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Non-technical summary

The contributions of information and communication technology (ICT) to firm performance have received major attention in recent years. Several studies have highlighted the importance of complementary organisational changes as prerequisites for making ICT work productively. Most studies fail to present a specific link between ICT and performance, however.

The focus of this paper is to investigate to what extent ICT applications foster product and process innovations by enhancing organisational flexibility. We argue that ICT primarily facilitates communication and access to information and thus favours the use of easily programmable machines, co-operation between non-managerial workers within firms as well as the co-ordination of business processes between work groups. These functions increase organisational flexibility, i.e. the ability of firms to react flexibly to changes in consumer preferences and allow the participation of employees on strategic decisions. Moreover, improvements in ICT facilitate the codification of knowledge and supply chain management and thus make outsourcing and co-operation with other firms less costly.

In our analysis on the impact of ICT on flexibility, we distinguish between *functional flexibility* (the ability of workers to co-operate and take decentralised decisions) and *numerical flexibility* (the reduction of fixed costs, mainly due to outsourcing business processes). Functional flexibility is measured by the share of employees working in teams, in job rotation, in quality circles or in autonomous groups. Numerical flexibility is proxied by two indicators: first, outsourcing activities over the past three years as reported by the firms, and, second, the share of intermediate goods and services in sales as a measure of accumulated outsourcing decisions during the past. With regard to technology use, we distinguish between various types of ICT applications and investments. For our empirical analysis, we use representative, large-scale and topical panel data from Germany including small and medium-sized firms.

The estimations reveal that ICT use and investment are associated with an increase in both functional and numerical flexibility. The implications for innovation activities differ, however. Our measure of functional flexibility is strongly positively associated with product and process innovations. In contrast, outsourcing allows firms to ‘buy’ innovations in the short run, but reduces innovative capacity in the longer run. The latter result may be a consequence of conflicting strategic innovation interests.

Technology Use, Organisational Flexibility and Innovation: Evidence for Germany

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August 2005

Abstract: This paper investigates to what extent the usage of information and communication technology (ICT) fosters innovation activities by facilitating more flexible organisational structures in firms. We distinguish between *functional flexibility* (the ability of workers to co-operate and take decentralised decisions) and *numerical flexibility* (the reduction of fixed costs, mainly due to outsourcing business processes). Our results from a large and representative data set of firms in Germany show that ICT use is associated with an increase in both types of flexibility but the implications for innovation activities differ. Functional flexibility is strongly positively associated with product innovations. In contrast, numerical flexibility allows firms to 'buy' innovations in the short run, but reduces innovative capacity in the longer run.

Key Words: ICT usage, flexibility, innovations.

JEL Codes: L22, L23, O31

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1 Introduction

The contributions of information and communication technology (ICT) to firm performance have received major attention in recent years. Most existing studies find substantial productivity contributions of ICT (Brynjolfsson and Hitt, 2003; Hempell, 2005c; Matteucci et al., 2005). Several studies highlight, however, that ICT is no panacea but merely an ‘enabling technology’ whose productive usage requires complementary activities by firms. They argue that ICT, unlike other capital goods, primarily supports innovations by improving possibilities of co-operation and information sharing between employees and firms (McEvily et al., 2004) instead of directly increasing productivity. This has motivated several authors to highlight the importance of complementary organisational changes and innovation efforts as prerequisites for making ICT productive (Brynjolfsson and Hitt, 2000; Hempell, 2005a,b). Their main argument is that ICT mainly facilitates the flow of information between firms and between employees and reduces information costs. In order to reap these benefits, firms have to give employees the possibility to react quickly to new information and communicate with each other or other firms (Batt, 1999).

Some empirical studies provide evidence that productivity of ICT is indeed highest if coupled with own innovation activities (Bresnahan and Greenstein, 1996; Hempell, 2005b) and with organisational changes such as decentralization of decision rights or employee participation (Bresnahan et al., 2002; Brynjolfsson and Hitt, 2003). None of these empirical studies, however, has analysed how and to what extent ICT use and investment enable firms to adjust their organisational structures in such ways that they can improve their innovation capabilities. In this paper, we argue that innovation success is an important explanation for the productivity effects of ICT. Instead of a direct “black-box-link” between ICT and productivity, we demonstrate that ICT has an impact on organisational flexibility and that the main part of the effect of ICT on innovation success can be explained by this flexibility link. In addition, differentiating between functional and numerical flexibility, we highlight specific ways how ICT affects organisation structures in firms. In a final step, we analyse the impacts of these different flexibility choices on product and process innovations in the short and long run.

Flexibility plays an increasingly important role for the competitiveness of firms. Technical developments shorten innovation cycles and product markets get increasingly segmented and customer-oriented. This development requires firms to make production more flexible in order to innovate and to provide a greater variety of customised products and services (Piore and Sabel, 1984). Inspired by seminal work by Atkinson (1984), various studies have highlighted two distinct ways of increasing flexibility: on the one hand, firms try to enhance *functional flexibility* by employing and training workers involved in team work and perform varying tasks; on the other hand, firms increasingly source out production processes in order to reduce fixed costs and thus increase *numerical flexibility*.

By lowering the costs of communication between firms as well as between employees, continuously cheaper and more powerful ICT is facilitating the use of easily programmable machines, co-operation between non-managerial workers within firms as well as the co-ordination of business processes beyond firm boundaries (Bresnahan et al., 2002). This development increases the ability of firms to react more flexibly to changes in consumer preferences and to enhance communication between employees. Moreover, improvements in ICT facilitate codification of knowledge and supply chain management and thus make outsourcing less costly (Caroli, 2003).

Both functional and numerical flexibility may be influential for a firm's ability to innovate. Employees in a functionally flexible work organisation have been argued to be better aware of the necessity to innovate and to be in a position to supply their specific knowledge on consumer demands and production inefficiencies (Levine and Tyson, 1990; Appelbaum et al., 2000). In contrast, the impact of numerical flexibility on innovation appears ambiguous. On the one hand, product innovation may be complicated severely if a large number of suppliers is involved in the development process. Moreover, strategic goals pursued by suppliers and client firms may be very different. On the other hand, purchasing technologically advanced intermediate goods may contribute to improve final good quality. In addition, there may be spillover effects between supplier and outsourcing firm with respect to the production design which might spur process innovations in the outsourcing enterprise.

Although ICT-enabled organisational flexibility has received broad attention in the economic literature (Bresnahan et al., 2002; Black and Lynch, 2004), little effort has been made to differentiate the diverse effects of ICT use on different types of flexibility and innovation performance. Our paper focuses on these issues accordingly.

For our empirical analysis, we use representative, large-scale and topical panel data from Germany including small and medium-sized firms. One particular advantage of the data is that they provide continuous metrics of the usage of functional and numerical flexibility instead of dummy variables. Functional flexibility is measured by the share of employees working in teams, in job rotation, in quality circles or in autonomous groups. Numerical flexibility is captured by two indicators: outsourcing during the past three years and the share of intermediate goods and services in sales as a measure of accumulated outsourcing decisions during the past. In addition, we are able to distinguish between the relevance of different types of ICT use and ICT investments for flexibility and innovation.

Our results show that ICT use and investment are associated with an increase in both functional and numerical flexibility but that the implications for innovation activities differ. Our measure of functional flexibility is strongly positively associated with product innovations. In contrast, outsourcing (which is our measure of numerical flexibility) allows firms to 'buy' innovations in the short run, but reduces innovative capacity in the longer run which may be due to conflicting strategic innovation interests. The direct effect of our ICT indicators declines strongly if flexibility measures are introduced to explain product or process innovations. This supports the hypothesis that ICT is mainly an enabling technology that requires complementary changes in functional flexibility.

The remainder is organised as follows. In section 2, we discuss the theoretical background on organisational flexibility, the role of ICT and the impacts of flexibility on innovation success and provide a simple empirical model in section 3. In section 4, we briefly describe our data source. Section 5 presents and discusses the empirical results, and section 6 concludes.

2 Background

In this section, we summarise the main theoretical ideas and some empirical evidence about functional and numerical flexibility, the role of ICT as an enabler of both types of flexibility, and the relevance of organisational flexibility for innovation.

