ICT, Complementary Firm Strategies and Firm Performance

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Eidesstattliche Erklärung

Hiermit erkläre ich, die vorliegende Dissertation selbständig angefertigt und mich keiner anderen als der in ihr angegebenen Hilfsmittel bedient zu haben. Insbesondere sind sämtliche Zitate aus anderen Quellen als solche gekennzeichnet und mit Quellenangaben versehen.

Mannheim, 04.04.2016 Fabienne Rasel

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Chapter 1

Introduction

Modern information and communication technologies (ICT), such as software applications or the Internet, have reduced transaction costs and enabled new forms of how firms can store, access and analyse information as well as how they can communicate within firm boundaries and with external business partners and customers. Consequently, while the adoption of ICT represents an innovation to the adopting firm, the use of ICT is recognized to have the potential to boost productivity and further innovation. However, the diffusion of ICT and the associated potential gains from using ICT will likely differ across firms from different industries, and even for firms within single industries, given implementation costs of ICT in addition to different absorptive capacities and capabilities of firms. Therefore, the adoption of ICT and ICT-enabled gains will likely depend on industry and firm characteristics. Investigating the interactions between ICT use, complementary firm strategies and productivity with a particular focus on the differences between the manufacturing and service sector is the common theme of this thesis.

The thesis covers three self-contained essays that all present empirical analyses applying microeconometric methods on data of firms from the manufacturing and service sector in Germany. Chapter 2 analyses the relationship between ICT use, workplace organization and productivity. Chapter 3 and 4 consider explicitly firms' international activities by examining the relationship between ICT use, productivity and activities on international markets in terms of exporting and importing, respectively in these two chapters. The appendices of each chapter with additional materials, such as robustness checks of the empirical analyses or additional explanations, are included immediately after each chapter. The bibliography with all the references of each chapter is at the end of the thesis.

The main data used for all empirical analyses in this thesis are from various waves of the ZEW ICT survey that is conducted by the Centre for European Economic Research (ZEW). The focus of the ICT survey is on the diffusion and use of ICT and it addresses firms from different industries and with different firm sizes. The majority of surveyed firms belongs to the group of small- and medium-sized firms (SMEs in the following), i.e. firms with at most 250 employees. This composition of firm sizes in the data corresponds to the firm size distribution of the German economy since in 2013 99.3 percent of all firms belonged to the group of SMEs and those firms employed more than 60 percent of all employees in Germany (Statistisches Bundesamt 2013).

All empirical analyses in this thesis take into account firms' use of enterprise software systems, such as enterprise resource planning software. Enterprise software systems are one important group of ICT applications by firms because they provide a computer-based backbone for various kinds of information from within and from outside the firm boundaries. The features of enterprise software enable firms to use new forms of information storage and analysis, which may optimally lead to a more efficient use of information than prior to their use, and to positive performance effects. Further ICT applications considered in this thesis are measures reflecting the use of computers or the Internet by employees and in Chapter 4 also electronic commerce (e-commerce in the following) applications are considered. Like enterprise software, computer and Internet use as well as e-commerce are attributed to spur performance gains as they help reduce transaction and coordination costs and enable new forms of coordination with suppliers and customers.

The central goal of this thesis is to shed light on the heterogeneity of the interactions between ICT use, complementary firm strategies and firm performance by taking account of firms from different industries and with different characteristics, such as firm size. From a policy perspective, knowing about reasons for a heterogeneous impact of ICT and about conditions under which ICT are most effective is essential to design policy measures and to target policies to special groups of firms, which might need them most, such as SMEs. From a theoretical perspective, the understanding of the contingencies, under which ICT are relevant for firm strategies and for firm performance outcomes, helps evaluate the applicability of theoretical predictions for firms from different sectors or with different characteristics as well as potentially guide the development of new theories.

The discussion about heterogeneity in the impact of ICT on economic performance has been initiated by empirical findings. On the one hand, empirical results have shown long-term growth contributions of ICT that were higher than the share of ICT capital in gross output, which can be rationalized by a complementary relation between ICT and other input factors, such as organizational capital (e.g. Brynjolfsson and Hitt 2003); on the other hand, productivity and growth returns from ICT capital have found to be higher in the U.S. than in European countries and also heterogeneous between manufacturing and service industries (e.g. Timmer et al. 2010). These findings have inspired empirical analyses on the importance of complementary factors to ICT use that may enhance the productivity of ICT. In particular, existing empirical work points to the relevance of decentralized workplace practices, which provide employees with more decision autonomy and responsibility for their work, for an effective use of ICT capital (e.g. Bresnahan, Brynjolfsson, and Hitt 2002; Bloom, Sadun, and Van Reenen 2012).

