THE DIVISION OF LABOUR, WORKER ORGANISATION, AND TECHNOLOGICAL CHANGE*

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Abstract

The model developed in this paper explains differences in the division of labour across firms as a result of computer technology adoption. We find that changes in the division of labour can result both from reduced production time and from improved communication possibilities. The first will shift the division of labour towards a more generic structure, while the latter will enhance specialisation. Although there exists heterogeneity, our estimates for a large sample of Dutch establishments in the period 1990-1996 suggest that productivity gains have been the main determinant for shifts in the division of labour for most firms. These productivity gains have induced skill upgrading, while in firms gaining mainly from improved communication possibilities specialisation increased and skill requirements have fallen.

Keywords: Division of labour, Wage level and structure; Technological change; Computerisation of the labour market
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The rapid spread of computer technology has led to substantial changes in the division of labour and a shift in the demand for labour in favour of skilled workers. Mostly these changes have been accompanied by flatter organisational structures, larger autonomy for workers or workgroups, the application of innovative human resource management practices, and so on. There are also less typical examples where computerisation is associated with increased specialisation (e.g., the rapid increase of call-centers), scripting of communication with clients and stricter procedures. Although the empirical relationship between information and communication technology (ICT) adoption and organisational change has been well-documented, disagreement remains about the reasons why computerisation provides firms with incentives to change the structure of their organisation and the skill requirements of their workforce. One class of explanations thinks about organisational change as an innovation. Computer technology (especially "organisational computing") provides non-trivial possibilities for the development of new services that also require other forms of cooperation between workers (e.g., Bresnahan, 1999) and as computers become cheaper and more powerful, the business value of the pure production process decreases, while managers can make a difference by making better use of the scarcer manpower (e.g., Brynjolfsson and Hitt, 2000 for an overview). In this view human resource management practices in the high-performance workplace play a crucial role in improving performance and originate from the increased marginal value of improvements in the way workers cooperate.[1] Such organisational innovations require innovative managers and a workforce that does not resist changes, so observed differences in the behaviour and performance of firms reflect differences in their success to deal with the new opportunities.

Others think about the effects of computer technology on the production process in terms of changes in marginal benefits and marginal costs. Computerisation has changed the relative value of skills, lowering the value of routine cognitive and manual tasks and increasing the value of non-routine cognitive and interactive tasks (e.g., Autor *et al.*, 2003 and Spitz, 2003). To relate shifts in costs and benefits to organisational change, considerations regarding the organisational structure have to be taken into account. Garicano and

[1] See e.g., the industry studies by Ichniowski *et al.* (1997) and Ichniowski *et al.* (2003), and the work by Black and Lynch (2001; 2004) for the United States.

Rossi-Hansberg (2003) investigate from this perspective shifts in the hierarchial structure of a firm that result from decreased costs of communication. In a very interesting case-study Autor *et al.* (2002) investigate how a large bank re-optimises the organisational procedures reacting to the possibilities offered by new technology. A possible interpretation of these cases is that computer technology affects the classical trade-off between the division of labour and communication costs, as studied by Becker and Murphy (1992), Radner (1993), and Bolton and Dewatripont (1994).[2] Without denying the potential for innovation that can be associated with the recent computer revolution, when the trade-off between the benefits of specialisation and the costs of communication determines the division of labour, it is hard to imagine that computers did not affect the division of labour. Yet, both increased productivity in separate tasks and increased efficiency of communication will affect the benefits of specialisation and communication costs.

The aim of this paper is to examine how far one can go toward explaining changes in the division of labour that recently occurred in relation to computer adoption using a simple framework about the cost and benefits of specialisation. In our model, a density function of a continuum of tasks represents the work that has to be carried out to produce output. Different types of workers are described by the time they need to carry out each of these tasks. In addition to production time, workers spend time communicating to coordinate activities. The way in which a firm assigns tasks to workers yields the division of labour within the firm. In this setting, on the one hand, a more extensive division of labour raises productivity because the returns to time spent on tasks are generally greater to workers who concentrate on a narrower range of tasks. On the other hand, a more generic division of labour minimises the costs of coordinating tasks between workers and may increase productivity as well. The optimal division of labour depends on the trade-off between the

[2]Originally Smith (1776) related the division of labour to the extent of the market. Now, more than two centuries later, markets have become very large, we know that many people within one market perform the same tasks without further specialisation. As always, Smith already noticed that communication costs are crucial in determining the division of labour. He notices in Chapter III "Were there no other communication between those two places, therefore, but by land-carriage, as no goods could be transported from the one to the other, except such whose price was very considerable in proportion to their weight, they could carry on but a small part of that commerce which at present subsists between them, and consequently could give but a small part of that encouragement which they at present mutually afford to each other's industry." In Smith time reduction in communication costs as a result of the introduction of "communication by water-carriage" increased the incentives for specialisation. Obviously, production costs have since then decreased so much compared to communication costs that now a decline in much more subtle communication between workers in the same workplace, already can make a difference.

benefits from specialisation and the costs of communication or coordination.

The adoption of computer technology can be beneficial in (1) supporting the workers to carry out tasks more rapidly and in (2) communicating more effectively. We show that both forms of increased productivity lead to changes in the division of labour. When the gains from computer adoption are due to a fall in communication costs between workers, there will be more specialisation. The observed trends in organisational structures seem to be more in line with the case where computer technology increases productivity in separate tasks, so the benefits of specialisation and the division of labour have diminished.

When gains in productivity are not equal for different tasks or for different groups of workers, computer adoption and the related adjustments in the division of labour will lead to shifts in the demand for labour. Our approach allows for several explanations why labour demand has shifted in favour of skilled workers. The most straightforward explanation follows from assuming that communication is a routine tasks, i.e. skilled workers have a larger advantage in production than in communication. Consequently, unskilled workers will spend a larger fraction of their time on production, and experience a larger fall in demand when productivity in production tasks increases. These effects explain a tendency towards generalisation of jobs, with an increase in the demand for skilled labour. An implication of this interpretation is that the relative increase in communication time reduces the productivity differential between skilled and unskilled labour, therefore counterbalancing the tendency toward increased demand for skilled labour.

Based on a panel of Dutch establishments we present suggestive evidence consistent with these findings. In the 1990s computer adoption is generally associated with less diversity in the types of workers employed, a smaller fraction of indirect workers, more hierarchical layers, smaller teams and establishments, and a lower standard deviation of wages. When we separate establishments − based on the pattern of ICT adoption − between those that are more likely to benefit from production gains and those that have gained more from improved communication, we observe that there is a tendency towards generalisation in the first group, while in the latter group specialisation is more important. While most establishments seem to belong to the first groups, establishments in the second group − who benefit relatively more from gains in communication − are typically part of larger organisations, export part of their production, use more advanced technologies, face a higher degree of competition, and compete in the high-quality segment.

These results are partly in contrast with the interpretations concerning organisational changes in the literature that focusses on workplace innovation. Both approaches are able to explain the link between computerisation and changes in the division of labour, but the innovations literature argues that computerising firms can further improve their productivity by emphasising team work and cooperation, while our approach suggests that computerisation decreases time needed for production tasks and increases the communication time. The organisational changes that result are an attempt of the firm to reduce this increasing load of communication time. Both approaches predict an increase in time devoted on communication per employee, but our approach predicts a reduction in communication time when measured in units of output.

The approach developed in this paper is related to a number of previous studies on the division of labour in markets and firms that do not consider technological change. Baumgardner (1988) derives that when the division of labour is limited by market size each worker specialises in different activities, which may well describe the position of specialists in rural markets.[3] Similar to our model, Becker and Murphy (1992) emphasise that the gains of specialisation are more likely to be limited by coordination cost and the level of knowledge in a market than by market size. Bolton and Dewatripont (1994) show that in the presence of returns to specialisation it may be efficient to have different workers share the same job despite the increased time cost of communication.[4] Work on organisational and technological change that is related to this paper is carried out by Milgrom and Roberts (1990) and Lindbeck and Snower (2000); the former focus on changes in production technology and the latter emphasise changes in the nature of work. Like Aghion *et al.* (1999) we argue that technological change is the driving force

[3]Similarly, Rosen (1983) uses the concept of human capital specific to particular activities to generate gains from specialisation. Non-specialisation occurs when the costs of investment in different skills are nonseparable.