2.1 Functional and numerical flexibility

Inspired by Atkinson (1984), a number of studies have established the distinction between two basic kinds of organisational flexibility of firms – *functional* and *numerical*.[1] Functional flexibility increases the possibilities to redeploy employees between activities and tasks by empowering workers with greater decision-making responsibility and assigning them a greater scope of diverse activities. It is frequently associated with team work, autonomous workgroups and flat hierarchies (Chadwick and Cappelli, 2002). A key feature of this concept of flexibility is to make workers identify closely with the aims of the firm, leading to a higher propensity of workers to co-operate with each other, to generate ideas for improving products and processes, and to exert varying activities within the firm (Appelbaum and Batt, 1994; Batt, 1999; OECD, 1999). Moreover, a firm resorting to functional flexibility must offer incentives to the employees to mobilise their tacit knowledge, which is why functionally flexible firms frequently employ financial incentives based on group performance (Macduffie, 1995). Since functional flexibility requires workers to acquire complex and firm-specific knowledge, firms resort to highly qualified in-house staff. Empirical studies have found functionally flexible firms to be both more productive (Black and Lynch, 2004; Zwick, 2004) and more innovative (Hujer and Radic, 2003).

Numerical flexibility, in contrast, aims at reducing fixed costs by contracting out jobs at reduced wages and benefits and buffer the regular work force from fluctuations (Gramm and Schnell, 2001). This helps firms to externalise risks with respect to demand fluctuations to external suppliers. Moreover, some goods and services can be bought cheaper or at higher quality from third parties because specialised providers can benefit from economies of scale and learning effects (Abraham and Taylor, 1996). For the outsourcing decision, a firm compares the costs associated with internal transactions and transactions over the market (Coase, 1937). In addition to the market price, the market transaction also incurs transaction costs in the outsourcing enterprise when intermediates are implemented in own production routines.

The two types of flexibility therefore differ in nature and purpose. This is why some researchers considered both types of flexibility as substitutes, reflecting opposed competition strategies. Functional flexibility is largely based on tacit knowledge, i.e. knowledge that is inseparable from the individual, as well as firm-specific knowledge acquired on-the-job or from continued training. Tacit knowledge provides competitive advantage for functionally flexible firms because it is particularly inimitable and non-substitutable (Hatch and Dyer, 2004). Costs of dismissals and thus costs of numerical flexibility are therefore particularly high in these firms since they are associated with high losses of tacit knowledge. The competitive advantage of numerical flexibility is mainly derived from cost reductions.

2.2 Flexibility and ICT

Some studies have argued that investments in and usage of ICT facilitate organisational changes that increase the flexibility of firms (Brynjolfsson and Hitt, 2000). These studies do not consider how the two partially conflicting flexibility forms are enhanced by cheaper and more powerful communication and storage facilities, however. Almost all empirical studies investigating the link

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[1] For a survey on these concepts, see Kalleberg (2001).

between ICT and reorganisation implicitly focus on the impacts of ICT use on functional flexibility (or closely related concepts, such as high-performance workplace practices) of firms. Milgrom and Roberts (1990, 1995) point out that more flexible machinery such as computer-aided manufacturing (CAM) favours clusters of complementary innovative workplace practices, including team work and decentralisation of decision authority and reduces the set-up time of machines. Lindbeck and Snower (2000) and Coutrot (2003) argue that ICT use provides workers with rapid and cheap access to information. This facilitates horizontal communication between employees. They argue that firms that resort to multitasking and team production (which they coin ”holistic” organisations) require workers to communicate with each other more intensively than ”Tayloristic” firms which aim at exploiting productivity potentials mainly by the specialisation of workers in specific tasks and hierarchical structures.

Several empirical studies have provided evidence of a positive link between ICT use and functional flexibility. Bresnahan et al. (2002) find for a cross-section of U.S. firms that various measures of ICT use are strongly correlated with a measure representing decentralisation. Moreover, they report evidence from a survey indicating that managers strongly agree with the statement that ICT use increases autonomy of workers. Similarly, Hempell (2005a) finds for a large cross-section of German firms that various measures of ICT use are closely associated with the presence of team work and subunits with profit responsibility. Bertschek and Kaiser (2004), however, do not find any statistically significant evidence that teamwork and flatter hierarchies favour ICT productivity.

While the impact of ICT on functional flexibility has thus received broad attention in the literature, the implications for numerical flexibility have remained little explored. As highlighted by Bensaou (1997), Innocenti and Labory (2002), and Grossman and Helpman (2002), ICT reduces the costs of finding appropriate suppliers, to monitor subcontractors and to co-ordinate ordering, scheduling and payment systems between firms. This means that outsourcing of business activities is enhanced by ICT use. Moreover, Caroli (2003) argues that ICT encourages coding and digitalisation of employees’ knowledge and skills. Therefore tacit knowledge accumulated by employees can be incorporated more easily into the firms’ information system by codification. Based on case studies, Balconi (2002) argues that increased use of electronic automation and measurement instruments has eroded the importance of tacit knowledge among workers at lower hierarchy levels and has strengthened tacit knowledge of supervisors and problem-solving staff instead.

Our data set allows us to test several hypotheses on the relationship between ICT investments and usage and both types of flexibility. In the next section, we develop two models that explain the numerical and functional flexibility decision of firms including the specific role of ICT. We empirically assess the hypotheses derived from the models in section five.

2.3 The impact of flexibility and ICT on innovations

Considering the implications of organisational flexibility for innovation, we focus on the capability of firms to introduce product innovations (i.e. new or significantly modified products or services) and process innovations. In the following, we discuss the role of functional and numerical flexibility on innovation success subsequently.

Functional flexibility: Several observers have argued that functionally flexible enterprises face lower barriers to innovate since higher discretion conceded to workers and closer co-operation in teams encourages a higher awareness to changing customer needs, joint problem-solving, continuous improvements, discovery and utilisation of local knowledge, and reactions to inefficiencies in the production process (Lindbeck and Snower, 2000; Cristini et al., 2004; Mahnke et al., 2005). Freeman and Lazear (1995) and Zoghi et al. (2005) stress that employees with private knowledge on improvement possibilities also need the capacity to act on the information or share it with someone who already has such capacity. A functionally flexible firm with decentralised decision making attributes this capacity directly to the employee.

The organisational aspects of functional flexibility have also received considerable attention in the innovation literature concerned with *absorptive capacity*, i.e. the capability of firms to absorb new knowledge, assimilate it and apply it to commercial ends (Cohen and Levinthal, 1990). Van den Bosch et al. (1999) argue that organisational forms favouring horizontal communication and co-operation enhance a firm's absorptive capacity in two respects: *scope*, i.e. the breadth of accessible knowledge about products, processes or markets; and *flexibility*; i.e. the extent to which the firm can access additional or reconfigure existing knowledge. However, emphasis on horizontal communication may harm knowledge absorption with respect to *efficiency*, since economies of scale can be better achieved by more centralised and hierarchical organisations.

In a case study, Brynjolfsson et al. (1997) show that the joint use of computer-based flexible machinery and substantial reorganisation of work towards higher functional flexibility dramatically increased the variety of products. Analysing a sample of German establishments, Hujer and Radic (2003) find that combining flexible workplace organisation with human resource management practices enhances innovation success. Similarly, Michie and Sheehan (1999) show for a sample of British establishments that high-performance workplace practices – including team work, incentive pay and a strong focus on communication – are strongly correlated with research and development (R&D) efforts. Zoghi et al. (2005) demonstrate for a large panel of Canadian establishments that decentralised decision making and information-sharing are positively correlated with product and process innovations.

Numerical flexibility: The theoretical predictions about the consequences of numerical flexibility for innovation are by far less clear-cut than for functional flexibility. Some authors highlight that a strong focus on numerical flexibility may harm innovation capabilities, at least in the long term. Novak and Eppinger (2001) argue that the development of complex products calls for stronger vertical integration in order to benefit from investments in specific skills that are needed to co-ordinate development and production of complex designs. They back this hypothesis with evidence from the automobile industry. Supporting this view, Caroli (2003) and Hatch and Dyer (2004) highlight the strategic role of tacit knowledge as a prerequisite for innovation and sustained competitive advantage. Numerical flexibility (and outsourcing in particular) induces the risk of undermining a firm's base of tacit knowledge and innovation capabilities. Similarly, Chesbrough and Teece (1996) argue on the basis of case studies that outsourcing may harm innovation capabilities in the long term since loose partnerships of firms carry a larger potential of conflicts of interest which may be the more harmful the more complex an innovation process is.

However, these considerations can be opposed by arguments suggesting a positive effect of numerical flexibility on innovation. For example, numerically flexible enterprises can acquire new competencies faster in the short run by contracting external specialists or by buying technologically advanced components from suppliers (Abraham and Taylor, 1996). Moreover, rapid renewal of personnel may be beneficial for firms that introduce radical innovations because tenured employees may be attached to outdated processes and resist change (Zwick, 2002).

