_H . Over this range, cross-matching firms' output rises steeply in managers' skill because it is more heavily sensitive to the manager's skill

which, through straightforward algebraic manipulations can be shown to be equivalent to

$$\alpha^\alpha(1-\alpha)^{1-\alpha} > \frac{1}{2}.$$

Let $\phi(\alpha) := \alpha^\alpha(1-\alpha)^{1-\alpha}$. Then

$$\phi'(\alpha) = \phi(\alpha) \ln[\alpha/(1-\alpha)].$$

For any $\alpha \in (0, 1)$, $\phi(\alpha)$ is obviously positive. Furthermore, for any $\alpha \in (\frac{1}{2}, 1)$, we know that $\alpha/(1-\alpha) > 1$. Thus, the logarithm will be positive as well, implying that $\phi'(\alpha) > 0, \forall \alpha \in (\frac{1}{2}, 1)$. Observe furthermore that $\lim_{\alpha \rightarrow \frac{1}{2}} \phi(\alpha) = (\frac{1}{2})^{1/2} (\frac{1}{2})^{1/2} = \frac{1}{2}$, which proves the strict inequality for the relevant range of α .

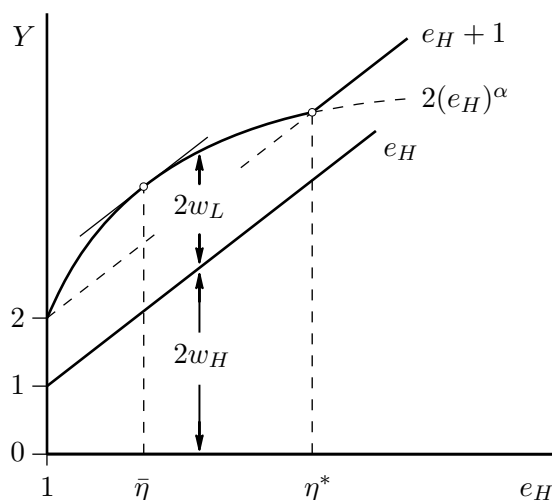


Figure 4: Wages and an Increase in High-Skilled Workers' Productivity.

level. Thus, as the output from cross-matching rises more strongly in e_H than high-skilled workers' outside option, the wage of the low-skilled rises. For higher levels of skill-dispersion, the advantage from employing unequally skilled workers within the same firm is increasingly overshadowed by efficiency losses from employing ever more heterogeneous workers at complementary tasks, causing the cross-matching output to rise less strongly in e_H . As soon as e_H exceeds $\bar{\eta}$, output rises less than one for one in e_H . When this effect sets in, productivity gains accruing to low-skilled workers from working with more skilled managers rise more slowly than high-skilled workers' outside option, thus causing a fall in low-skilled wages.

Observe that Figure 4 also conveys how, as e_H rises beyond the critical value for cross-matching, η^* , low-skilled workers will eventually prefer self-matching to cross-matching with high-skilled workers in order to avoid a further decrease in their wage, thus resulting in labor market segregation between high- and low-skilled workers.

Let it still be noted that similar forces are at work—in the opposite direction—in determining the wage of the high-skilled when low-skilled workers are abundant and the productivity of low-skilled workers changes. In this case, differentiating the wage of high-skilled workers (11a) yields a critical value of $\tilde{\eta} = [2(1 - \alpha)]^{-\frac{1}{\alpha}}$ such that for a high dispersion of skills ($\eta > \tilde{\eta}$) an increase in low-skilled workers' productivity has the familiar effect of raising high-skilled workers' wages, whereas for a low skill-

dispersion ($\eta < \tilde{\eta}$) a further increase in low-skilled productivity decreases the wage of the high-skilled.

Returning to the more interesting case of abundant high-skilled labor, Kremer and Maskin again propose two reasons for a rise in e_H responsible for the observed rise in inequality and the fall in low-skilled workers' wages: an exogenous increase in high-skilled workers' level of education, and skill-biased technical change which increases high-skilled workers' productivity. If skills (or productivity) are sufficiently dispersed, both can result in a fall in low-skilled workers' wages as high-skilled workers' outside option (the output of the HH -firm) rises more strongly with the increase than the output of the cross-matching firm. Furthermore, since both explanations posit a further increase in skill- (productivity-) dispersion, they are also both in accordance with the observed increase in segregation of workers across firms, as both of them raise segregating firms' output relative to cross-matching firms.

However, as noted already in Section 3.2, both explanations face problems. Regarding the exogenous increase in the dispersion of skills, evidence is at best scarce. Concerning the SBTC-hypothesis, we pointed out above already that an increase in e_H within the present model represents a somewhat stronger assumption than what is usually understood as skill-biased technical change. It is not immediately obvious why SBTC should have increased high-skilled workers' productivity identically whether they are employed as a manager or at the production floor.