[4]However, a crucial assumption of their model is that the firm's organisation of labour is fixed and cannot be changed at reasonable costs to achieve a more efficient assignment of workers to jobs. As a result of this assumption, some of the firm's workers may be idle for some time. Other related work is done by Radner (1993) whose model is concerned with minimising delay in processing tasks through job rotation to reduce the time workers stand idle.

of the changing division of labour and that changes in organisational design are of a secondary nature. Bresnahan (1999) argues that computer-intensive production is likely to be more skill-intensive when complementary changes to organisational practices are made. Finally, Garicano and Rossi-Hansberg (2003) and Borghans and Ter Weel (2004) explore mechanisms through which the optimal organisational structure changes as a result of technological change. From a theoretical perspective these models are also related to Rosen (1978), who shows that production functions can be described as the outcome of the optimal assignment of workers over heterogeneous tasks. This offers the possibility to analyse changes in the production process explicitly.[5]

Empirically our study is related to the work of Black and Lynch (2001; 2004), Brynjolfsson and Hitt (2003) and Bertschek and Kaiser (2004), who find that investments in computer technologies have enhanced firm productivity and have led to skill upgrading without focussing on the task assignment of workers in firms. The findings of Osterman (1994), Caroli and Van Reenen (2001) and Bresnahan *et al.* (2002) suggest both independent and complementary effects of organisational change and computer technology adoption on the demand for labour in Britain, France and the United States. However, these studies focus on decentralisation of authority within firms, whereas the present paper addresses the effects of technological change on the division of labour and the task assignment of workers in establishments. The changes in the assignment of workers to tasks as a result of technological change is related to papers by Borghans and Ter Weel (2002), Autor *et al.* (2003) and Spitz (2003), but they focus on individual workers and do not take into account worker organisation in establishments as we do here.

The paper is organised as follows. In the first section we present the model of the division of labour and worker organisation in the face of technological change. Then we discuss the data. Section 3 presents the estimation results. Section 4 concludes.

[5] This feature of the model is also related to Sah and Stiglitz (1985), Sobel (1992) and Kremer (1993) who focus on the effects of failure on a product's value and try to model the ways to isolate the impact of mistakes and lessen the effects of detrimental shocks. Kremer (1993) derives that it is most efficient to match higher skilled workers with other higher skilled workers. Sah and Stiglitz (1985) and Sobel (1992) apply a similar theory to reliability in organisations by focussing on the subdivision of tasks. Sah and Stiglitz compare organisations where a number of workers have to approve a project to ones where a single worker has to approve a project. Sobel derives the optimal scale of operation by deriving the size of the task that has the minimum expected costs per step.

1 Model

1.1 Basic setting

We assume an economy characterised by a competitive labour market and assume that firms are sufficiently small to prevent them from exerting market power. To produce one unit of output, a continuum of tasks $x \in [0,1]$ with density $f(x)$ and cumulative density $F(x)$ has to be performed. A firm potentially employs n types of workers indexed hierarchically by $1, \ldots, n$. Demand for type $i \in \{1, \ldots, n\}$ is denoted by L_i. The time a worker of type i needs to perform his tasks is described by the function $\tau_i(x, \gamma)$, where γ is a productivity parameter which allows us to analyse what happens when productivity is increased as a result of computer adoption. Without computer technology $\gamma = 1$, but after computer adoption and with computers becoming more powerful over time $\gamma < 1$. Worker i's wages equal w_i.[6]

Tasks are sorted on the interval [0,1] such that $\tau_i(x, \gamma)/\tau_{i+1}(x, \gamma)$ increases with x, i.e. worker i's comparative advantage (compared to worker $i+1$) decreases with x, and lower values of i will be associated with lower skilled workers. When tasks are divided between different types of workers, cost minimisation yields a point μ_i (with $\mu_0 = 0$ and $\mu_n = 1$) such that i performs all tasks on the interval $[\mu_{i-1}, \mu_i]$. The parameters μ_i describe the division of labour in the firm. If $\mu_{i-1} = 0$ and $\mu_i = 1$ the production process is completely generic and workers of type i performs all the work. In contrast, if there is equal demand for a large variety of worker types many workers carry out specific tasks and a high degree of specialisation is reached.

Figure 1 provides a graphical example of the model we have in mind. The figure gives an example of a firm with five types of workers. The upper panel shows the wage costs (i.e., the time requirements multiplied by the wage) of each of these five workers for the tasks on the interval [0,1]. From cost minimisation it follows that workers are assigned

[6] More generally, the time needed for worker i with skill level S_i to perform the tasks could be described by $\tau_i(x, \gamma, S)$. Based on a wage function $w(S_i)$, the optimal division of labour and the optimal skill requirements per group have to be analysed simultaneously. When a large number of worker types is distinguished − with potentially 0 employment − the same results can be obtained in a model that only investigates the division of labour.

to tasks in which their comparative advantage is exploited and the division of labour will be optimal. In this example worker 1 performs the tasks on the interval $[\mu_0, \mu_1]$, worker 2 the tasks on the interval $[\mu_1, \mu_2]$ and so on. The shaded areas show the wage bill shares of each of the five types of workers.

Unless the production process is completely generic and apart from the time workers need to perform their own set of tasks, there is also time required for the coordination of work to manufacture one unit of output. We focus on the communication between workers that carry out different tasks for the production of the same good and do not take into account communication to coordinate the work of workers who carry out similar tasks.[7] Assuming that each couple of tasks – or at least all tasks that are within close distance to the tasks of a certain worker – requires an equal amount of coordination time (δ) for both workers involved, coordination time between workers i and j is equal to $\delta(F(\mu_i) - F(\mu_{i-1}))(F(\mu_j) - F(\mu_{j-1}))$. Total communication time for worker i equals $\delta(F(\mu_i) - F(\mu_{i-1}))(\Omega - F(\mu_i) - F(\mu_{i-1}))$, in which Ω denotes the number of tasks worker i has to communicate about. In the basic case, $\Omega = \int_0^1 f(x)dx$ but it is unlikely that every worker has to communicate about his work with every other worker in the firm. Hence, Ω can be smaller but we need that every worker at least has to communicate about the tasks within close vicinity of his own tasks. Of course, this is a rather crude assumption and communication requirements for each combination of tasks could be different; communication about a larger range of tasks could be more efficient than communication about each task separately. An alternative model is to define the time needed by worker i to communicate about his tasks with others as a function $c(\delta(F(\mu_i) - F(\mu_{i-1})))$, with $c' > 0$ and $c'' < 0$. Similarly, rather than meeting each colleague separately, a worker could inform his manager, who could inform all the colleagues. This leads to hierarchical structures in the model, as developed by Radner (1993). In our model this leads to

[7] When this kind of communication between workers sharing the same tasks would be included, assuming that every workers participates a given amount of time in communication about each task, a more generic organisation would increase these coordination costs because more workers are involved in meetings about a certain task. It is more realistic to regard this kind of coordination to be endogenous. When more workers share the same function, the probability that one of them has an insight that is beneficial for the others increases, so the organisation will gain. Ichniowski *et al.* (2003) point at the externalities that are associated with knowledge sharing and argue that in more generic organisations the marginal value of new work practices that promote cooperation will be higher.

returns to scale when many workers have to be informed, and this could be modelled as $h(\delta(\Omega - F(\mu_i) - F(\mu_{i-1})))$, with $h' > 0$ and $h'' < 0$. Hierarchical levels in this view could be substitutes for increased communication. These extensions do not alter the findings of our model qualitatively, and to keep notation simple we follow the straightforward approach.