3 Empirical Models of Flexibility and Innovation

This section provides models and hypotheses about the factors determining a firm's decision to introduce numerical and functional flexibility and innovations.

3.1 Numerical flexibility: a firm's outsourcing decision

In order to derive some hypotheses on the determinants of the firms´ outsourcing decisions, we employ a simplified variant of the model proposed by Bartel et al. (2005). Suppose producing a final good of quantity Q requires goods or services S in fixed proportions such that $S = \alpha Q$ and that S (denoted as intermediate in the following for simplicity) can be produced either completely in-house or be bought from external suppliers. The firm will choose the option that minimises the costs of the required quantity of the intermediate.

Producing the intermediate *in-house* costs $C_i(S)$ or $c_i(S)=C_i(S)/S$ per unit with $c'<0$. For the outsourcing firm, unit costs are composed by the market price p for purchasing the intermediate, observable transaction costs t for contracting suppliers and co-ordinating activities internally and externally, and additional unobservable firm-specific costs and benefits u (compared to in-house production), such as adjustment costs or knowledge spillover effects. Therefore total unit costs of outsourcing can be defined as $c_o(S)=p(S)+t(S)+u$. The market price of the intermediate p is assumed to be equal for all firms. Transaction costs t are firm-specific and depend on a firm's endowment with information and computer technology (ICT), the amount of requested intermediates S, and several additional factors X discussed below, such that $t=t(ICT,S,X)$. The amount of intermediates S bought reduces t since transaction costs are subject to economies of scale, i.e. $t'<0$.

An important pre-requisite of the model is that ICT reduces transaction costs. This notion is based on the observation that ICT allows a faster and cheaper exchange of information between firms and thus helps to co-ordinate the activities of suppliers and clients more easily. This is important because outsourcing frequently induces an intensive interaction between buyer and supplier. As highlighted by Bensaou (1997) and Innocenti and Labory (2002), falling costs of ICT reduce the costs of finding appropriate suppliers and of comparing market prices of the intermediate (Grossman and Helpman, 2002). Moreover, ICT facilitates co-ordination of ordering, scheduling and payment systems between firms. The use of ICT has helped to apply Just-in-Time Management by accelerating the process of identifying the need for ordering, the accomplishment and transmission of the order, and the delivery of the intermediates. Moreover, as argued by Caroli (2003), ICT encourages the coding and digitalisation of knowledge and skills. Therefore tacit knowledge accumulated by employees can be more easily incorporated into the firms' information system by codification. This helps firms to lower the risk of losing firm-specific knowledge, which can be conceived as transaction costs incurred by outsourcing in a broader sense.

A variety of other firm-specific internal costs and benefits of outsourcing u are extremely difficult to observe. For example, the costs of adjusting a firm's routines to outsourcing depends on the flexibility of its management and employees. The decision to outsource business processes may directly affect job tasks of individual workers, and the cost of reorganisation hinges on the ability, willingness and costs of workers to be trained for new tasks or the costs to lay them off. Moreover, outsourcing business processes is associated with strategic dependence on suppliers and may thus incur risks of knowledge leakage. Besides unobserved costs, there may be also unobserved benefits from outsourcing, however. Co-operation with external suppliers may lead to learning and knowledge spillover effects, in particular if innovative intermediates are purchased externally.[2] Moreover, outsourcing may help to reduce insider bargaining power of workers. The management may threat to shift business processes to third parties in wage negotiations. We assume the sum of these unobserved costs and benefits u to be normally distributed across firms: $u \sim \phi(0;\sigma)$.

A firm decides to outsource the production of intermediates (*OUTS*=1) if total unit costs of externally purchased intermediates are lower than the unit costs of production in house: $p(S)+t(\bullet)+u<c_i(S)$, or $u<c_i(S)-p(S)-t(\bullet)$. This means that the probability of outsourcing is given by: $\Pr(OUTS=1)=\Phi\left(c_i(S)-p(S)-t(\bullet)\right)$, with $\Phi(\bullet)$ denoting the cumulative normal distribution.

The unit cost functions of producing the intermediate S consist of fixed costs ξ and marginal costs r: $c_i(S) = \xi/S+r$. As highlighted by Bartel et al. (2005), in an equilibrium analysis, the rationale for outsourcing in this model is based on scale effects. If fixed costs ξ are sufficiently large, it will be cheaper to buy S externally from a specialised firm that sells its products to several clients despite transaction and internal costs associated with outsourcing.[3] The effect of the total amount of requested intermediates S is therefore ambiguous. On the one hand, scale economies in production decrease in-house production costs. On the other hand, the stronger bargaining power and scale economies in transaction costs reduces the costs of outsourcing for larger firms.

Overall, a firm's decision to outsource can be summarised by the following equation:

$$\Pr(OUTS=1)=\Phi\left(\xi/S+r-p(S)-t(ICT,S,X)\right) \qquad (1).$$

For computational simplicity, we assume the observable transaction costs t to be a linear function of their arguments. Apart from ICT use and the quantity of intermediates needed, we consider a variety of further control variables X that may affect the outsourcing decision. A large share of skilled workers and thus tacit knowledge in the firm may imply that the exchange of knowledge

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2 Nearly every fifth innovative firm in Germany cites suppliers as an important source of relevant knowledge for innovations, see Gottschalk et al. (2001).

3 In reality, external suppliers of the intermediate goods may face further cost advantages, in particular lower variable costs due to specialisation and learning effects. The modelling of different production technologies, however, is beyond the theoretical scope of this paper.

with suppliers is more difficult and may involve higher risks of knowledge leakage.[4] Exporting firms as well as firms belonging to conglomerates may face lower transaction costs since they are able to benefit from international contacts and existing networks in finding cheap and suited suppliers i.e. they face lower search costs in outsourcing (Osterman, 1994). Works councils frequently increase wages (Addison et al., 2001) or induce higher termination or overtime costs for core employees (Gramm and Schnell, 2001). This might lead to a higher inclination of firms to outsource part of production to cheaper suppliers.

For simplicity, we model transaction costs as a result from the linear function $t = \beta_0 + \beta_1 ICT + \gamma' X$. The empirical model of outsourcing can thus be summarised in the following form:

$$\Pr(OUTS = 1) = \Phi(\beta_0 + \beta_1 ICT + \gamma' X) \qquad (2),$$

which can be estimated using a conventional Probit approach.

A natural extension of the model is to assume that there is a continuum of intermediate goods for which the 'make or buy' decision must be taken. Therefore, in the empirical part, we also use a linear model with the share of intermediates in total output as the dependent variable. This variable can be interpreted as accumulated outsourcing decisions in the past.

3.2 Functional flexibility: a firm's decision to introduce holistic work organisation

Suppose that a firm has the choice to produce its output in two alternative regimes as proposed by Lindbeck and Snower (2000): either in a 'Tayloristic' type of work organisation (*T*) with each worker specialising in a specific subtask; or in a 'holistic' or functionally flexible organisation (*H)* based on team work, job rotation, flat hierarchies or multi-tasking (Osterman, 1994; Chadwick and Cappelli, 2002). Several empirical studies show that firms can increase their productivity by introducing functional flexibility (Macduffie, 1995; Ichniowski et al., 1997; Appelbaum et al., 2000; Zwick, 2004). However, employees in flat hierarchies and teams need more training and probably demand a compensation for their increased responsibilities. In addition, installation for higher co-ordination and horizontal communication such as meeting rooms or Intranet are costly.

Taking fixed costs of installed capital as given, costs of producing output *Q* in the Tayloristic regime are given by the simplest functional form $C_T(Q)=vQ+w$, with *v* denoting variable costs and

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[4] In addition, high skilled employees may oppose outsourcing because their skills become obsolete and outsourcing might threat their work places (Ichniowski and Shaw, 1995; Zwick, 2002).

w being an i.i.d error term with expected value 0. The more productive holistic work organisation causes costs $C_T(Q)$ resulting from the function

$$C_H(Q) = ((1-\lambda)v + \theta)Q + u \qquad (3),$$

where λ (with $0 < \lambda < 1$) represents the fraction by which the holistic organisation is more productive (or equivalently less costly for a given level of output) compared to the Tayloristic regime, and θ denotes additional unit costs in the holistic system resulting from more intense communication and co-ordination between employees and higher wage demands. While λ is assumed to be identical for all firms, co-ordination costs θ are assumed to be a function of ICT capital available as well as further observable factors summarised by *X* (see below), such that $\theta = \theta(ICT, X)$. Finally, *u* again represents unobserved firm-specific variables affecting the relative costs of the holistic regime compared to a Tayloristic work organisation, such as adequacy of the firms' products or services for team work, the willingness of employees to work in flat hierarchies or firm-specific internal organisation agreements.