In what follows, we will therefore turn back to the idea developed above, namely that recent changes in the way firms organize to produce has made output more evenly responsive to workers' skills, and examine its implications on wage inequality. As we shall see, in contrast to the reasons for increased segregation and higher wage inequality proposed by Kremer and Maskin, this approach has the virtue that it need not rely on any across-the-board increases in high-skilled workers' productivity in order to explain increased wage inequality. Rather, it goes more directly to the heart of how workers' skills interact in production.

3.3.2 Changes in Tasks' Sensitivity to Skill

Consider how changes in the relative sensitivity of tasks to skill as represented by the parameter α affect the distribution of wages. Again, the effect on wages

depends on the state of the labor market. If the labor market is segregated, then wages are determined by equations (9a) and (9b), and the relative sensitivity of tasks has no effect on wages and therefore also not on wage inequality. The reason is simply that in the segregating equilibrium, firms' overall productivity does not change as a response to a change in α . This in turn derives from the fact that, since firms' workforces are homogenous and thus both tasks in each firm are executed by workers of an identical level of skill, a decrease in productivity stemming from a decreased skill-sensitivity of one task is exactly offset by the corresponding increase in productivity at the other task.

Things are different when cross-matching is efficient. In this case, we must again differentiate according to which type of labor is abundant. First, if low-skilled labor is abundant, then wages are determined by equations (11a) and (11b), and the skill premium works out to

$$\frac{w_H}{w_L} = 2(e_H/e_L)^\alpha - 1. \quad (12)$$

Hence, if low-skilled labor is abundant, wage inequality is *reduced* by a fall in the relative sensitivity of skill, which we identified above as one of the driving forces behind increased segregation. Second, consider the case in which high-skilled labor is abundant. Then, wages are determined by equations (10a) and (10b), and the skill premium becomes

$$\frac{w_H}{w_L} = \frac{1}{2(e_H/e_L)^{\alpha-1} - 1}. \quad (13)$$

In this case, a fall in the relative sensitivity of tasks to skill obviously serves to *increase* wage inequality. Why this discrepancy? Remember that which skill-group is abundant determines who is able to capture the rent associated with cross-matching over self-matching. As argued above, a change in the relative sensitivity of tasks to skill has no effect on the productivity of self-matching firms. Thus, changes in α do not affect the wage of the abundant skill-group, since this group's wage is solely determined by the productivity of the self-matching firm. Rather, such shifts only affect the wage of the scarce skill-group via changes in the gains from cross-matching vis-à-vis self-matching. We have seen in the previous section that, when tasks become more equally sensitive to skill (i.e., when α decreases), the output of the cross-matching organizational form decreases relative to that of the

self-matching firm for any given level of skill-dispersion as workers' own productivity comes to depend more on the skill-level of their co-worker. A decrease in α will therefore always lower the gains from cross-matching and therefore (in absolute terms) depress the wage of the scarce skill-group, which is appropriating this rent, and leave the wage of the abundant skill group unaffected. Hence, if low-skilled labor is abundant, a decrease in α will leave the low-skilled wage unaffected while lowering the high-skilled wage and thus compressing the skill-premium. On the other hand, if high-skilled labor is abundant, a decrease in α will not alter the wage of the high-skilled, but lower the wage of the low-skilled, thereby spreading wages.

What may appear somewhat awkward about this line of argument is the fact that the underlying change in the production function, namely a decrease in α , does not increase firms' productivity. In fact, while a decrease in α leaves the output of the self-matching firm, $Y_{ii} = \frac{1}{2}e_i$ ($i = H, L$), unaltered, it decreases the output of the cross-matching firm, $Y_{HL} = (e_H)^\alpha(e_L)^{1-\alpha}$. If we assume that the adoption of technical and organizational innovations is voluntary, it seems unlikely that firms will carry through on such changes if these lower productivity.

This seemingly paradox situation is a consequence of our focus on organizational changes in production as captured by the parameter α *without* taking into account the overall productivity enhancing effect of the technological innovations responsible for these reorganizations. With some qualifications however, the results developed—particularly the possibility of an absolute fall in low-skilled workers' wages—are reconcilable with a more plausible scenario incorporating skill-neutral technical change, in which productivity increases in both firm types. Low-skilled wages will nevertheless fall if the resulting productivity gains resulting from reorganization and technological adoption are sufficiently stronger in the cross-matching than in the self-matching firm.

To illustrate this, let the production function take on the form

$$F(e_m, e_p) = A(e_m)^\alpha(e_p)^{1-\alpha}, \quad (14)$$

where A denotes a general, skill-neutral technology parameter which increases exogenously over time along with the assumed decrease in α .