The bottom panel of Figure 1 shows the coordination between workers needed to produce output, which is reflected in communication time. The lines show that the more tasks a worker is performing the less the time needed to communicate. The shaded areas are the tasks communication is required about and it is easy to see that these areas will become smaller the less communication is performed between workers. If communication is costly this reveals a trade-off between specialisation and communication. This trade-off will be explored in more detail in the remainder of this section.

Given total output (Y), the demand for each type of worker $i \in \{1, \ldots, n\}$ equals

$$L_i = Y \left(\underbrace{\int_{\mu_{i-1}}^{\mu_i} \tau_i(x, \gamma) f(x) \mathrm{d}x}_{T_i^p} + \underbrace{\delta(F(\mu_i) - F(\mu_{i-1}))(\Omega - F(\mu_i) - F(\mu_{i-1}))}_{T_i^c} \right). \tag{1}$$

Total demand for labour equals $L = \sum_{i=1}^{i=n} L_i = Y(T^p + T^c)$. The concentration index $\sum_{i=1}^{i=n} (L_i/L)^2$ could serve as an indicator of the division of labour. We will explore such an indicator in the empirical analysis below.

The costs, C, to produce one unit of output equal

$$C = \sum_i w_i \left(\int_{\mu_{i-1}}^{\mu_i} \tau_i(x, \gamma) f(x) \mathrm{d}x + \int_{\mu_{i-1}}^{\mu_i} \delta f(x) \left(\Omega - \int_{\mu_{i-1}}^{\mu_i} f(x) \mathrm{d}x \right) \mathrm{d}x \right) \tag{2}$$

or

$$C = \sum_i w_i \left(\underbrace{\int_{\mu_{i-1}}^{\mu_i} \tau_i(x, \gamma) f(x) \mathrm{d}x}_{T_i^p} + \underbrace{\delta \left(F(\mu_i) - F(\mu_{i-1}) \right) \left(\Omega - F(\mu_i) + F(\mu_{i-1}) \right)}_{T_i^c} \right), \tag{3}$$

which consist of the wage costs and time requirements of the workers and the communication costs required for the production process. Note, it follows from equation (3) that there is a clear trade-off between communication and specialisation: if the firm increases the number of tasks to be performed by worker i, it saves on expensive communication time. This can be seen in the bottom panel of Figure 1. If the number of tasks is divided between less workers the number of tasks that requires communication is reduced (i.e., the surface of the gray areas become smaller). Note also that we allow $\tau_i(x,\gamma)$ to vary with i, x and the effect of γ on δ to be unequal for i, x, whereas δ is equal for all workers and tasks. As such this might be a plausible assumption, but we will discuss below the case in which $\delta_i(x,\gamma)$ is a function of i and x with a pattern changing in γ.

Minimising costs with respect to the division of labour yields the following condition:

$$\begin{aligned} \tfrac{\partial C}{\partial \mu_i} = \quad & w_{i-1}\tau_{i-1}(\mu_i)f(\mu_i) - w_i\tau_i(\mu_i)f(\mu_i) \\ & +w_{i-1}\delta f(\mu_i)(\Omega - 2(F(\mu_i) - F(\mu_{i-1}))) \\ & +w_i\delta f(\mu_i)(2(F(\mu_i) - F(\mu_{i-1})) - \Omega) \qquad = 0 \end{aligned} \tag{4}$$

From this result it is easy to see that if $\delta = 0$ the worker who is able to perform the task at the lowest costs will carry out the task, i.e. $\frac{\partial C}{\partial \mu_i} = w_{i-1}\tau_{i-1}(\mu_i)f(\mu_i) - w_i\tau_i(\mu_i)f(\mu_i) = 0$. If there is a need for coordinating tasks $\delta > 0$. In this case equation (4) suggests that the worker with the largest number of tasks will get additional tasks, because this saves expensive communication time. This means that the firm accepts that workers who are at the margin less able in performing a certain task will nevertheless carry out this task, because communication time will be economised on.[8]

Given the first order condition in equation (4), the second order condition equals

$$\frac{\partial^2 C}{\partial \mu^2} = f(\mu_i)\left(w_{i-1}\tau'_{i-1}(\mu_i) - w_i\tau'_i(\mu_i) - 2\delta f(\mu_i)(w_{i-1} + w_i)\right) > 0. \tag{5}$$

This model yields a trade-off between specialisation and communication because there exists a trade-off between production time ($\tau_i(x)$ and $\tau_{i+1}(x)$) and communication costs (δ). The more specialised workers are, the more communication is necessary to coordinate all workers' activities and the larger is the variety of different workers the firm employs

[8]Equation (4) also depends on the wages of the workers, reflecting that one reason for employers to change the division of labour is a change in relative wages. When the wages of worker $i+1$ increase in comparison with the wages for worker i, employers will shift some tasks from $i+1$ to i to diminish the cost increases. The resulting division of labour will be such that the tasks of worker $i+1$ will be concentrated more on the performance of tasks in which he has a clear comparative advantage. For that reason, an increase in wage differentials between skilled and unskilled workers leads to changes in the division of labour and an increase in the job complexity of both skilled and unskilled workers.

for a given firm size (e.g., Baumgardner, 1988, Becker and Murphy, 1992 and Bolton and Dewatripont, 1994). In addition, this model of time requirements implicitly describes a production function. By choosing the optimal division of tasks, a relationship between the inputs (time used by the workers) and output is obtained. Rosen (1978) discusses this approach to denote production functions, provides some examples and argues that it yields an interesting opportunity to explicitly model particular features of the production process. Our focus is on the effects of computer technology on the production process and the optimal division of labour between the workers.

1.2 Computer technology adoption

When a firm considers the reasons to adopt computer technology, it could expect computer technology to (1) reduce the time needed for the coordination (or to reduce communication costs) of activities between workers or (2) to reduce the time needed to perform specific tasks.

We assume that workers do not share computers and that the costs of a computer are equal for each worker, so the break-even point for cost-efficient computer adoption can be calculated. When computer technology has only a productivity advantage the benefits are equal to $(1-\gamma)w_i\left(\frac{T_i^p}{T_i^p+T_i^c}\right)$, which suggests that the advantage of computer adoption is higher the higher the worker's wage and when less time is devoted to communication. Note that the adoption decision for one type of worker in this case does not depend on the adoption of others.

When the gains from using computer technology stem from lower communication costs, the decisions to adopt computer technology for each group of workers become interrelated. If a projection of the diffusion of computer technology within a firm ranges from the most skilled and most expensive workers to the workers with the lowest wages, it can be shown that the benefits from computer use will decrease due to lower wages but at the same time also increase for two reasons: (1) the larger the fraction of workers in a firm already using computer technology, the larger will be the benefit of an additional user; and (2) when more workers use computer technology the benefits for those who already adopted will increase further. Consequently, the benefits from computer use might increase more with every additional computer user than the total costs. When computer technology is merely adopted for communication reasons, it can be expected that all workers adopt computer technology at the same point in time. More general, adoption will tend to be concentrated at one point in time if communication benefits are the main determinant of adoption, while the diffusion pattern will be smoother over time when productivity benefits are relatively more important.

1.2.1 Communication costs

First, we more formally investigate what would be the effect of a reduction of communication costs (δ) on the optimal division of labour between workers. Defining μ_i in equation (1) as an implicit function of δ (i.e., $\mu_i(\delta)$), comparative statics can be obtained by taking the derivative of equation (2) with respect to δ. When taking only the effect on μ_i into account and thus keeping $\frac{\mathrm{d}\mu_{i-1}}{\mathrm{d}\delta} = 0$ and $\frac{\mathrm{d}\mu_{i+1}}{\mathrm{d}\delta} = 0$ we obtain

$$\begin{aligned} w_{i-1}\tau'_{i-1}(\mu_i)\mu'_i - w_i\tau'_i(\mu_i)\mu'_i - 2\delta(w_{i-1} + w_i)f(\mu_i)\mu'_i + \\ w_{i-1}(\Omega - 2(F(\mu_i) - F(\mu_{i-1}))) + w_i(2(F(\mu_{i+1}) - F(\mu_i)) - \Omega) &= 0, \end{aligned} \tag{6}$$

which yields

$$\frac{\mathrm{d}\mu_i}{\mathrm{d}\delta} = \frac{(w_i - w_{i-1})\Omega + w_{i-1}2(F(\mu_i) - F(\mu_{i-1})) - w_i 2(F(\mu_{i+1}) - F(\mu_i))}{\frac{\partial^2 C}{\partial u^2}}. \tag{7}$$

The first term of equation (7) shows that decreasing the costs of communication will lower μ_i and thus shift tasks to the worker with a higher wage. The reason for this is that communication time for a certain task is assumed to be equal for every worker regardless of his skill level and wages, while productivity increases with the skill level. Consequently, skill differences between two types of workers become larger when communication becomes less important. We will further explore this skill bias in Section 1.3.