A firm will decide to introduce a holistic regime if $C_H(Q)<C_T(Q)$ or if $\frac{u}{Q} - w < \lambda v - \theta$. With *u* and *w* following a normal distribution, the probability of a firm's choosing the holistic regime is given by $\Pr(HOL = 1) = \Phi\left(\lambda v - \theta(ICT, X)\right)$. Assuming in addition that 'holistic' coordination costs θ are a linear function of *ICT* and *X*, the empirical model simplifies to a conventional Probit approach:

$$\Pr(HOL = 1) = \Phi(\beta_0 + \beta_1 ICT + \gamma' X) \qquad (4).$$

If the organisational form is chosen at the level of subunits in the firm and not for the firm as a whole, the empirical model may be replaced by a linear model with an intensity measure of functional flexibility as the dependent variable.

Considering control variables *X*, we expect functional flexibility to be positively correlated with human capital in firms (such as a high share of highly qualified employees, apprenticeship training or continuing training) because they are complements to team work, quality circles, autonomous teams and other forms of employee involvement in high performance work organisations (Cappelli and Neumark, 2001; Jones and Kato, 2005). Highly qualified employees are also better able to analyse more abstract and formal information needed in team work production and to make use of the scope offered by higher responsibilities and more discretion (Lindbeck and Snower, 2000). Several observers note that incentive payments are a crucial prerequisite for high performance workplace systems to be productive (Ichniowski et al., 1996; Ichniowksi, Shaw and Prennushi, 1997; Cappelli and Neumark, 2000). Works councils help employers to spread the risk of long-term training, development and innovation in work design, as well as on a high level of trust between managers and workers (Arnal et al., 2001; Kalleberg, 2001). They therefore might be positively correlated with functional flexibility. Works councils also have their agenda, however. Being concerned about losing their power basis, they may hamper autonomous work organisations that grant more discretion and responsibilities to the work floor (Godard, 2004; Zwick, 2004). Therefore, there might also be a negative relationship between works councils and the incidence of team work, quality circles and autonomous work groups.

3.3 Specific hypotheses about ICT applications and flexibility

Our analytical framework above predicts that ICT use and investments enhance both types of flexibility. In the first place, ICT use reduces transaction and co-ordination costs, making cheaper both co-operation between workers of the same firm and co-ordination with external suppliers. The data set allows us to discriminate between different types of ICT applications, whose expected impacts on organisational flexibility are briefly discussed in the following.

We use the share of employees who mainly work with a PC (PCWORK) as an indicator for the intensity of ICT usage. ICT investment is directly measured by INVICT. The availability of an Intranet (INTRA) is an important tool for facilitating communication and sharing of knowledge in in-house communication. INTRA is thus expected to enhance the adoption of functional flexibility. In contrast, we expect no impacts of INTRA on the outsourcing decision of firms. The share of PCs connected to a network (NETPC) should be positively correlated to both sorts of flexibility, however, since broader access to networks not only enhances co-operation between employees within the same firms but possibly also with other firms.

Training workers in IT-specific skills (ICTTRAIN) may be necessary for both the introduction of functional flexibility and outsourcing since tasks of employees may be changing in the course of these reorganisations. However, firms may be much more inclined to invest in workers' skills under functional flexibility whereas investments in human capital enhance internal fixed costs which contradicts the idea of numerical flexibility. We thus expect ICTTRAIN to correlate positively with a higher degree of functional flexibility but not (or even negatively) with the propensity of outsourcing.

We also dispose of information on the aims that firms pursue by using ICT. Development of new products is expected to be a goal of ICT usage applying to functional flexibility but not to outsourcing. Using ICT in order to achieve payroll costs savings should be a specific goal of outsourcing decisions. In contrast, the production regimes based on functional flexibility tend to be associated with higher costs (for training, communication etc.) such that we expect no correlation or a negative one between the aim of saving costs with functional flexibility.

3.4 Flexibility and Innovations

We estimate the probability that an enterprise innovates by the following Probit model including the flexibility strategy and ICT activities according to section 2.3:[5]

$$\Pr(INNO = 1) = \Phi(\beta_0 + \beta_1 FLEX\_FUNC + \beta_2 FLEX\_NUM + \beta_3 ICT + X\gamma) \qquad (5),$$

where *INNO* is an indicator of whether an establishment has introduced a product innovation (*PROD-INNO*) or a process innovation (*PROC-INNO*) and *FLEX_FUNC* and *FLEX_NUM* are variables measuring numerical and functional flexibility (see next section). As mentioned earlier, we assume that functional flexibility increases product and process innovations. Numerical flexibility should have – if at all – only a short-term impact on product innovations if innovative intermediates contribute important new characteristics to final goods output while they may harm innovative capability in the long run. Numerical flexibility might induce lagged process innovations, however, if it takes time to adjust production processes to outsourcing decisions.

Among the additional control variables, we first include measures of ICT use and investment in order to control for other channels than organisational flexibility through which ICT may enhance innovation capabilities. The potentially positive impact of enhanced vertical co-operation between employees and management on innovations is captured by the works council measure in vector *X* (Zoghi et al., 2005). Additional explanatory variables for innovations are financial incentives (INCENTIVE) – they are used to give non-managerial workers an incentive to come forward with innovations that might improve efficiency but also might put the worker´s own job at risk (Black and Lynch, 2005). The size of the firm (SIZE) might be positively related to innovations since there may be more product lines and services that are open to efficiency and quality improvements. Firm age (AGE) may negatively affect innovation since older institutions may be able to benefit more strongly from products already established in the markets. Moreover, older firms may find it costlier and more difficult to adjust internal processes and routines established over a longer period of time.

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[5] For a very similar approach, see Zoghi et al. (2005).

4 The Data

The data used for empirical testing of the theoretical hypotheses stem from the *ZEW survey on the diffusion and use of ICT* among German firms. This survey is based on Computer-aided telephone interviews (CATI) among about 4,500 representatively chosen firms in Germany with five and more employees in the years 2002 and 2004. Apart from the large variety of indicators on the use of ICT and e-business, the survey includes information on organisational changes and workplace practices, innovation success and detailed characteristics of employees, including formal qualification, age, and the share of workers enrolled in training measures. The size of the firms is calculated from the number of full-time employees. Using only data on firms with information from both 2002 and 2004 and after excluding data with incomplete information on items employed, the sample used for the main empirical explorations includes about 900 firms. Descriptive statistics and short descriptions of the variables used in the empirical part of the study are summarised in Table A1 in the Appendix.

In order to measure the importance of ICT usage and investment in the enterprise, we use the share of employees mainly working on a PC (PCWORK) and ICT investments (INVICT). We assume that these complementary measures give a comprehensive picture of both the importance of ICT for work practices and of financial importance of ICT. In extensions of the reference specifications, we also include the share of workers involved in ICT-specific training (ICTTRAIN), the average number of personal computers connected to a network per worker (NETPC), the existence of an Intranet (INTRANET) as well as two dummies indicating that ICT is used in the firm in order to develop new products (GOAL_INNO) and to save payroll costs (GOAL_PCOST). As illustrated in Table A2 in the Appendix, the alternative measures of ICT use are strongly correlated.

In order to measure the degree of functional flexibility, we employ the share of employees of a firm working in autonomous teams, quality circles or job rotation, and financially autonomous work units. Applying the procedure suggested by Bresnahan et al. (2002), we construct a comprehensive measure of functional flexibility (FLEXFUNC) by aggregating the measures in standard deviations (STD) from sector means in the following way:

$$FLEXFUNC = STD[STD(TEAM) + STD(CIRCLE) + STD(HIERARCHY) + STD(PROFIT)]\ .$$

As proxies for numerical flexibility, we resort to two different measures of outsourcing. A first measure is the share of intermediate goods and services in total sales (INTERMED). A high value for INTERMED indicates that a large part of the value of goods and services sold has been generated by suppliers. In this sense, INTERMED is a measure of accumulated outsourcing activities in the past. A second measure (OUTSOURC) of numerical flexibility is a dummy variable indicating whether a firm has outsourced business activities during the period 2001-2003. This variable is an indicator for an extension of numerical flexibility during the more recent past.