Exogenous technical innovations now result in two types of changes to the pro-

duction function in task-space: First, they raise all organizational types' general productivity in a skill- and task-neutral way through increases in A . Second, such innovations lead to changes in the firms' organization of production (i.e., the way in which the firm uses differently skilled workers to produce output) of the type outlined in Section 3.2 which lower α . Concerning IT-advances in particular, we might interpret the rise in A as *potential* productivity gains available through falling costs of network-communication which, however, may only be reaped through organizational changes (particularly the delayering of hierarchical structures) which in turn have the effect of making tasks more evenly sensitive to skill, thus reducing α . This assumption accords with the evidence provided by Brynjolfsson and Hitt (2000) that investment in information technology is most productive when it goes hand-in-hand with organizational change, most notably decentralization and delayering.

The output of the two relevant firm types is now

$$Y_{HH} = Ae_H, \quad (15)$$

$$Y_{HL} = A(e_H)^\alpha(e_L)^{1-\alpha}, \quad (16)$$

whereas wages are

$$w_H = \frac{1}{2}Ae_H, \quad (17)$$

$$w_L = A[(e_H)^\alpha(e_L)^{1-\alpha} - \frac{1}{2}e_H]. \quad (18)$$

In isolation, the exogenous rise in A obviously serves to increase all firms' output and all wages, whereas the corresponding decrease in α reduces the cross-matching organization's output Y_{HL} and low-skilled workers' wages w_L while leaving the cross-matching organization's output Y_{HH} and high-skilled workers' wages w_H unchanged. Now, observe first that an increase in A affects both w_H and w_L evenly so that our comparative static effects regarding the skill premium's response to changes in α , (12) and (13), are unaffected by an increase in overall productivity A . Hence, even if organizational changes resulting in a fall in α have been accompanied by an increase in A which raises both firm-types' output, the wage gap will nevertheless have decreased if low-skilled labor is abundant and increased if high-skilled labor is abundant.

Perhaps the most intriguing mechanism developed above is that, if high-skilled workers are abundant, organizational changes resulting in a decrease in α cause a reduction in low-skilled wages w_L in absolute terms. If this result were dependent on a decrease in the output of cross-matching firms, its relevance could be questioned by putting forward that if such changes reduce output, they are unlikely to be adopted in the first place. We can now show by means of the extended production function (14) that w_L may decrease in response to an exogenous fall in α and a corresponding increase in A , even if both firm-types' output rises. Totally differentiating Y_{HL} and w_L , we have

$$\begin{aligned} dY_{HL} &= \frac{\partial Y_{HL}}{\partial A} dA + \frac{\partial Y_{HL}}{\partial \alpha} d\alpha, \\ dw_L &= \frac{\partial w_L}{\partial A} dA + \frac{\partial w_L}{\partial \alpha} d\alpha. \end{aligned}$$

From equations (16) and (18) it is straightforward to see that $\frac{\partial Y_{HL}}{\partial \alpha} = \frac{\partial w_L}{\partial \alpha} = A[(e_H)^\alpha (e_L)^{1-\alpha}] \ln(e_H/e_L)$, and thereby

$$\frac{\partial Y_{HL}}{\partial \alpha} = \frac{\partial w_L}{\partial \alpha} > 0,$$

whereas $\frac{\partial Y_{HL}}{\partial A} = (e_H)^\alpha (e_L)^{1-\alpha}$ and $\frac{\partial w_L}{\partial A} = (e_H)^\alpha (e_L)^{1-\alpha} - \frac{1}{2}e_H$, and therefore

$$\frac{\partial Y_{HL}}{\partial A} > \frac{\partial w_L}{\partial A} > 0.$$

Hence, while—at the margin—the decrease in α reduces both w_L and Y_{HL} by the same amount, the increase in A raises Y_{HL} more strongly than w_L . Therefore, if the decrease in α is accompanied by a modest rise in A (that is, within a certain interval), then the HL -firm's output will rise ($dY_{HL} > 0$), and w_L will fall ($dw_L < 0$). To understand this less formally, remember that the wage of the low-skilled is determined by the difference between the cross-matching firm's output and the outside opportunity of high-skilled workers (i.e., half of the self-matching firm's output). Since the fall in α does not affect high-skilled workers' outside option, it reduces Y_{HL} and w_L evenly. The increase in A , on the other hand, also raises the output of the cross-matching firm Y_{HL} , but at the same time increases the outside option of high-skilled workers, thus making w_L increase by less than Y_{HL} .

Figure 5 illustrates this point by graphing linearized wage- and output-isoquants in the space of difference in tasks' sensitivity to skill α and general productivity