The second and the third part of the equation are, for the moment, the more interesting parts of the effect of reduced communication costs. When communication costs go down tasks will be shifted from workers with the largest set of tasks to workers with the smallest set of tasks, i.e. a higher degree of specialisation will be optimal. As a result of lower costs of communication due to computer technology adoption, firms will reorganise by increasing the level of specialisation and stressing the division of labour.[9]

1.2.2 Production costs

Secondly, computer technology might also reduce the time needed to carry out each task, i.e. γ might decrease. To analyse these two effects we start by assuming that the productivity gain in each task is proportional for all i: $\tau_i(x, \gamma) = \gamma\tau_i(x)$ for all workers. Evaluating the effect for $\gamma = 1$ and defining μ_i as a function of γ, gives

$$\mu_i' = \frac{w_{i-1}\tau_{i-1}(\mu_i) - w_i\tau_i(\mu_i)}{\frac{\partial^2 C}{\partial u^2}}. \tag{8}$$

Based on the first order condition (4) and making use of equation (5) this can be rewritten as

$$\frac{\mathrm{d}\mu_i}{\mathrm{d}\gamma} = \delta\frac{(w_{i-1} - w_i)\Omega - w_{i-1}2(F(\mu_i) - F(\mu_{i-1})) + w_i 2(F(\mu_{i+1}) - F(\mu_i))}{\frac{\partial^2 C}{\partial u^2}}. \tag{9}$$

Apart from the scalar δ this effect of computerisation on the division of labour is exactly the opposite of the effect of lower communication costs. This yields that in contrast to the decreasing costs of communication, reduced production time resulting from computer adoption leads to a more generic division of labour in the sense that the number of tasks carried out by the worker with the largest set of tasks is increasing.

1.2.3 Which effect dominates?

In the model, the question whether computerisation leads to specialisation or more generic functions boils down to the question whether in absolute terms production time or communication time is stronger affected. When thinking of γ as a parameter affecting both production time τ and the time needed to communicate $\delta(\gamma)$ the total effect of γ on the

[9] This result is consistent with the results obtained by Becker and Murphy (1992) and Bolton and Dewatripont (1994). They study the trade-off between communication costs and specialisation and find that lower communication costs increase the amount of specialisation in the economy.

division of labour equals:

$$\begin{aligned}\frac{\mathrm{d}\mu_i}{\mathrm{d}\delta} &= \frac{\mathrm{d}\mu_i}{\mathrm{d}\delta}\frac{\mathrm{d}\delta}{\mathrm{d}\gamma} + \frac{\mathrm{d}\mu_i}{\mathrm{d}\gamma} \\ &= \left(\frac{\mathrm{d}\delta}{\mathrm{d}\gamma} - \delta\right)\frac{(w_i - w_{i-1})\Omega + w_{i-1}2(F(\mu_i) - F(\mu_{i-1})) - w_i 2(F(\mu_{i+1}) - F(\mu_i))}{\frac{\partial^2 C}{\partial u^2}},\end{aligned} \tag{10}$$

implying that there will be net specialisation when

$$\frac{\frac{\mathrm{d}\delta}{\mathrm{d}\gamma}}{\delta} > 1. \tag{11}$$

From the comparative statics results two main conclusions can be drawn with respect to the relationship between computer technology adoption and the division of labour. First, both changes in communication costs and changes in production time induce changes in the division of labour. This result holds despite the fact that reduced production time leaves all features of the communication structure unaffected. Secondly, both changes will affect the division of labour in a different way. Lower communication costs will promote a greater division of labour and result in a more specialist form of workplace organisation, whereas lower production time will induce a more generic organisational structure in which one worker performs relatively many tasks.

Figure 2 provides an example of what happens to the division of labour when communication costs increase. The picture is based on simulations for a case with five types of workers and 250 tasks, in which we gradually increase communication costs. Initially, when communication costs are zero, the division of labour is fully determined by the product of wages and time needed to perform a task, for each task separately. When communication costs increase the firm shifts tasks from workers with a smaller set of tasks to workers with a larger set of tasks to save on communication costs.

1.3 Skill upgrading

The adoption of computer technology leads to a bias in labour demand and the division of labour when the decrease in time needed to perform tasks is not proportional for all tasks or workers. To see this, define for a certain division of labour $\hat{\tau}_i^c(x) = \tau_i(x,\gamma) + \delta^c(\Omega - F(\mu_i) + F(\mu_{i-1}))$ and $\hat{\tau}_i^{nc}(x) = \tau_i(x,1) + \delta^{nc}(\Omega - F(\mu_i) + F(\mu_{i-1}))$ as the total production time needed by agent i to perform task x with and without computer technology, respectively. Now, two sources of non-neutral changes can be distinguished.

First, the ratio $\frac{\hat{\tau}_i^c(x)}{\hat{\tau}_i^{nc}(x)}$ can be non-constant in x, implying that the time needed for the performance of some tasks falls stronger as a result of computerisation than the time requirements for other activities. Secondly, for the performance of the same task the ratio $\frac{\hat{\tau}_i^c(x)}{\hat{\tau}_i^{nc}(x)}$ can differ between types of workers. In the latter case the productivity of higher skilled workers increases more in this specific task. The reason for this type of bias could be that the productivity gain is related to the skills of the worker directly, or it could be related to the fact that a task consists of two subtasks. If the time needed for one subtask is more strongly related to the skill level than the time needed to carry out the other subtask (e.g., a task consists of a non-routine and a routine subtask), and if computerisation proportionally decreases the non-routine part more, higher skilled workers gain relatively more.

This non-neutral decrease in the time needed to perform certain tasks has two opposite consequences. First, when the division of labour is left unchanged, and since $L_i = Y\left(T_p + T_c\right)$, less time is required to produce the same level of output. A bias in the time gain from computer technology adoption will therefore disproportionally lower labour demand for those workers who benefit most from increased productivity. Increased productivity might lead to increased demand on the product market, and therefore act as a counterbalancing factor on labour demand. Such an increase in labour demand will however increase demand for all types of workers in the production process, so in relative terms the workers who face the largest increase in productivity will loose demand when no changes in the division of labour are taken into account.

Secondly, our model can be used to show the effects of a skill bias on the division of labour because the productivity gain from using computer technology γ is a function of i and x: $\tau_i(x, \gamma)$ with $\frac{\partial \tau_i(x,\gamma)}{\partial \gamma} > 0$.