5 Empirical Results

5.1 Estimation Strategy

In the first step, we explain functional and numerical flexibility by several ICT indicators and other factors. Disentangling the causal effects of ICT use on organisational flexibility is not an easy task, however. In fact, there are reasons to argue that the decisions to implement new technologies and to introduce new organisational forms are simultaneous (Milgrom and Roberts, 1990). In this case, regressing measures of organisational flexibility on ICT variables and controls cannot be interpreted as causal effects but as correlations that may be due to complementarities between technology use and organisational change.

There is one theoretical and one methodological reason, however, why we believe the results of our analysis should be interpreted as running from technology use to organisation. First, as argued by Bresnahan et al. (2002), prices of ICT goods and services have been falling dramatically over the past decades due to rapid technological progress and competition in the ICT sector. For individual firms, these price declines are exogenous changes that substantially increase the propensity to adopt these technologies. In contrast, there is no reason to believe that the costs of introducing organisational changes have changed in a similar order of magnitude (or even changed at all). This means that if ICT and organisational changes are complements, price decline in ICT is the external variation that increases both the demand for ICT and the attractiveness of organisational changes as its complement. Second, in our empirical approach according to equations (2) and (4), we employ a well-defined temporal sequence by using flexibility measures for 2004 as dependent variables and lagged values from 2002 for the explanatory variables.

Similar endogeneity issues may also apply to the estimation of the innovation equations (5). To address these issues, we also employ a measure of innovation success referring to the time period 2001-2003 and explanatory variables referring to 2001 for the most part.

The share of intermediates and our composed functional flexibility measure are estimated in a linear model by OLS, while outsourcing is estimated by a Probit model. Moreover, we apply instrumental variable (IV) approaches for our measures of flexibility making use of the hypothesis that ICT use affects innovation efforts primarily via organisational flexibility.

5.2 Results

In the first set of regressions reported in Table 1, we explore to what extent ICT use and investments favour the introduction of numerical and functional flexibility. We estimate equations (2) and (4) using three dependent variables: OUTSOURC (outsourcing yes/no) and INTERMED (expenditures for intermediate goods relative to sales) as proxies for numerical flexibility on the one hand, and the constructed measure FLEXFUNC for functional flexibility on the other. For each variable, we firstly conduct a parsimonious regression (with PCWORK and INVICT as the only ICT indicators) and, secondly, an extended regression with more detailed ICT variables. While the latter specifications give a more detailed picture of specific ICT applications, multicollinearity between the ICT measures may blur the real contributions of ICT use to organisational flexibility. This risk is substantially smaller in the parsimonious regressions.

Considering the parsimonious specifications (1), (3), and (5) in Table 1, at least one of the two ICT variables turns out significantly positive in each of the specifications. INVICT increases the probability of outsourcing in the subsequent period, while PCWORK is positively associated with a higher share of intermediate goods in total sales. This result is consistent with our predictions if we consider PCWORK as the result of accumulated computer investments in the past and, similarly, INTERMED as the result of accumulated outsourcing activities. Both, computer use by workers and ICT investment are positive and significant in the regression with functional flexibility as the dependent variable.

Including a set of additional variables measuring ICT use in more detail (columns 2, 4, and 6 in Table 1), the coefficients of PCWORK and INVICT lose a considerable part of their significance. As suggested above, this may be partially the result of high correlation between the different measures of ICT use (confer Table A2). Some interesting differences in the patterns of the detailed ICT measures occur. While all additional measures are insignificantly different from zero for the INTERMED variable, the number of personal computers connected to a network (NETPC) and the fact that a firm uses ICT for saving payroll costs (GOAL_PCOST) is associated with a significantly higher probability of outsourcing activities in subsequent periods. This shows that outsourcing firms focus on cost savings when using ICT. In addition, communication costs with external suppliers and information costs on market prices are reduced if the Internet is used.

In contrast, all the additional ICT use variables – except the dummy for cost savings via ICT – enter significantly positive in the regression for FUNCFLEX (equation 6). This shows that firms with a high degree of functional flexibility have invested strongly in ICT-specific training, dispose of an Intranet, have a relatively high number of PCs connected to networks, and they pursue the goal of developing innovative products and/or services with the help of ICT. These results show that functional flexibility obviously requires a much broader range of ICT applications than outsourcing activities. A possible explanation is that while ICT use for outsourcing activities is concentrated mainly on a small set of 'gate keepers' dealing with external suppliers, it is important that ICT is used by a predominant part of workers involved in functional flexibility. Finally, functional flexibility creates new demands on employee skills in contrast to outsourcing. These new communication skills and decision taking responsibilities are supported by the Intranet and ICT training.

Also the coefficients of the control variables in the regression yield some noticeable results. Our hypothesis that firms with a well qualified workforce more frequently choose functional flexibility is not confirmed in our data: no indicator for functional flexibility is significantly positively correlated with the lagged share of employees with a university diploma (HIGHQUAL) or the share of apprentices (APPRENT).[6] On the other hand, incentive wages (INCENTIVE), a further assumed complement to high performance workplaces, is more widespread in functionally flexible firms. Also according to our hypothesis, larger firms tend to resort to functional flexibility more frequently than smaller firms. Works councils obviously do not endorse functional flexibility because it reduces their power basis. Older firms use functional flexibility less intensively, probably in order to protect specific human capital investments of their employees.

[6] Further sensitivity checks revealed that the insignificance of the qualification variables may be due to the strong correlations between qualification ICT use. When we exclude PCWORK and INVIL from specification (5) in Table 1, the share of highly qualified employees is positive and significant at the 5 percent level.

Table 1: Characteristics of numerically and functionally flexible firms

	Numerical Flexibility								Functional Flexibility			
	(1)		(2)		(3)		(4)		(5)		(6)	
Dependent var:	**OUTSOURC**		**OUTSOURC**		**INTERMED**		**INTERMED**		**FUNCFLEX**		**FUNCFLEX**	
	Coeff.	S.e.	Coeff.	S.e.	Coeff.	S.e.	Coeff.	S.e.	Coeff.	S.e.	Coeff.	S.e.
ICT indicators												
PCWORK	0.226	0.199	0.064	0.209	0.055**	0.028	0.052*	0.029	0.358***	0.125	0.203	0.129
INVICT	0.069*	0.040	0.045	0.042	0.001	0.006	0.001	0.006	0.085***	0.027	0.050*	0.027
ICTTRAIN			0.154	0.239			0.022	0.038			0.423**	0.184
INTRANET			-0.125	0.111			-0.017	0.015			0.149**	0.074
NETPC			0.193**	0.089			0.008	0.010			0.095*	0.055
GOAL_INNO			0.081	0.101			-0.022	0.014			0.177***	0.067
GOAL_PCOST			0.202**	0.102			-0.000	0.014			0.033	0.064
Controls												
INVNONICT	-0.027	0.034	-0.030	0.035	0.010*	0.005	0.011**	0.005	0.037	0.023	0.036	0.023
HIGHQUAL	-0.677**	0.308	-0.729**	0.315	-0.067	0.043	-0.070	0.044	0.080	0.207	-0.074	0.207
LOWQUAL	-0.411*	0.212	-0.393*	0.211	-0.005	0.030	-0.006	0.031	-0.221	0.154	-0.230	0.151
APPRENT	-0.704	0.737	-0.761	0.736	-0.088	0.097	-0.077	0.098	-0.005	0.433	-0.164	0.430
INCENTIVE	0.182	0.129	0.174	0.131	-0.008	0.017	-0.010	0.017	0.454***	0.093	0.442***	0.092
U30	0.148	0.254	0.134	0.258	-0.054	0.035	-0.046	0.035	0.169	0.162	0.129	0.159
EXP	0.223**	0.111	0.210*	0.112	0.047***	0.017	0.053***	0.017	-0.056	0.079	-0.089	0.078
AGE3	-0.082	0.191	-0.061	0.194	-0.021	0.027	-0.026	0.027	-0.131	0.138	-0.129	0.136
AGE7	-0.239	0.157	-0.193	0.158	0.011	0.022	0.010	0.022	-0.223*	0.116	-0.188*	0.113
GROUP	0.232**	0.107	0.219**	0.108	0.008	0.016	0.010	0.016	0.088	0.074	0.066	0.074
WORKSCOUNC	0.334***	0.125	0.307**	0.127	0.029	0.018	0.030*	0.018	0.128	0.089	0.082	0.088
EAST	-0.182	0.120	-0.190	0.122	-0.012	0.016	-0.013	0.016	0.136*	0.079	0.150*	0.079
SIZE20-50	-0.132	0.125	-0.109	0.127	-0.007	0.018	-0.004	0.018	0.158**	0.078	0.173**	0.077
SIZE51-200	-0.011	0.129	0.038	0.133	-0.014	0.019	-0.011	0.019	0.192**	0.089	0.194**	0.089
SIZE201-500	-0.020	0.173	0.062	0.178	-0.012	0.028	-0.002	0.028	0.227	0.139	0.213	0.138
SIZE501-1000	0.531**	0.223	0.627***	0.231	-0.013	0.031	-0.004	0.031	0.160	0.160	0.154	0.168
SIZE>1000	-0.022	0.309	-0.005	0.328	-0.027	0.043	-0.027	0.046	1.047***	0.257	1.064***	0.262
Constant	0.185	0.467	-0.224	0.488	0.501***	0.070	0.509***	0.073	0.447	0.320	0.033	0.323
14 sectors	yes		yes		yes		yes		yes		yes	
Pseudo R^2	0.109		0.116									
R^2					0.259		0.262		0.159		0.185	
Observations	949		942		843		836		925		918	

Significance levels: ***<0.01, **<0.05, *<0.1, heterogeneity robust standard errors, source: ZEW ICT surveys 2002 and 2004.