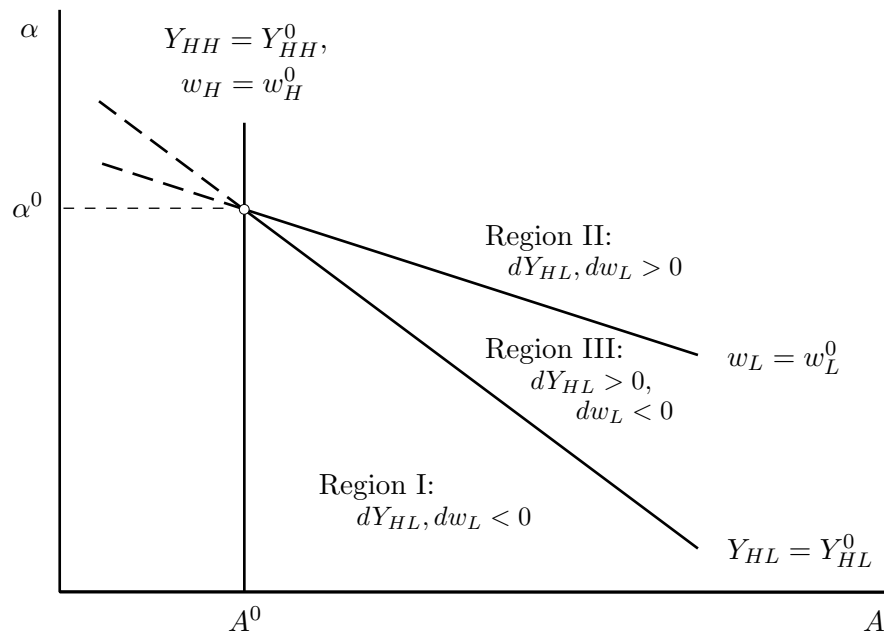


Figure 5: The Effect of Marginal Changes in α and A on Wages and Output.

A . Picture an initial situation in which the production process is characterized by $A = A^0$ and $\alpha = \alpha^0$ and let w_H^0, w_L^0 denote the resulting wages and Y_{HH}^0, Y_{HL}^0 the output of the two firm types. The isoquants plot combinations of A and α in the marginal vicinity of (A^0, α^0) which yield the same wage/output as the initial situation (A^0, α^0) . Isoquants for Y_{HH} and w_H are obviously verticals, as they both depend only on A ; furthermore, both Y_{HH} and w_L increase in A . The isoquants for Y_{HL} and w_L both have a negative slope, as both functions rise in A and α . More precisely, the slope of the isoquants is

$$\left. \frac{d\alpha}{dA} \right|_{Y_{HL}=Y_{HL}^0} = - \frac{\partial Y_{HL} / \partial A}{\partial Y_{HL} / \partial \alpha},$$

$$\left. \frac{d\alpha}{dA} \right|_{w_L=w_L^0} = - \frac{\partial w_L / \partial A}{\partial w_L / \partial \alpha}.$$

We have seen that for any (A, α) -combination, particularly for the initial values A^0 and α^0 , the denominators are equal, whereas the numerator of the Y_{HL} -isoquant is greater than that of the w_L -isoquant. Hence, around (A^0, α^0) , the w_L -isoquant is flatter than the Y_{HL} -isoquant.

Furthermore, it is easily verified that for both isoquants, the northeastern half-plane is associated with a rise in Y_{HL} (w_L) and vice versa for the southwestern half-plane.

We can now visually classify the impact of an exogenous decrease in relative task sensitivity α accompanied by an increase in overall productivity A according to their effects on the output of cross-matching firms Y_{HL} and on the wage of low-skilled workers w_L : If the decrease in α is accompanied by a very low increase in A (Region I), both Y_{HL} and w_L fall. This includes $dA = 0$ and $d\alpha < 0$, analyzed above, as a special case. As we have argued, this constellation is unlikely because it lowers the output of the cross-matching firm. If the decrease in α is accompanied by a very strong increase in overall productivity A (Region II), then both output Y_{HL} and the wage w_L will fall. Finally, if the decrease in α is accompanied by a modest increase in A (Region III), output Y_{HL} will rise, thus making the underlying technical and organizational changes efficiency enhancing, but the low-skilled wage w_L will fall.

While the focus on marginal changes in A and α facilitates an understanding of the driving mechanisms, the analysis can easily be extended to global changes. Starting from the defining equations (16) and (18), the isoquants relating to an initial situation (A^0, α^0) may be solved explicitly for A yielding

$$A(\alpha)|_{Y_{HL}=Y_{HL}^0} = A^0 \frac{\eta^{\alpha^0}}{\eta^\alpha} \quad (19)$$

for the Y_{HL} -isoquant, and

$$A(\alpha)|_{w_L=w_L^0} = A^0 \frac{\eta^{\alpha^0} - \frac{1}{2}\eta}{\eta^\alpha - \frac{1}{2}\eta}. \quad (20)$$

for the w_L isoquant, where $\eta = e_H/e_L$ again denotes the exogenous level of skill-dispersion. Expression (20) is easily seen to exceed (19) for the relevant range of α and A , with the difference increasing as α falls. When considering discrete changes in α , however, it is important to bear in mind that the derived isoquants are valid only for cross-matching equilibria. From our discussion in Section 3.2 we know that, given the dispersion of skill η , there exists a critical α such that cross-matching is efficient for any $\alpha > \alpha^*$.