Equation (8) can now be extended to

$$\frac{\partial \mu_i}{\partial \gamma} = \delta \frac{w_{i-1} t_{i-1}(\mu_i) \frac{\partial \tau_{i-1}}{\partial \gamma} - w_i t_i(\mu_i) \frac{\partial \tau_i}{\partial \gamma}}{\frac{\partial^2 C}{\partial u^2}}, \tag{12}$$

which is equal to (8) when $\frac{\partial\tau}{\partial\gamma}=1$. This expression can be rewritten as

$$\frac{\partial\mu_i}{\partial\gamma} = \delta\frac{((w_{i-1}-w_i)\Omega - w_{i-1}2(F(\mu_i)-F(\mu_{i-1}))+w_i2(F(\mu_{i+1})-F(\mu_i)))\frac{\partial\tau_i}{\partial\gamma}}{\frac{\partial^2 C}{\partial u^2}} + \frac{w_{i-1}t_{i-1}(\mu_i)\left(\frac{\partial\tau_{i-1}(\mu_i,\gamma)}{\partial\gamma}-\frac{\partial\tau_i(\mu_i,\gamma)}{\partial\gamma}\right)}{\frac{\partial^2 C}{\partial u^2}}. \quad (13)$$

The second term of this equation reflects the additional changes in the division of labour related to the skill bias. Note that when the advantage of the new technology differs between tasks, this has no direct effect on the division of labour. Consequently, only the demand for labour performing this task is affected. When two types of workers have proportionally different gains from computer use, the optimal division of labour will be affected. Comparison of worker $i-1$ to worker i yields that μ_i will decrease – and thus the more skilled worker i will get more tasks – when $\frac{\partial\tau_{i-1}}{\partial\gamma}<\frac{\partial\tau_i}{\partial\gamma}$. In a skill interpretation this is the case when skills complement computer technology; in the routine vs. non-routine task interpretation, this result says that subtasks that are relatively independent of skill gain more from computerisation than the non-routine subtasks.

In the previous section it has been shown that a decrease in time needed for communication could lead to a shift of tasks to more skilled workers. This is actually a good example of the routine−non-routine interpretation. When communication time is independent of skills, while productivity depends on the skill level of the worker, a decrease in communication time is in fact a decrease in the routine aspect of a job, and therefore leads to a skill bias. Consequently, it is not because skilled workers are better communicators, but because they are equally good communicators compared to unskilled workers, which leads to an increased demand for skilled workers from improved communication technology.

2 Data

The data we use come from a survey among Dutch establishments carried out on a biannual basis by the Institute for Labour Studies (OSA) in the period 1990-1996.[10] Many

[10] Borghans and Ter Weel (2003) provide a detailed outlay of the data and discuss and compare the data with other data sources.

establishments are in the survey for several years, so we can use the data to construct a panel of establishments over a period of time. The primary advantage of the database is that it allows us to exploit a nationally representative survey of establishments to determine the effect of the adoption of computer technology on the division of labour. Another advantage is that we have observations on establishments at different points in time in a crucial and turbulent period regarding the boom in information and communication technology adoption to control for unobserved time invariant firm characteristics. Although the length of time is generally relatively short to investigate developments over time, we believe that the 1990s are sufficiently characterised by major changes in the use of computer technology to capture a significant number of changes in worker organisation. The period is also sufficiently limited to warrant that the results are not driven or influenced by attrition or the entrance of a great many new firms.[11]

Since changing the division of labour within an establishment is only possible when this has a sufficient scale, we only include establishments with more than 10 employees in the database subject to empirical analysis.[12] The change in computer technology use is measured by the change in the number of personal computers per employee. While this measure is incomplete and misses workers who use devices with embedded microprocessors, it does reflect a particularly prevalent form of computer technology that has been important in both the production process and in facilitating modern forms of communication within most firms. In the data we have information about the establishments in 1990, 1992, 1994, and 1996. This allows us to investigate changes in three two-year periods. Based on pooled data from these two-year periods, Table 1 presents the mean and standard deviation of the biannual change in computer technology use, which equals 5.8 percent with a sizeable standard deviation of .223 suggesting the differences in the rates of computer technology adoption between establishments to be large. Information about the division of labour is very rare, but our source includes detailed establishment-level data, which relate to the division of labour. The data contain information about the

[11] The results presented in Osterman (2000) suggest that especially the period 1985-1995 is characterized by a large number of organisational changes that are most likely correlated with the adoption of computer technologies.

[12] Most of the establishments that do not meet this criterium actually have only one worker, which makes an analysis of the division of labour obsolete.

employment structure, organisational structure and wages within establishments. With regard to changes in employment structure we use information about changes in the shares of skilled workers, which is measured as the share of workers with a higher degree of education such as higher vocational or university education.[13] We also explore changes in the ratio of indirect to direct employees to assess changes in the relative importance of employing specialists. Finally, we construct a measure of concentration to address whether over time specialisation or generalisation of labour demand has become more influential: $\sum_{i=1}^{i=n} (L_i/L)^2$, based on a classification of educational attainment in five levels. The second panel in Table 1 reports the means and standard deviations of these three measures of changes in employment structure. The numbers suggest that the degree of concentration has increased as well as the share of skilled workers.[14] The former implies a tendency towards less specialisation whereas the latter is consistent with the general trend towards upgrading experienced in most OECD countries. The change in the ratio of indirect to direct employees has generally fallen, which is in line with the trend towards less specialisation observed from the change in the concentration index.

The organisational structure is analysed by taking into account the number of hierarchical layers, team size and establishment size. The third panel of Table 1 presents the mean values of these three variables. Consistent with other studies focussing on the decentralisation of control there exists a trend towards less hierarchical layers although the mean value is relatively small and the standard deviation is considerable. In line with decentralisation is the increase in the change in team size. Finally, establishments have a tendency to become larger although only marginally so.

Finally, we explore information about wages. We focus on the biannual changes in the log average wages paid by establishments and the change in the standard deviation of the log wages. The former suggests an increase in the average wages paid but the latter is more interesting revealing a large increase in the standard deviation of wages within establishments, which suggests that wage dispersion within establishments has increased

[13] This level of education is comparable to a college degree in the United States and professional and university qualifications in the United Kingdom.

[14] On average the change in the number of skilled workers has been 9.3 percent and the change in the employment of unskilled workers was −3.0 percent.

considerably over a relatively short period of time.

The data also provide information about the ownership structure of establishments, the products produced, the degree of market competition, the type of competition faced and the use of new technologies. Table 2 presents an overview of the biannual means of these variables over the period 1990-1996 (column 1). We observe with respect to ownership that 38.0 percent of all establishments in our data is owned by the management and that 42.0 percent of the surveyed establishments is part of a larger enterprise. Since the database includes both private and public establishments, the exclusion of establishments in the public sector results in 43.8 percent ownership and in 48.1 percent of all establishments being part of a larger business firm. The second panel in Table 2 shows the division of different products that we distinguish. Almost fifty percent of all establishments produces consumer goods and 29.9 percent manufactures semi-manufactured products. Exporting products occurs among 35.3 percent of all establishments in our data.

A certain degree of competition is faced by a large majority of all firms. Distinguishing between different types of competition, and selecting by firm the most important one, it turns out that competition based on fast delivery (21.5 percent), high quality (20.6 percent), low price (18.2 percent) and good service (16.5 percent) are most often mentioned to be most relevant.

Finally, the information about technology adoption and engagement in innovative activities suggests that about one-fifth of the establishments have recently adopted advanced technologies (other than computer technologies) and are carrying out research and development. The extent to which advanced technology is being employed relative to other establishments suggests that 19.6 percent of all establishments thinks they are using such technologies to a greater extent than their competitors.

3 Estimation Results

We are interested to distinguish between establishments that benefit from computerisation mainly because of increased productivity in the performance of separate tasks and establishments that gain relatively more because of improved communication. To make this distinction we use predicted differences in the adoption pattern of these establishments. Rapidly adopting establishments are more likely to use computer technology to improve coordination between workers and to save on expensive communication time because coordination will only be effectively improved if a substantial fraction of the workforce adopts computer technology at the same time. As a starting point, we estimate the determinants of computer adoption to examine whether establishments who computerised the workplace rapidly are different from those who adopted computers at a more gradual pace. To do so we first construct a measure to address the pace of computer adoption Γ:

$$\Gamma = \left(\frac{\Delta C_{90-92}}{\Delta C_{90-96}}\right)^2 + \left(\frac{\Delta C_{92-94}}{\Delta C_{90-96}}\right)^2 + \left(\frac{\Delta C_{94-96}}{\Delta C_{90-96}}\right)^2, \tag{14}$$

where ΔC is the change in computer technology use per employee in the relevant periods. The maximum value of Γ equals 1 and is observed when the change in computer technology use in one period is equal to the overall change in computer technology use in the period 1990-1996. The minimum value of Γ is equal to 1/3, which is observed when the rate of computer technology adoption is equal in all three periods. In the data the mean value (standard deviation in brackets) of Γ equals .723 (.220); the minimum value .339 and the maximum is 1. We define establishments who have above average values of Γ as fast adopters. The number of fast adopters is equal to 219, which is 10.9 percent of the total sample of firms.[15]

To get an impression what kind of establishments typically adopt computers rapidly, we explain Γ by a number of establishment characteristics presented in Table 2. The results of these estimates are reported in column 2 of Table 2. We find a significant negative effect of managerial ownership and a significant positive effect of establishments being part of a larger company adopting computer technology suggesting that for establishments that cooperate with other parts of the organisation on different locations, the communication possibilities of computers are more important. This result carries through when we divide the data into private sector and public sector establishments (column 3).