Exporting firms (EXP) are frequently more numerically flexible than functionally flexible firms, which is consistent with the hypothesis that export activities help to cultivate international networks that facilitate finding appropriate suppliers. The results also confirm our conjecture that conglomerates (GROUP) can outsource easier. Firms controlled by works councils (WORKSCOUNC) are frequently numerically flexible, which may be due to the fact that remuneration in these firms is frequently particularly generous and lay-off rules for core employees strict.

We used a composed measure of functional flexibility so far. As a check to the sensitivity of our results to this aggregation, we employ an alternative measure defined as the number of the following measures used by the firms in 2004: team work, independent work group, quality circles or job rotation (compare Table A1). If we use this functional flexibility indicator as the dependent variable in an ordered Probit estimation (see results reported in Table A3 in the Appendix), we find a pattern in the explanatory variables which is very similar to the one obtained in the OLS regressions of specifications (5) and (6) in Table 1: all ICT indicators have a positive and significant impact on functional flexibility.

5.3 Consequences for product and process innovations

In the second part of the empirical assessment, we analyse to what extent functional and numerical flexibility are associated with a higher propensity of firms to introduce new products and services (PRODUCT-INNO) or change processes (PROCESS-INNO). For this purpose, we run Probit regressions according to equation (5) with product and process innovations in 2004 as the dependent variables and our functional and numerical flexibility measures for 2002 as explanatory variables plus all the covariates in 2002 used in the previous part of the empirical exploration. Table 2 reports the marginal effects from these regressions evaluated at the sample means.

Most strikingly, the regressions show that FUNCFLEX enters significantly positive in both, the product and process innovation estimations. This supports the hypothesis that intense horizontal co-operation among employees not only enhances product and services improvements, but also helps to adjust processes more easily.

In contrast, outsourcing business activities is not associated with any statistically significant increase in the probability of product innovations after two years. However, outsourcing activities coincide with contemporaneous product innovations. This is shown in supplementary regressions reported in Table A4 in the Appendix. We interpret these results as evidence that firms may ‘buy’ innovations and expertise from external suppliers in the form of innovative intermediates that significantly affect the quality of final goods or services. Sustained improvement of products and services, however, may suffer when, as argued in the theoretical part of the paper, conflicting interests between firms and lack of required internal tacit knowledge hamper innovation capabilities. Our results for outsourcing are reversed if we consider process innovations instead of product innovations. Outsourcing activities do affect subsequent process innovation success but not contemporaneous process innovation success. Outsourcing seems to trigger process innovations only after a time lag. Obviously enterprises need some time to adapt to the new organisation requirements after outsourcing.

Table 2: Flexibility and innovation propensity

Variable	PRODUCT-INNO		PROCESS-INNO	
	coeff.	s.e.	coeff.	s.e.
INTERMED	-0.134	0.269	-0.528*	0.278
OUTSOURC	0.068	0.116	0.329***	0.121
FUNCFLEX	0.162***	0.056	0.167***	0.057
PCWORK	0.302	0.195	0.098	0.192
INVICT	0.072*	0.042	0.084*	0.044
INVNONICT	-0.003	0.035	0.090**	0.037
HIGHQUAL	0.421	0.312	-0.149	0.317
LOWQUAL	-0.485**	0.220	-0.303	0.224
APPRENT	-0.020	0.658	1.139*	0.659
INCENTIVE	0.181	0.141	0.085	0.144
U30	-0.109	0.264	-0.659***	0.253
EXP	0.316**	0.111	0.160	0.115
AGE3	-0.140	0.202	-0.029	0.207
AGE7	0.013	0.165	-0.144	0.167
GROUP	0.182	0.116	-0.026	0.116
WORKSCOUNC	0.204	0.136	0.193	0.140
EAST	-0.094	0.121	-0.127	0.122
SIZE20-50	0.198	0.122	0.083	0.122
SIZE51-200	0.298**	0.140	0.412***	0.138
SIZE201-500	0.475**	0.213	0.667***	0.219
SIZE501-1000	0.622**	0.275	0.436	0.295
SIZE>1000	0.338	0.347	0.716*	0.398
14 sectors	yes		Yes	
Pseudo R^2	0.187		0.136	
N	860		861	

Significance levels: ***<0.01, **<0.05, *<0.1, heterogeneity robust standard errors, source: ZEW ICT surveys 2002 and 2004.

If outsourcing is practiced for a long period of time, the firm seems to lose its capacity for product and process innovations and its absorptive capacity for new information – confer the insignificant coefficients of INTERMED.

A look at the other control variables reveals some patterns that are consistent with findings in the empirical innovation literature. There seems to be a tendency that a higher qualified workforce has a positive effect on product innovations while the qualification structure does not have an impact on process innovations. This finding is consistent with the view that innovation activities require tacit and firm-specific knowledge and exacerbate the strategic role of human capital development (Hatch and Dyer, 2004). Exporters are also more innovative – this may be due to the fact that they are exposed to more competitors with different competition strategies they can use as benchmarks.[7] The dummies controlling for firm size show that the likelihood of firms to innovate is increasing in firm size (Cohen, 1995). Somewhat surprisingly, the results do not provide any evidence supporting the conjecture that younger firms or firms with a high share of young workers are particularly innovative.[8] Finally, also the vertical communication channel between employees and management via works councils (Zoghi et al., 2005) does not seem to enhance the innovative capacity in Germany.

5.4 Organisational flexibility as a link between ICT use and innovation success

In the regression results from Table 2, we present some weak evidence that technology use positively affects innovation success. The coefficient for ICTINV is significantly positive, albeit at the 10% level only. In the case of process innovations, however, this result may be driven by the necessity to increase overall investment for renewing processes.[9] The weak evidence of direct contributions of ICT use to innovations supports the view that ICT fosters innovation activities in firms mainly by contributing to organisational flexibility (as shown in the previous section). A

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[7] For an empirical assessment of the causal links between innovation and exports, see Ebling and Janz (1999) and Arnold and Hussinger (2005).

[8] The share of employees younger than 30 years is even significantly negative in the regressions for process innovations. A possible explanation for this odd result might be that the share of younger workers is particularly high in firms with less formalized production processes and therefore process innovations are difficult identify.

[9] This view is supported by the fact that investment in non-ICT capital goods (INVNONICT) enters significantly positive in the process innovation equation, too.

subset of these organisational adjustments, i.e. functional flexibility, directly contributes to innovation success.

The observation that innovation contributions of ICT run primarily via organisational flexibility is backed by further regressions reported in columns (2) and (3) in Table A4 in the Appendix. These regressions replicate the specifications from Table A3 with the exception that the flexibility measures are omitted from the set of regressors. The results show that an omission of the flexibility indicators leads to an increase and gain in terms of statistical significance of the coefficients for INVICT and PCWORK whereas, for example, the coefficient of INVNONICT or other coefficients are not affected or even decrease.