Figure 6 plots the derived isoquants for Y_{HL} and w_L relating to an initial equilibrium with $A^0 = 1$ and $\alpha^0 = 0.8$ over a range of α and A (and for different values

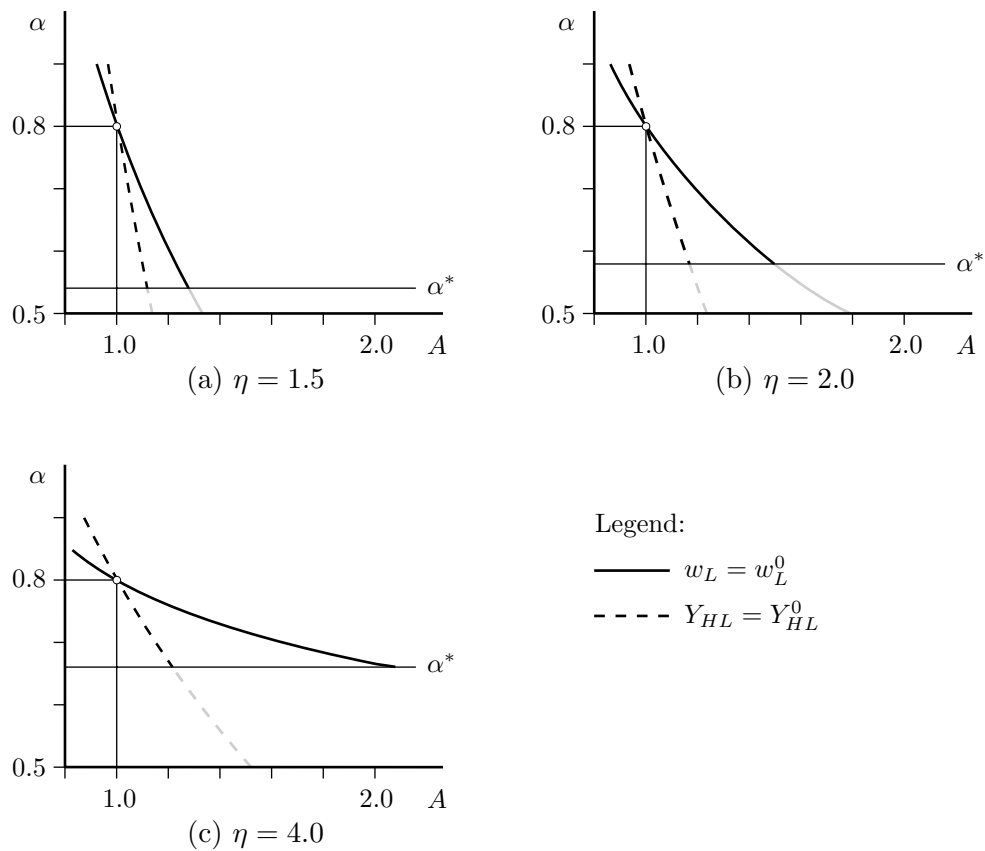


Figure 6: Wage- and Output-Isoquants for Select Values of η .

of skill-dispersion η), along with α^* , the critical value of α for cross-matching. First, this shows the marginal effects described above to be more globally valid for discrete exogenous changes in A and α . For the specific parameter constellations, there appears to be a significant scope for simultaneous changes in technology and organization yielding an increase in overall output and at the same time a decrease in the low-skilled wage. Second, it shows how the dispersion of skills η influences the possible range of exogenous changes in A and α for such an effect to occur.²⁸ On the one hand, as seen in Section 3.2, an increase in skill-dispersion raises α^* , the threshold for cross-matching to occur. The higher η , the more likely it is that a decrease in tasks' relative responsiveness to skill will lead to segregation, at which point a further decrease no longer affects wages and output. On the other hand, a higher η

²⁸Let it be noted that varying A^0 and α^0 primarily causes a simple shift in the isoquants, altering their shape very little over the relevant range of A and α .

makes increases in productivity and a fall in the low-skilled wage compatible with larger increases in the overall productivity-parameter A . This is because the larger the dispersion of skills, the larger the productivity loss in cross-matching firms and thereby the fall in low-skilled workers' wages due to a decrease in α .

In sum, we have seen that within our generalization of the Kremer/Maskin-model, coupled efficiency-enhancing changes in both organization and technology may have aggravated inequality in the case of abundant high-skilled labor. If *ex-ante* skill-neutral technical advances (as represented by A) are accompanied by modifications to the organizational structure (thought of primarily as decentralization and layering) which make workers' tasks more evenly responsive to skill, then the skill-premium can be shown to increase. Furthermore, if the technological advances are relatively modest compared to changes in the organization (or if the dispersion of skills is relatively high), this increase in inequality will to some extent be caused by an absolute fall in low-skilled workers' wages.