[15] The constructed measure for fast adoption may not be perfect for all situations because for different patterns of adoption over time the same coefficient can be obtained. However, we only apply values of the measure that are relatively high and pointing at an adoption pattern concentrated at one point in time.

We find that the production of different types of output is not strongly related to the pace of within-establishment computer technology adoption, although the production of consumer products seems to be more closely connected to fast adoption than the production of semi-manufactured and other goods. We find a positive and significant relationship for exporting establishments, suggesting that coordination is more important for exporting establishments. This effect might be the result of communication with foreign customers in the case of producing consumer goods or communication with a foreign-based parent company or other foreign-based parts of the company in the case of producing semi-manufactured products. When we include information about foreign ownership into the regression equation we find no effect, so it is more likely that this effect is due to communication with foreign customers.

When we turn to measures of competition we find that a higher degree of market competition appears to be significantly related to faster computer technology adoption. This is particularly true for companies competing based on high quality. Competition based on low prices and fast delivery is negatively associated with fast within-establishment computer technology adoption. Other measures of competition do not seem to matter for the rate of computer technology adoption. The estimates for low-price and fast-delivery competition are consistent with the production of relatively low-quality products involving a low degree of complexity. Generally the manufacturing of these products does not require an advanced division of labour and the employment of a great many specialists who communicate a lot. The positive association between high-quality competition and fast computer adoption is an expression of the reverse argument: complex products composed by specialist workers who communicate intensively.

In an effort to try to investigate complementarities between computer technology and the adoption of other technologies and to distinguish high-tech from low-tech establishments, we include various measures of an establishment's technological advancement such as the extent to which advanced technology is used, the recent adoption of advanced technologies other than computer technologies and research and development. The first two measures are significantly correlated with the rate of computer technology adoption suggesting that communication is more important in establishments making use of more advanced technologies. The coefficient for research and development is negative. To explain these findings we tried interacting the measures of technology with high-quality competition to attempt to determine whether these firms are more effective in the presence of communication. However, only the interaction with research and development turned out to be statistically significant related to the rate of computer adoption suggesting that if high-quality competition coincides with research and development communication between workers is more important.

Table 2 also presents separate results for the private sector. The results presented in column 3 are largely consistent with the results displayed in column 2. We find estimated coefficients on most variables that are reasonable and similar to those in the regression results using the full sample. This suggests that the majority of the explanation to distinguish between establishments adopting for communication reasons and establishments adopting for productivity reasons is present in the private sector.

The next step is to examine the impact of computer technology adoption on changes in the establishment's structure. We examine a number of regression equations applying the biannual changes in computer technology adoption as the exogenous variable. In addition, we distinguish between establishments adopting at an above-average and below-average rate as derived in equation (14). We explore three different sets of regressions.[16] The first column in Table 3 reports the results of estimating equations containing only sector and year dummies and an intercept. The results presented in column 2 also include the information about the biannual change in the rate of computer adoption. Finally, we estimate equations including also a variable for establishments adopting computers at an above-average rate, which is the product of the fast adoption dummy and the biannual change in computer technology adoption. The regressions reveal information about changes in the employment, organisational and pay structure of establishments in the period 1990-1996. For the dependent variables the mean and standard deviations have been reported in Table 1 and discussed in the previous section.

[16] We experimented with splitting the data for different values for Γ. Although the results change quantitatively, for reasonable values of Γ the estimated coefficients remain similar in qualitative terms.

We find in column 1 of Table 3 that there has been an increase in employment concentration and the share of skilled workers, while the number of indirect employees has fallen considerably compared to the employment of direct employees.[17] The organisational structure shows a tendency towards decentralisation of authority revealed by a reduction in the number of hierarchical layers and an increase in team size. Generally, establishments have also been increasing in terms of size over this period. Finally, average wages have risen modestly, and the dispersion of wages has been non-negligible as can be observed from the change in the standard deviation of the establishment's wages.

Our estimated coefficients on the change in computer technology adoption, presented in column 2 in Table 3, are in most cases statistically significant. The coefficients related to changes in employment structure reinforce the trends presented in column 1: Larger changes in computer adoption lead to more employment concentration, a higher share of skilled workers and relatively more direct personnel. With respect to the organisational structure of establishments we find that changes in computer technology adoption are correlated with an increasing number of hierarchical layers, smaller teams and smaller establishment size. These findings suggests that establishments faced with an increasing burden of communication try to reduce coordination costs by increasing the number of hierarchies. Smaller team size reflects the generalization of work, while the fall in employment and establishment size could reflect the increase in productivity. Taken together the findings imply that the communication advantages of computer technology are probably generally less important than the productivity improvements. We also find that establishment size is decreasing in computer technology adoption. Together with the increase in the share of skilled workers and the increase in the relative number of direct employees this suggests downsizing at the expense of lower skilled workers.[18] Finally, we find that there is no significant change in the difference between the average wages paid to workers in computer adopting establishments. We do find a significant fall in the standard

[17] Estimation of regression equations for the change in the log number of skilled and unskilled workers yield estimates consistent with the change in the share of skilled workers. The number of unskilled workers is decreasing relatively to the number of skilled workers.

[18] Alternative measures of changes in the share of skilled workers or the ratio of indirect to direct employees yield similar results.

deviation of wages which is consistent with the the concentration of employment and the suggestive trend towards downsizing at the expense of lower skilled (and paid) workers in computer adopting establishments.

We finally turn to measure the difference between fast-adopting establishments and establishments taking a more gradual approach to adopting technology. From the theory developed above we expect establishments that adopt computers at a gradual rate to decide upon adoption based on (individual workers') productivity benefits, whereas the adoption that takes place at once is related to communication advantages for the establishment as a whole. Our estimated coefficients on changes in computer technology adoption and fast-adopting establishments are presented in column 3 in Table 3. The most striking observation is that the coefficients on the fast-adoption variable are generally of the opposite sign compared to the coefficient on the ordinary adoption variable. The first set of three regressions explaining changes in the employment structure suggests a negative change for establishments adopting fast compared to the gradual adopters. Overall the change in employment concentration does not differ substantially from the general trend estimated in column 1. This result suggests a relative tendency of fast adopting establishments to shift to a more specialised mode of production because they employ a relatively great number of different types of workers, which is consistent with cheaper coordination and lower communication costs. This trade-off between communication costs and specialisation is also present when we review the coefficient on the change in the ratio of indirect to direct employees, since fast adopters hire relatively more indirect workers. When communication costs fall, putting out tasks to other workers becomes beneficial. Finally, the significant and negative coefficient on the change in the share of skilled workers for fast adopters suggests that lower communication costs go along with downgrading. These estimated coefficients may be interpreted in terms of skill advantages and in that case suggest that lower skilled workers gain more from improved communication possibilities within the firm than higher skilled workers. At the same time, and consistent with the estimates concerning changes in employment structure and the division of labour, the coefficients suggests that the division of tasks to specialised workers results in simple tasks to be performed by relatively lower skilled workers.