We exploit this latter finding for additionally using an IV approach to assess the innovation contributions of organisational flexibility. Wald-tests suggest that the extended set of ICT indicators (as employed in the specifications (2), (4) and (6) from Table 1) do not have any joint significant impact on the decision to innovate if we also include the flexibility indicators.[10] Therefore, we use the lagged ICT indicators INVICT, PCWORK, ICTTRAIN, INTRANET, and NETPC as instruments. Jointly with the theoretical arguments described in section 2 about the 'enabling' character of ICT, this result suggests that the ICT variables are suitable instruments for the flexibility indicators.[11]

As illustrated in Table A5a, the IV estimation leads to a higher and more significant coefficient of functional flexibility while outsourcing stays insignificant. This increase in the coefficient of functional flexibility means that those firms that decentralize decisions and introduce teamwork due to strong ICT use and investments are also more innovative.[12] This shows that indeed ICT increases innovation and absorptive capacities of firms mainly by supporting functional flexibility instead of a direct impact.[13]

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[10] The joint significance test yield a *p*-value of 0.126 in the product innovation equation and 0.304 in the process innovation equation.

[11] Endogeneity tests (Wu-Hausman *F*-test and Durbin-Wu-Hausman χ^2-test) indeed confirm that our flexibility measures are endogeneous.

[12] See Card (2000) for a theoretical treatment of the interpretation of instrumented variables. An alternative reason for the increase in the IV coefficients probably is that the flexibility indicators are measured with error and therefore are negatively biased (Griliches and Hausman, 1986). By adding additional information on the type of firms that are flexible this bias is reduced.

[13] Several tests and sensitivity checks support the validity of our IV approach. Correlations between instruments and flexibility measures are strong (see Staiger and Stock, 1997) – the ICT indicators are jointly and individually frequently highly significant predictors of outsourcing and functional flexibility (compare Table A5b). Sargan tests of overidentification do not reject the validity of our instruments. Finally, we check the robustness of our results estimating the innovation propensities in a linear

6 Conclusions

This paper investigates to what extent the usage of ICT fosters innovation activities by facilitating more flexible organisational structures in firms. ICT is seen as multi-purpose or enabling technology that possibly plays different roles in enterprises. We focus on functional flexibility, proxied by a comprehensive measure including the share of employees in team work, job rotation, profit centres and quality circles, and numerical flexibility, proxied by a firm's decisions to outsource business processes and to buy a high proportion of intermediate goods and services from external suppliers.

Our results from a large and representative data set of firms in Germany show that an intensive ICT use and high investments in ICT are associated with an increase in both types of flexibility. Flexibility requires higher transaction and coordination efforts either between employees (functional flexibility) or between firms (numerical flexibility). As ICT reduces these co-ordination and transaction costs, it raises the incentives of firms to adopt flexible organisational forms. Functional flexibility is especially supported by the presence of an Intranet, a high share of employees using a PC, by ICT training and by the development of new products and services as a goal for ICT investments. In contrast, numerical flexibility is driven by usage of the Internet and ICT investments motivated by reductions of personnel costs.

The impacts of both flexibility types on innovation activities also differ. Functional flexibility significantly increases the probability of product and process innovations in subsequent periods by more than 10 percent. Outsourcing, by contrast, leads to contemporaneous product innovations but there is no statistically significant product innovation effect in the long run. We interpret this result as evidence that outsourcing is frequently used to buy new and innovative intermediates that directly help to improve own products and services but that have no impact on own generic product innovation activities. Outsourcing leads to more process innovations after a time lag, however. Apparently, firms optimise their internal organisation structures and processes some time after the outsourcing contract.

These results are robust with respect to various tests and sensitivity checks. Outsourcing and functional flexibility are endogeneous in the innovations estimations. Using several ICT indicators

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probability model by OLS in order to allow for a direct comparison of the coefficients in the IV approach which is also based on a linear model. Compared to the Probit model, the coefficients of the as instruments for both types of flexibility, we find that ICT is an important enabling technology for functionally flexible firms to innovate. It only plays a neglectable direct role for innovations, however.

Overall, our representative empirical results highlight that organisational adjustments are a crucial way by which ICT contributes to innovation activities in the overall economy. ICT lowers the cost of communication and coordination both between employees and between firms. This helps firms to adopt more flexible organisational structures that contribute to own innovation activities. Our study shows that in the longer run, these innovation effects persist only if the absorptive capacity is increased by team work and decentralisation of decision power.

flexibility indicators are smaller (see Table A6) but the significance levels are similar.

Appendix

Table A1: Descriptive Statistics

Variable	Means	Description
INTERMED	0.347	share of intermediate goods in sales in 2001
INTERMED03	0.346	share of intermediate goods in sales in 2001
OUTSOURC	0.268	outsourcing in period 1999-2001 (yes/no)
OUTSOURC04	0.248	outsourcing in period 2001-2003 (yes/no)
SHARE INDEPENDENT WORK GROUPS	0.323	share employees involved in independent work groups end of 2002
SHARE INDEPENDENT WORK GROUPS 04	0.314	share employees involved in independent work groups end of 2004
SHARE TEAMWORK	0.225	share employees working in autonomous teams end of 2002
SHARE TEAMWORK 04	0.231	share employees working in autonomous teams end of 2004
SHARE QUALITY CIRCLES 04	0.205	share employees involved in quality circles
GROUP04	0.618	existence of independent work groups 2004 (yes/no)
TEAM04	0.384	existence of Team work 2004 (yes/no)
CIRCLE 04	0.421	existence of Quality circles 2004 (yes/no)
ROTATION 04	0.178	existence of Job rotation 2004(yes/no)
PCWORK	0.507	share of employees mainly working at a PC
INVICT	1836.238	log of investment in ICTin € per employee 2001
INVNONICT	14275.650	investment in non-ICTin € per employee 2001
HIGHQUAL	0.201	share of employees with university degree 2001
LOWQUAL	0.555	share of employees with *Fachschul* degree or vocational training 2001
APPRENT	0.056	share of apprentices in total number of employees
INCENTIVE	0.284	share of workers receiving performance-based remuneration
U30	0.280	share of employees 30 years and younger
EXP	0.548	exporting firm (yes/no)
AGE3	0.152	firm aged 3 years or less in 2001 (yes/no)
AGE7	0.747	firm aged 4-7 years or less in 2001 (yes/no)
GROUP	0.356	firm is part of group of companies (yes/no)
WORKSCOUNCIL	0.345	works council (yes/no)
EAST	0.221	firm located in East Germany (yes/no)
ICTTRAIN	0.143	share of workers involved in ICT-specific training in 2001
INTRANET	0.419	firm disposes of Intranet (yes/no)
NETPC	0.646	number PCs connected to networks relative to number of employees
GOAL_QUAL	0.537	firm uses ICT for development of new products
GOAL_PCOST	0.625	firm uses ICT for saving payroll costs

Values from 2002 if not stated otherwise; yes/no indicates dummy variable. Sample values reported. Source: ZEW ICT surveys 2002 and 2004.

Table A2: Correlations between measures of ICT use

	INVICT	PCWORK	ICTTRAIN	NETPC	INTRANET
INVICT	1.000				
PCWORK	0.445	1.000			
ICTTRAIN	0.325	0.375	1.000		
NETPC	0.457	0.541	0.308	1.000	
INTRANET	0.200	0.179	0.220	0.200	1.000

Table A3: Ordered Probit estimation of individual functional flexibility measures

Variable	Functional Flexibility		Functional Flexibility extended	
	coeff.	s.e.	coeff.	s.e.
PCWORK	0.385***	0.144	0.200	0.151
INVICT	0.102***	0.032	0.067**	0.033
INVNONICT	0.068***	0.025	0.069***	0.026
HIGHQUAL	-0.292	0.221	-0.463**	0.232
LOWQUAL	-0.422**	0.171	-0.429**	0.173
APPRENT	0.866*	0.525	0.714	0.547
INCENTIVE	0.432***	0.099	0.407***	0.100
U30	0.551***	0.187	0.542***	0.189
EXP	0.101	0.091	0.063	0.090
AGE3	-0.153	0.149	-0.144	0.149
AGE7	-0.220*	0.130	-0.187	0.129
GROUP	0.207***	0.079	0.179**	0.081
WORKSCOUNC	0.202**	0.098	0.179*	0.098
EAST	-0.078	0.085	-0.064	0.086
SIZE20-50	0.245***	0.093	0.263***	0.095
SIZE51-200	0.583***	0.101	0.590***	0.102
SIZE201-500	0.659***	0.153	0.630***	0.156
SIZE501-1000	1.001***	0.200	0.989***	0.209
SIZE>1000	1.498***	0.242	1.557***	0.247
ICTTRAIN			0.536***	0.194
INTRANET			0.168**	0.084
NETPC			0.097*	0.059
GOAL_QUAL			0.223***	0.078
GOAL_PCOST			0.018	0.077
14 sectors	yes		yes	
Pseudo R^2	0.104		0.114	
N	928		922	