Under the assumption that high-skilled labor is abundant, the simple extension to Kremer and Maskin's model of segregation by skill thus turns out to be quite compatible with a number of trends in the structure of production and its labor market effects, particularly for the US economy. Initially, as long as the entrepreneurial landscape is dominated by cross-matching firms of the General Motors type, gradual changes in the efficient organization of production (brought about by technical advances, presumably mainly in ITs) decrease the relative sensitivity of workers' tasks to skill, thereby raising inequality. First, our generalization can show this increase in the skill premium to not only be the result of a rise in high-skilled workers' wages, but largely also a consequence of decreasing low-skilled workers' wages.²⁹ Second but closely related to the first point, the rise in inequality need not be accompanied by a corresponding boom in total factor productivity—one of the main empirical arguments put forward against the skill-biased technical change hypothe-

²⁹For instance, Snower (1999) notes that in the US, wage inequality has been brought about mainly by a decrease in low-skilled workers' wages as opposed to a rise in high-skilled wages: From 1973 to 1994, males in the lowest decile of the distribution saw their real earnings decline by over 25 percent while those in the top decile experienced a rise of about 10 percent over that period. Accordingly, only those in the top 20–25 percent of the earnings distribution have experienced positive growth in real earnings since the mid-1970s, while the rest have witnessed real earnings declines.

sis.³⁰ Rather, our extension predicts that part of rising inequality may be attributed to a redistribution of low-skilled workers' income toward high-skilled workers caused by reorganization. Even for relatively low values of growth in total factor productivity, if the accompanying reorganizational measures cause a relatively large decrease in the difference of tasks' responsiveness to skill, ensuing redistributions of income may have more noticeable effects on wage inequality.

Third, this rise in inequality is accompanied by an increase in the dispersion of firms' total productivity. As the decrease in tasks' sensitivity to skill will only adversely affect cross-matching firms' productivity, self-matching firms' output (which is higher already since they are composed of pairs of high-skilled workers) will rise more strongly when technical advances are coupled with organizational changes.

Fourth, the model's prediction that increases in total productivity through technical changes and reorganizations have been strongest in firms employing only high-skilled workers is consistent with Caroli and Van Reenen's (1999) finding that the introduction of organizational change in skill intensive firms leads to significantly faster productivity growth than the introduction of organizational change in less skill intensive firms.

Finally, as workers' tasks within firms become more equal in sensitivity to skill, the relative profitability of a cross-matching organizational form falls, and firms increasingly find it profitable to segregate workers by skill, thus explaining the increased homogenization of firms' workforces. Eventually, as segregation spreads, wage inequality is no longer as strongly affected by decreases in the relative sensitivity of tasks to skill brought about by organizational changes through further falls in IT-costs, which accords with Snower's (1999) observation that since 1996 the persistent fall in the earnings of the poor in the US appears to have come to a halt.

Since the above analysis has shown the effects of parameter changes on the wage distribution to crucially depend on what type of labor is abundant, a further comment on the interpretation of "abundance" in the model's context seems appropriate.

³⁰See Aghion et al. (1999), who points out that the observed productivity slowdown in the US and the UK question the validity of a hypothesis that attributes the increase in wage differentials to an acceleration of technical progress aimed at the high-skilled.

Remember that, as we have argued above, the entire model centers around the investigation of interactions in *qualitative* characteristics of factor inputs at the cost of neglecting *quantitative* interactions to a large extent. Thus, quantitative changes in the skill-distribution generally have no effects on wages as they simply change the number of firms of each type, but not workers' productivity. The only instance when quantitative effects are important is when a skill-group switches from being the abundant group to being scarce, or vice versa, as this causes a discrete shift in bargaining power as described above and thereby redetermines the group which is able to appropriate the cross-matching surplus. With this in mind, the criterion of "abundance" might therefore more appropriately be replaced by asking more directly which skill group is able to reap the benefits arising from high-skill/low-skill-complementarities in cross-matching firms. If in the past, these benefits have to a large extent accrued to low-skilled workers, then the extension of Kremer and Maskin's model presented above is able to capture the idea that recent changes in technology, organization, and the skill-dispersion which reduce the productivity of firms employing a heterogeneous workforce have increasingly destroyed the kinds of jobs that pay low-skilled workers well.

3.4 Summary and Outlook

The focus of the presented model is on organizational change as characterized by the move toward firms which are more homogenous in skill. Its central element is a production function defined over two tasks (or jobs)—rather than directly over homogeneous factor inputs—each of which is to be carried out by one worker. Given a two-point distribution of skills, segregation is then defined simply by firms employing two workers of identical skill (self-matching), whereas the other possibility is a completely mixed workforce consisting of one worker of each type (cross-matching).

Within this framework, our initial question was what may lead firms to self-match rather than cross-match workers. A first possible reason, identified by Kremer and Maskin (1996), is an exogenous increase in the dispersion of workers' productivity. This may be caused either by exogenous changes in workers' actual skills (as represented, for instance, by their level of education), or by skill-biased technological

change.