We find that organisational changes play a less prominent role in explaining differences between fast and gradual computer adopting firms. The only major difference between the two sets of establishments is the change in establishment size. Whereas gradual adopting firms become smaller, the net change in establishment size for fast adopters is negligible. Comparison of this result to the results for changes in the employment structure suggests consistency because fast adopting establishments become less concentrated in terms of employment structure, downgrade, and employ relatively more indirect workers. In addition, this result is consistent with the prediction of our model and the theoretical results of Bolton and Dewatripont (1994) which reveal that lower communication costs increase establishment size. When we turn to changes in the wage structure we observe that the change in the average wages paid in fast-adopting establishments have been fallen over the period 1990-1996, whereas the changes in the standard deviation of wages are similar to gradual adopters. Again, these results are consistent with the trade-off between communication and specialisation.

4 Conclusions and Implications

A simple framework about the division of tasks among workers helps illuminate many aspects of changes in the organisational structure related to the improvements in information and communication technology. The actual division of labour can be seen as the optimal trade-off between the benefits of specialisation and the costs of communication. As computer technology can both improve communication and production, the adoption of this technology is able to change the division of labour in two directions: when communication costs are decreased there will be a tendency towards more specialisation and when production time is decreased there will be more generalisation. The net effect of both possibilities will determine the direction of the division of labour. By distinguishing between firms that adopt because of communication reasons and those that adopt because of reduced production time − based on the specific diffusion pattern − we find a consistent pattern in our data.

An important question is how the changes in the division of labour associated with the adoption of new technologies relate to recent shifts in demand toward skilled labour. The model shows that there are potentially several patterns that could explain a skill bias in the demand for labour. Gains in time requirements could be larger for certain tasks as well as for certain workers. Two effects have to be distinguished. First, if the division of labour would be kept constant, workers who gain most or workers who perform tasks that gain most from the adoption of computer technology see the relative demand for their activities being reduced. Secondly, when certain workers gain more in terms of productivity than others, the division of labour will be adjusted to benefit from this productivity advantage. As a consequence, when the reduction in communication time would be the main advantage of computer adoption, increased demand for skilled labour could either be the result of reduced communication costs for simple tasks or a relative gain for skilled workers in communicating. Since the trend is towards generalisation, it is more likely that the skill bias in labour demand has to be found in relation with reduced production time. Hence, either simple tasks have been automated or skilled workers gain more from reduced production time. Taking into account production time and communication simultaneously puts forward a third potential skill bias in the demand for labour. Assuming that communication is a routine task and production is more related to skill (non-routine job activity), a reduction in communication time − even when this is proportional for all workers − would shift demand towards skilled labour. However, because the reduction in production time has been more important in the fact of computer adoption, it can be expected that this has led to downgrading counteracting some of the skill bias in labour demand. Empirically we obtain estimates suggesting that upgrading is only present in the case of a reduction of production time and not in the case of reduced communication costs (it even runs in the opposite direction).

The paper has made three arguments of general interest. First, the impact of computer technology on the division of labour over the past decades reveals how important and time consuming communication between workers must be nowadays. While some time ago physical distances between cities where a major limiting factor for the division of labour (e.g., Smith's quote in footnote 2), nowadays productivity has increased so much that even subtle conversations between co-workers bound the division of labour. Secondly, the paper shows that a more detailed description of the production process, in which these high communication costs are explicitly taken into account, can be a powerful tool to predict changes in the division of labour. This approach might be an avenue for future research to understand how firm adjust to changing circumstances. Finally, computer technology has induced a flood of innovations, also in relation to changes in worker organisation. We deliberately looked at how far we could go to explain changes in the division of labour without considering these innovative work practices. Our model and empirical results provide a baseline for researchers who are looking for the effects of successful organisational innovations.

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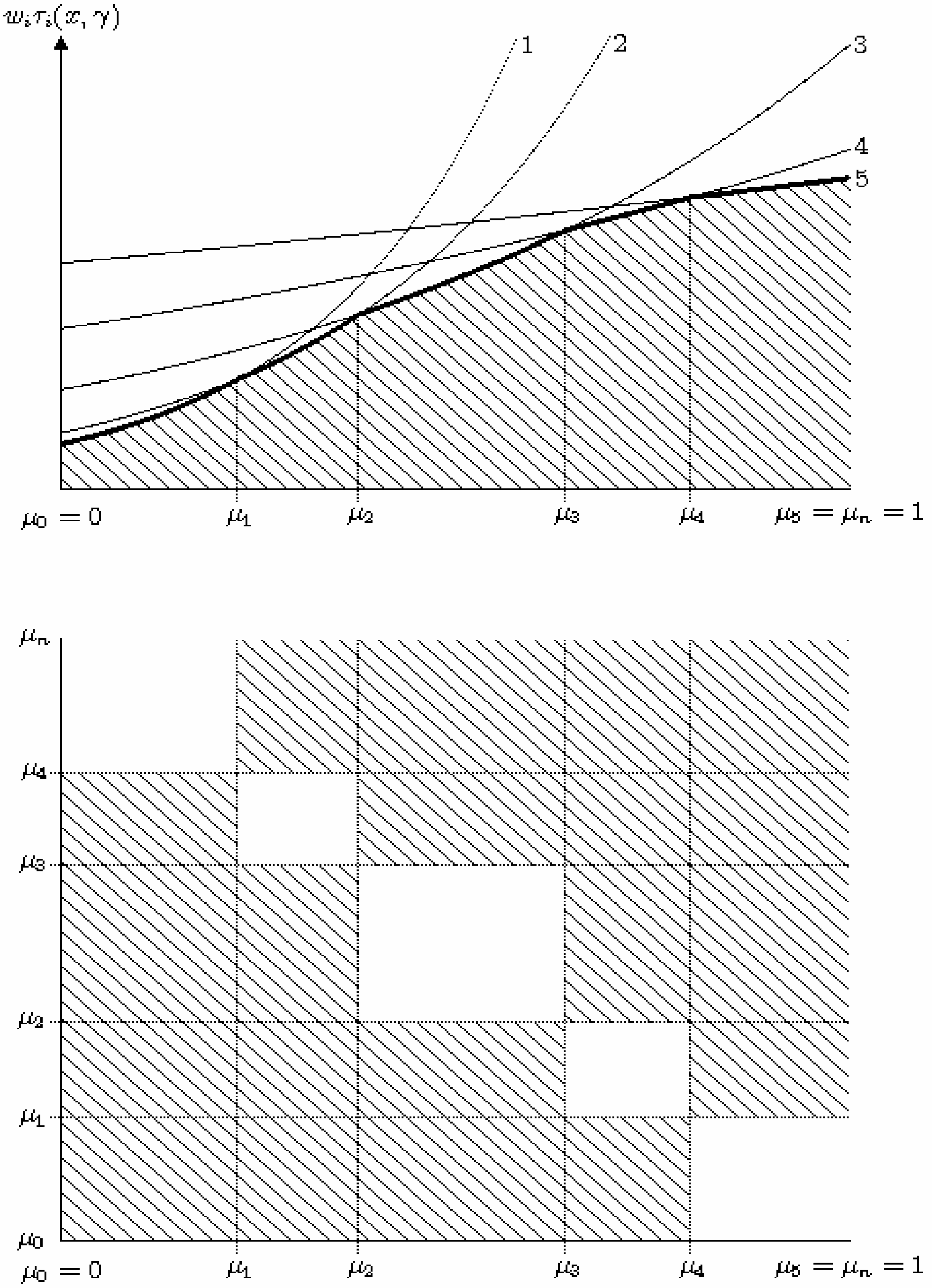
Figure 1