Significance levels: ***<0.01, **<0.05, *<0.1, heterogeneity robust standard errors

Table A4: Additional Innovation Estimations

	(1) Product innovations, contemporary effects		(2) Product innovations, lagged effects		(3) Process innovations, lagged effects	
	coeff.	s.e.	coeff.	s.e.	coeff.	s.e.
INTERMED	0.023	0.186				
OUTSOURC	0.281***	0.080				
FUNCFLEX	0.099***	0.038				
PCWORK	0.272**	0.138	0.322*	0.184	0.060	0.184
INVICT	0.049*	0.028	0.085**	0.040	0.110***	0.041
INVNONICT	0.027	0.020	-0.007	0.033	0.054	0.034
HIGHQUAL	0.436*	0.225	0.469	0.295	0.057	0.301
LOWQUAL	0.004	0.150	-0.341*	0.207	-0.224	0.213
APPRENT	1.096**	0.498	-0.312	0.637	1.145*	0.625
INCENTIVE	0.246**	0.103	0.230*	0.131	0.180	0.134
U30	0.120	0.184	0.043	0.251	-0.382	0.242
EXP	0.544***	0.078	0.339***	0.104	0.145	0.109
AGE3	0.037	0.142	-0.027	0.186	-0.023	0.194
AGE7	0.142	0.117	0.037	0.153	-0.139	0.154
GROUP	0.054	0.081	0.179*	0.107	0.031	0.108
WORKSCOUNC	0.090	0.092	0.169	0.128	0.165	0.130
EAST	0.031	0.087	-0.066	0.112	-0.147	0.113
SIZE20-50	0.167*	0.088	0.226*	0.116	0.079	0.115
SIZE51-200	0.336***	0.096	0.342***	0.131	0.424***	0.132
SIZE201-500	0.387***	0.139	0.518***	0.200	0.688***	0.207
SIZE501-1000	0.283	0.188	0.453*	0.264	0.455*	0.272
SIZE>1000	0.371*	0.217	0.517	0.319	0.936**	0.382
Constant	-0.032	0.349	0.324	0.465	1.576***	0.488
14 Sectors	yes		yes		yes	
Pseudo R^2	0.176		0.162		0.109	
N	1706		949		951	

Significance levels: ***<0.01, **<0.05, *<0.1, heterogeneity robust standard errors.

Table A5a: Instrumental Variable Innovation Estimations

	Product innovations, IV		Process innovations, IV	
	coeff.	s.e.	coeff.	s.e.
OUTSOURC	-0.060	0.404	-0.025	0.389
FUNCFLEX	0.312**	0.158	0.279*	0.146
INTERMED	-0.15	0.114	-0.257**	0.107
INVNONICT	0.01	0.012	0.035***	0.012
HIGHQUAL	-0.081	0.206	-0.244	0.198
LOWQUAL	-0.179*	0.092	-0.122	0.087
APPRENT	-0.062	0.247	0.278	0.234
INCENTIVE	-0.059	0.069	-0.069	0.065
U30	-0.169	0.129	-0.315***	0.121
EXP	0.140**	0.062	0.086	0.060
AGE3	-0.034	0.074	-0.006	0.071
AGE7	0.013	0.069	-0.032	0.066
GROUP	0.008	0.051	-0.042	0.049
WORKSCOUNC	0.075	0.053	0.07	0.050
EAST	-0.028	0.043	-0.037	0.041
SIZE20-50	0.022	0.052	-0.012	0.049
SIZE51-200	0.015	0.068	0.044	0.063
SIZE201-500	0.058	0.088	0.089	0.085
SIZE501-1000	0.088	0.105	0.038	0.100
SIZE>1000	-0.066	0.15	0.011	0.140
Constant	0.861 **	0.334	1.221***	0.315
14 sectors	yes		yes	
N	858		859	

Significance levels: ***<0.01, **<0.05, *<0.1, heterogeneity robust standard errors.

Table A5b: First Step Results in Instrumental Variable Innovation Estimations

	Product innovation				Process innovation			
	OUTSOURC		FUNCFLEX		OUTSOURC		FUNCFLEX	
	coeff.	s.e.	coeff.	s.e.	coeff.	s.e.	coeff.	s.e.
INTERMED	0.039	0.081	0.465***	0.171	0.041	0.081	0.460***	0.171
INVNONICT	-0.013	0.011	-0.038	0.023	-0.013	0.011	-0.038	0.023
HIGHQUAL	-0.170*	0.097	0.617***	0.205	-0.179*	0.097	0.641***	0.204
LOWQUAL	-0.087	0.070	0.049	0.146	-0.086	0.070	0.046	0.146
APPRENT	0.018	0.213	-0.037	0.449	0.021	0.213	-0.044	0.449
INCENTIVE	0.059	0.042	0.389***	0.089	0.058	0.042	0.393***	0.089
U30	0.020	0.081	0.562***	0.169	0.018	0.080	0.565***	0.170
EXP	0.101***	0.035	-0.069	0.074	0.101***	0.035	-0.071	0.074
AGE3	-0.056	0.061	-0.023	0.129	-0.056	0.061	-0.023	0.129
AGE7	-0.099**	0.050	-0.042	0.106	-0.100**	0.050	-0.040	0.106
GROUP	0.118***	0.034	0.199***	0.072	0.118***	0.034	0.200***	0.072
WORKSCOUNC	0.049	0.041	-0.057	0.086	0.048	0.041	-0.055	0.086
EAST	0.019	0.037	0.059	0.078	0.020	0.037	0.056	0.078
SIZE20-50	0.004	0.039	0.168**	0.081	0.004	0.039	0.170**	0.081
SIZE51-200	0.045	0.042	0.379***	0.089	0.044	0.042	0.379***	0.089
SIZE201-500	0.009	0.061	0.341***	0.129	0.005***	0.061	0.354***	0.128
SIZE501-1000	0.225***	0.081	0.453***	0.170	0.225	0.081	0.453***	0.170
SIZE>1000	0.027	0.102	0.616***	0.216	0.028**	0.102	0.615***	0.216
INVICT	0.029**	0.013	0.059**	0.028	0.029	0.013	0.059**	0.028
PCWORK	-0.099	0.062	0.108	0.131	-0.097	0.062	0.102	0.131
ICTTRAIN	0.162**	0.078	0.600***	0.164	0.151**	0.077	0.627***	0.162
INTRANET	-0.047	0.034	-0.016	0.073	-0.044	0.034	-0.023	0.072
NETPC	0.058**	0.028	0.028	0.059	0.059**	0.028	0.027	0.060
Constant	0.524	0.159	-0.843	0.335	0.525	0.159	-0.846	0.335
14 sectors	yes	yes	yes	yes	yes	yes	yes	yes
N	858	858	858	858	858	858	858	858

Significance levels: ***<0.01, **<0.05, *<0.1, heterogeneity robust standard errors.

Table A6: OLS Innovation Estimations

	Product innovations, OLS		Process innovations, OLS	
	coeff.	s.e.	coeff.	s.e.
OUTSOURC	0.025	0.035	0.084**	0.034
FUNCFLEX	0.050***	0.017	0.048***	0.016
INTERMED	-0.042	0.082	-0.154*	0.079
INVNONICT	0.009	0.011	0.033***	0.010
HIGHQUAL	0.180**	0.091	0.004	0.087
LOWQUAL	-0.120*	0.069	-0.082	0.066
APPRENT	-0.010	0.215	0.265	0.206
INCENTIVE	0.047	0.043	0.022	0.041
U30	-0.026	0.082	-0.177**	0.079
EXP	0.113***	0.035	0.066*	0.034
AGE3	-0.046	0.062	-0.012	0.060
AGE7	0.004	0.051	-0.031	0.049
GROUP	0.058*	0.035	-0.012	0.034
WORKSCOUNC	0.064	0.041	0.051	0.039
EAST	-0.031	0.037	-0.04	0.036
SIZE20-50	0.066*	0.039	0.021	0.037
SIZE51-200	0.100**	0.042	0.119***	0.041
SIZE201-500	0.141**	0.060	0.162***	0.057
SIZE501-1000	0.178**	0.080	0.115	0.077
SIZE>1000	0.094	0.104	0.154	0.100
Constant	0.530***	0.127	0.911***	0.122
14 sectors	yes		yes	
Pseudo R^2	0.213		0.133	
N	875		877	

Significance levels: ***<0.01, **<0.05, *<0.1, heterogeneity robust standard errors

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