Generalizing the production function employed by Kremer and Maskin has allowed us to highlight a second reason for increased segregation: changes in tasks' sensitivity to skill. We have shown that if output becomes more equally sensitive to the level of skill employed at the respective tasks, then a more homogeneous workforce becomes more profitable as complementarities among workers' skills gain in importance. Furthermore, we have argued that such decreases in tasks' relative sensitivity to skill are the consequence of *other* recent organizational changes (which are exogenous to the model), mainly delayering and decentralization. Thus, our extension has not only enriched Kremer and Maskin's model by another possible driving force behind segregation, but in effect uncovered a link between separate elements of recent organizational changes.

In a second step, we analyzed the effect of these changes on wages. As a result, we were able to pin down the idea that the increased segregation of workers is destroying the jobs that pay low-skilled workers well. In the context of the model, a precondition for this to occur is that low-skilled workers are scarce. More generally, however, all that is needed for this effect is that when there are both firms consisting of only high-skilled workers and such hiring both low- and high-skilled workers, the larger share of the surplus associated with cross-matching accrues to the low-skilled. In this setting, any increase in output which makes cross-matching less efficient relative to self-matching (i.e., a heterogeneous workforce relative to a homogeneous one) will increase inequality and most likely depress the low-skilled wage in absolute terms.

Again, this may occur either as a consequence of an increase in the dispersion of workers' productivity, as suggested by Kremer and Maskin, or—in the context of the generalized production function—due to the aforementioned exogenous changes in the organization of production which lower the difference in tasks' sensitivity to skill. In a further extension of the model we were able to show that even if such organizational changes are coupled with skill-neutral technical advances that improve *both* firm types' productivity, they may nevertheless depress low-skilled wages in absolute terms.

Consequently, our extension of Kremer and Maskin's model of segregation by

skill to include both skill-neutral technical and organizational change is not only able to link segregation, decentralization and an increase in the skill-premium. It also accords with a number of more detailed facts regarding recent developments in wages and firms' productivity which standard models of skill-biased technical change do not explain. In particular, these include an absolute fall in low-skilled workers' wages, low growth in total factor productivity compared to the increase in the wage gap, and an increased dispersion of firms' productivity.

While Section 3's analysis carries us a long way towards understanding some important stylized facts, it is worth pointing out some limitations and possible extensions. A first limitation has already been pointed out in Section 3.2.3 above, namely the restriction to a two-point skill distribution. As briefly described, an extension of the presented model to a continuous distribution of skills would not only serve to generalize our results. Rather, by inducing actual adjustments in the within-firm dispersion of skills, it would presumably give our explanation of increased segregation through more equal skill-sensitivities of tasks an edge over Kremer and Maskin's hypothesis. How our derived effects of a decreased relative sensitivity of tasks to skill on *wages* would hold up to such an extension must be left open for further analysis.

Second, the model assumes a fixed size of firms, thus allowing for no substitutability between quality and quantity of workers. However, the derived qualitative results would presumably carry over to variable firm sizes, as long as quantity and quality are imperfect substitutes (see Saint-Paul, 2001).³¹

Third, the production function employed abstracts completely from firms' capital input. As there is no capital and hence no capital owner, there are also no firms independent of workers in the model. Workers of various skill basically meet each other and decide whether to produce or not, as there is no cost associated with setting up a firm. In reality, the reorganization of work is of course a costly process involving large sunk-cost investments. Furthermore, most of these investments will

³¹Saint-Paul (2001) analyzes the impact of worker stratification by skill on wages within a model permitting changes firm size. However, his specification requires that firm-output may be expressed as a function of the workforces *average* level of skill. Unfortunately, this restriction to an aggregate measure of skill is not reconcilable with the assumption of unequal sensitivity of tasks to skill, which is crucial to our analysis. This makes Saint-Paul's analysis unsuitable to our purpose.

be specific to the qualificational structure of the firm's prospective workforce, thus creating separate jobs for separate skills. If there are frictions in the matching process between capital and workers (such as incomplete information or labor turnover costs), firms' optimal investment decisions may lead to unemployment for certain skill-groups (see Acemoglu, 1999).

Even under full employment, the inclusion of capital investment decisions tailored to the firm's workforce are likely to bear consequences on the wage distribution. As newer forms of capital are generally assumed to be more strongly complementary to higher skills, the switch toward more skill-homogenous workforces will be accompanied by a shift in capital from low- to high-skill firms. An increased segregation of workers by skill will then not only cut off low-skilled workers from positive productivity-spillovers due to higher skilled coworkers. Additionally, low-skilled workers' productivity will be depressed as they are increasingly segregated from capital.

Finally, our above analysis has assumed perfectly competitive labor markets. As pointed out by the large literature on efficiency wages, however, wages are likely to play a more complicated role than simply equating supply and demand. Specifically, wages may be used to supply workers with incentives when effort is not readily observable, to reduce turnover costs when hiring a worker is associated with fixed costs, or to affect the pool of job applicants by adverse selection when the applicants' productivity is costly to determine. Recent changes in firms' organizational structure are certain to have affected the way wages are used in such a context. For example, Aghion et al. (1999) hypothesize that the skills important to reorganized firms may be harder to measure, leading firms to more strongly use wages for purposes of adverse selection. Holmstrom and Milgrom (1991) point out that the assignment of workers to multiple tasks complicates the use of wages as an incentive device. However, a rigorous analysis of such changes on the aggregate structure of wages and employment is still on the agenda.