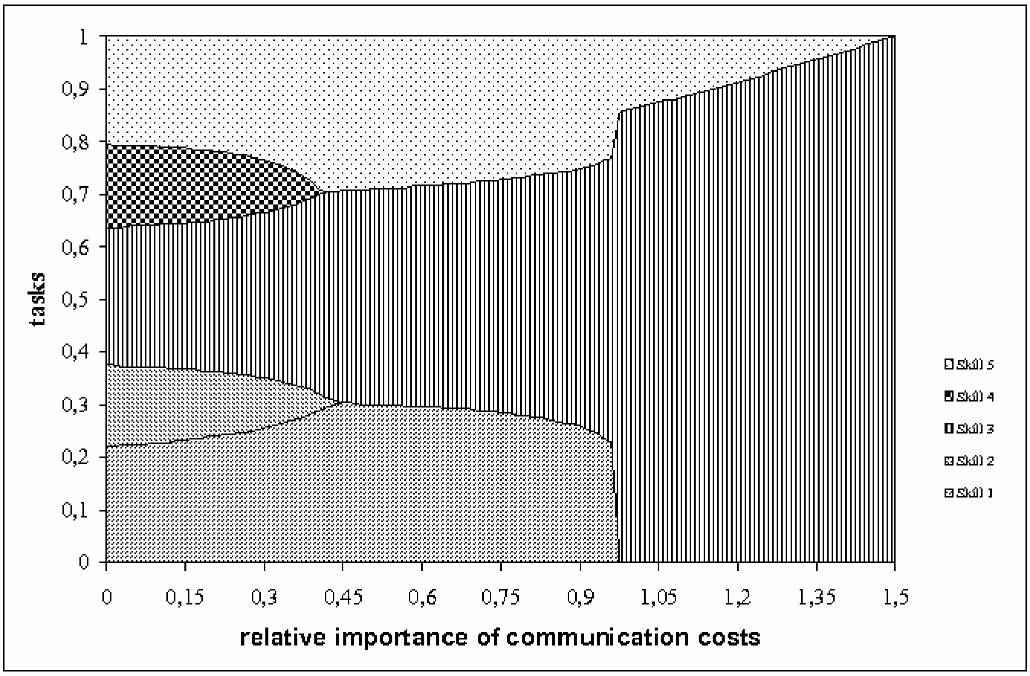
Time Needed for Production and Communication for Five Types of Workers



Production and communication costs for firm with tasks uniformly distributed on the interval [0,1], with five types of workers (i=1, …, 5), with $\tau_i(x,1) = e^{a_i x}$, w_2=1.25 w_1, w_3=2.20 w_1, w_4=3.55 w_1, w_5=5.00 w_1, and a_1=4, a_2=3, a_3=1.5, a_4=0.75, a_5=0.32. Dashed lines represent the optimal division of labour when communication costs are not taken into account.

Figure 2

Numerical Example of the Optimal Division of Labour when Communication Costs Increase



Simulations are based on 250 tasks (x), uniformly distributed on the interval [0,1], with five types of workers (i=1, …, 5), with $\tau_i(x,1) = e^{a_i x}$, w_2=1.25 w_1, w_3=2.20 w_1, w_4=3.55 w_1, w_5=5.00 w_1, and a_1=4, a_2=3, a_3=1.5, a_4=0.75, a_5=0.32.

Table 1

Descriptive Statistics

Variables	Mean (st.dev.)
Change in computer technology use	.058 (.223)
Employment structure	
Change in employment concentration [a]	.029 (.101)
Change in share of skilled workers	.022 (.188)
Change in ratio indirect/direct employees	–.316 (.337)
Organisational structure	
Change in number of hierarchical layers	–.012 (.871)
Change in log team size	.090 (.214)
Change in log establishment size	.030 (.379)
Wages	
Change in log average wages	.066 (.133)
Change in standard deviation of log wages	.114 (.446)
N	2,010

[a] An establishment's employment concentration is measured as the sum of squared terms of the share of four types of workers categorised by level of education.

Table 2

The Determinants of Fast Within-Establishment Computer Technology Diffusion

Independent variables	(1) Mean (st.dev.)	(2) Full sample	(3) Private sector firms
Ownership			
Management owns establishment	.380 (.486)	–.060 (.029)**	–.070 (.028)***
Establishment is part of a larger enterprise	.420 (.494)	.054 (.023)**	.057 (.026)**
Products			
Production of consumer products	.461 (.480)	.038 (.025)	.020 (.025)
Production of semi-manufactured products	.299 (.170)	.012 (.049)	.006 (.049)
Production of other products	.240 (.249)	ref.	ref.
Part of the production is exported	.353 (.478)	.111 (.034)***	.088 (.032)***
Competition			
Degree of market competition	.951 (.823)	.061 (.020)***	.062 (.019)***
Competition based on low price	.182 (.144)	–.403 (.085)***	–.395 (.092)***
Competition based on fast delivery	.215 (.160)	–.436 (.094)***	–.325 (.099)***
Competition based on high quality	.206 (.169)	.292 (.081)***	.231 (.087)***
Competition based on good service	.165 (.172)	.074 (.077)	.013 (.087)
Competition based on branding	.063 (.133)	–.071 (.091)	–.108 (.106)
Competition based on product advancement	.011 (.061)	–.078 (.085)	–.072 (.085)
Competition based on tailor-mades	.076 (.142)	–.050 (.045)	–.060 (.046)
Competition based on high-fashion products	.033 (.154)	.085 (.061)	.092 (.063)
Technology and innovation			
Extent to which advanced technology is used	.196 (.623)	.051 (.017)***	.053 (.020)**
Recent adoption of advanced technologies (other than computer technologies)	.194 (.452)	.051 (.022)**	.062 (.026)**
Research and development (involvement in both internal and external projects)	.192 (.497)	–.074 (.027)***	–.047 (.027)*
Intercept		.741 (.068)***	.740 (.063)***
N	2,010	2,010	1,742
Adjusted R^2		.428	.409

Standard errors are reported in brackets in columns (2) and (3). All regressions are based on characteristics of the establishment in 1990, WLS weighted by establishment size and include sector dummies. *** denotes significance at the 1 percent level; ** at the 5 percent level; and * at the 10 percent level.

Table 3

The Impact of Computer Technology Adoption on an Establishment's Employment, Organisational and Pay Structure

	Independent variables					
	(1)	(2)		(3)		
Dependent variables	Intercept	Biannual change in computer adoption	Intercept	Biannual change in computer adoption	Fast adopting firms	Intercept
Employment structure						
Change in	.018	.033	.017	.042	–.046	.017
employment concentration [a]	(.005)***	(.009)***	(.005)***	(.010)***	(.023)**	(.005)***
Change in	.026	.040	.026	.066	–.133	.026
share of skilled workers	(.008)***	(.017)**	(.008)***	(.018)***	(.041)***	(.008)***
Change in	–.256	–.424	–.193	–.600	.497	–.190
ratio indirect/direct employees	(.087)***	(.153)***	(.076)**	(.190)***	(.320)	(.076)**
Organisational structure						
Change in	–.106	.161	–.113	.158	.009	–.113
number of hierarchical layers	(.048)**	(.083)*	(.048)**	(.096)*	(.187)	(.048)**
Change in	.065	–.172	.042	–.156	.062	.022
log team size	(.019)***	(.035)***	(.020)**	(.041)***	(.079)	(.012)*
Change in	.048	–.220	.027	–.266	.226	.029
log establishment size	(.015)***	(.027)***	(.015)*	(.030)***	(.066)***	(.015)*
Wages						
Change in	.078	.008	.079	.022	–.064	.079
log average wages	(.006)***	(.012)	(.007)***	(.014)	(.030)**	(.007)***
Change in	.206	–.149	.206	–.112	–.175	.205
standard deviation of log wages	(.019)***	(.037)***	(.019)***	(.041)***	(.087)**	(.019)***

Standard errors are reported in brackets. All regressions are weighted by establishment size, except for the regressions in which establishment size is the dependent variable. All regressions include time and sector dummies. The number of observations equals 2,010. The number of establishments classified as fast adopting establishments in column (3) equals 219. See the text and equation (14) for more details on the definition of fast adopting establishments. *** denotes significance at the 1 percent level; ** at the 5 percent level; and * at the 10 percent level.

[a] An establishment's employment concentration is measured as the sum of squared terms of the share of four types of workers categorised by level of education.