Turning more specifically to the focus of our model, a further explanation of non-competitive wage setting, which lends itself to an analysis of the effect of segregation upon wage inequality, is the "fair-wage" hypothesis. Initiated by Akkerlof (1982) and Akkerlof and Yellen (1990), this strand of literature argues that within

firms composed of heterogeneous workers, wages do not only have the function of compensating individuals' disutility of work. Rather, in order to keep up morale and cooperation within a firm when individual efforts are not readily measurable, workers of different skill levels will enter a type of social contract in which high-skilled workers are paid less than their marginal product, and the difference is paid out to low-skilled worker on top of their marginal contribution to output. Within cross-matching firms, the concept of a "fair wage" will thus compress the effective wage gap below the difference in relative productivity. Now, in the light of trends leading firms to homogenize their workforces, the scope for such redistributive measures within firms decreases, and workers' wages will move closer towards their actual productivity. The fair-wage mechanism in conjunction with the reorganization of firms into more skill-homogenous units may thus provide a further explanation for the increasing wage gap and the observed absolute decrease

4 Conclusion

The recent past has seen widespread changes in firms' organizational structure: decentralization and delayering, a move toward more flexible and organic forms of communication and delegation, the assignment of workers to multiple tasks, the introduction of collective work forms, as well as an increased segregation of workers across firms. In this essay, we have sought to evaluate the impact of such organizational changes on labor demand and wage inequality, and the extent to which incorporating organizational aspects can enhance the pure "technical" approach of standard skill-biased technical change hypotheses.

Empirical studies suggest that organizational changes have augmented the productivity and demand for high-skilled labor—creating a skill bias which is possibly even stronger than the isolated bias associated with pure technical innovations such as advances in information technologies. As the strand of literature seeking explanations for this phenomenon is still rather young, it comes as no surprise that there is yet no straightforward answer to *how* recent organizational changes may have served to magnify wage inequality. The heterogeneity of approaches is further amplified by the fact that organizational change has a number of different facets, and each facet in turn a number of possible causes and consequences for wage inequality. Faced with this disparity in approaches, we have chosen to focus primarily on what appears to be the most intriguing development in firms' organization with respect to its labor market consequences: the increased segregation of workers across firms.

The basic idea of how segregation affects wage outcomes is simple: by increasingly sorting workers by skill, recent organizational change is destroying the types of jobs that pay high wages to low-skilled workers. As high-skilled workers (and capital) are increasingly withdrawn from firms employing low-skilled workers, the latter cease to benefit from complementarities in production. Likewise, high-skilled workers' productivity is no longer depressed by a lower productivity of their coworkers and a possibly lower level of capital. Hence, increased segregation primarily causes a reallocation of productive resources and thereby a "redistribution" of workers' individual productivities from low- to high-skill, which in turn widens wage inequality. In the face of relatively low rates of total factor productivity growth in recent

years and declining wages of the low-skilled, such an explanation provides a valuable extension or even an alternative to standard models of plain skill-biased technical changes.

Possible reasons for increased segregation include skill biased technical change, and an exogenous increase in the dispersion of skills through changes in educational possibilities and choices. By extending Kremer and Maskin's model, we have pointed out a further possible cause for increased segregation: changes in the organization of production that make output more evenly responsive to workers' skill. What sets this explanation apart from the previous ones is that it not only draws a link between increased segregation and a number of stylized facts regarding the development of wages. Additionally, it traces stronger segregation back to other organizational developments—particularly more decentralized firm structures and the removal of hierarchical layers—thus providing a more parsimonious picture of the interaction between technical and organizational changes, and their effects on the labor market.

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Erklärung

1. Ich versichere hiermit, daß ich die vorliegende Arbeit mit dem Thema:

**„The Effects of Technical and Organizational Change
on Labor Markets“**

selbständig verfaßt und keine anderen Hilfsmittel als die angegebenen benutzt habe. Die Stellen, die anderen Werken dem Wortlaut oder dem Sinne nach entnommen sind, habe ich in jedem einzelnen Falle durch Angaben der Quelle, auch der benutzten Sekundärliteratur, als Entlehnung kenntlich gemacht.

Die Arbeit wurde bisher keiner anderen Prüfungsbehörde vorgelegt und auch noch nicht veröffentlicht.

2. Diese Arbeit wird nach Abschluß des Prüfungsverfahrens der Universitätsbibliothek Konstanz übergeben und ist durch Einsicht und Ausleihe somit der Öffentlichkeit zugänglich. Als Urheber der anliegenden Arbeit stimme ich diesem Verfahren zu.

Konstanz, den 14. 08. 2001


(Unterschrift)