Chapter 2 addresses this complementary relationship between ICT use and decentralized workplace practices for firms of different size. Prior research shows that smaller firms benefit less from ICT use in terms of productivity than larger firms and one potential reason is suggested to be differences in complementary factors, such as work organization, between firms of different size (Tambe and Hitt 2012). However, empirical evidence for differences in the complementary relationship between ICT and organizational factors across firm size is lacking. Having suitable data, I evaluate this complementarity relationship by comparing empirical results for SMEs to results for larger firms. For the empirical analysis, I conduct correlation and productivity analyses. ICT is captured by firms' usage intensities of different enterprise software systems. In line with prior evidence, the results show that SMEs have on average lower productivity contributions of ICT than larger firms. Moreover, only for larger firms does the ICT productivity contribution depend on decentralized workplace organization. Even though I find that SMEs that apply decentralized workplace practices use ICT more intensively, my results of the productivity analysis suggest that they do not benefit from the combined use of ICT and decentralized workplace practices like larger firms do. The results for manufacturing and service firms separately are mainly similar. Overall, the findings provide new firm-level evidence for the heterogeneity of ICT contributions to performance outcomes with respect to workplace organization and to firm size. These results are consistent with the notion that smaller firms sometimes benefit less from certain ICT than larger firms. The results underline that policy measures for a most effective ICT use should consider further firm strategies, such as workplace organization, and firm size.

In Chapter 3 and 4, I focus on firms' ICT use, their productivity levels and their international activities as well as on the distinction between manufacturing and service firms. ICT are viewed to facilitate international trade by lowering coordination costs across distance and facilitating foreign market access. In particular, the Internet is seen as an important factor to make service trade possible at all since digitally codified information can be transmitted over it. Firms' productivity is regarded as a key factor that determines entry into international markets. This role of productivity is modelled in theories of heterogeneous firms in international trade (e.g. Melitz 2003 for exporting; e.g. Antrás and Helpman 2004 for importing). Those theories are the common theoretical base in both chapters. They primarily aim at reflecting international trade behaviour of manufacturing firms, given the larger share of manufacturing trade in global trade volumes. However, in recent years service trade has expanded, which is partly attributed to the diffusion of the Internet (Freund and Weinhold 2002). Moreover, with the availability of data on firms trading services, the empirical analysis of characteristics of service trading firms has received more attention (e.g. Breinlich and Criscuolo 2011). Chapter 3 and 4 contribute to the literature on the relationship between technology and international trade as well as to the still rather small literature on service firms' trade. Both chapters inform about whether predictions of heterogeneous firm models of international trade, targeted at manufacturing firms, can also be empirically supported by trade behaviour of service firms.

Chapter 3, which is co-authored with Irene Bertschek and Jan Hogrefe, assesses the validity of recent theories of gains from trade liberalization through technology adoption by expanding exporting firms (e.g. Lileeva and Trefler 2010; Bustos 2011). These theories rely on strict assumptions regarding the productivity sorting of firms with different technology levels. This sorting is based on the assumption that firms face different cost-benefit trade-offs of technology adoption depending on their firm size in terms of market volume. As trade liberalization may be a source of market expansion, some firms will then find it profitable to invest in the new technologies. First evidence for the plausibility of such a productivity sorting across technology and export status for German firms is based on using research and development (R&D) expenditures as a measure for technology use (Wagner 2012; Vogel and Wagner 2013). We complement this research by testing the sorting of German firms based on data on actually implemented technologies, which we measure by different levels of enterprise software systems. Such software systems can be seen as suitable proxies for the notion of advanced technologies in those theories of trade-induced technology adoption because the gains from adoption will likely depend on firm size. Thus, this chapter examines the role of heterogeneity in ICT adoption according to export status and its relationship to productivity. For manufacturing firms, our results confirm the sorting pattern of the most productive firms being high-tech exporters, followed by low-tech exporters and then domestic low-tech firms. For services, the evidence is mixed. Therefore, we conclude that the productivity sorting across export status and technology level potentially depends on the tradability of the considered services and that recent heterogeneous firm models of exporting and trade-induced technology adoption seem to reflect better international trade behaviour of manufacturing firms than of service firms.

In Chapter 4, I investigate the frequently mentioned argument that ICT are a relevant factor for the increase in international trade in intermediate inputs because ICT may lower costs associated with trading across borders, such as communication costs. Thus, more ICT-intensive firms will be more likely to source inputs from abroad (Abramovsky and Griffith 2006). Furthermore, heterogeneous firm models of importing predict that more productive firms are more likely to import inputs (e.g. Antrás and Helpman 2004). I evaluate those predictions by analysing the relevance of different ICT applications and of productivity for firms' probability of global sourcing of inputs for manufacturing and service firms separately. As prior research has focused on manufacturing firms, my empirical analysis provides first evidence for the role of ICT and of productivity for global sourcing activities of service firms. The empirical findings show some differences between the manufacturing and service sector. Controlling for various sources of firm heterogeneity, firms in the manufacturing sector are more likely to import inputs when more of their employees have Internet access within the firm. Moreover, firms that use more channels of e-commerce are more likely to source inputs from abroad but generally, this relationship between e-commerce and global sourcing is only robust in services and much stronger there than in manufacturing. In both sectors, it is strongest in industries with higher upstream industry diversity in terms of the number of distinct industries an industry sources inputs from. This finding supports the view that ICT seem to be particularly relevant for coordination across distance in industries with many suppliers and therefore, with potentially high coordination costs. Moreover, labour productivity is positively related to global sourcing in the manufacturing and in the service sector. This result suggests that the assumption in heterogeneous firm models of importing that more productive firms are more likely to import is plausible for firms from both sectors.

Chapter 2

Combining Information Technology and Decentralized Workplace Organization: SMEs versus Larger Firms*

2.1 Introduction

Information and communication technologies (ICT) have been important drivers of productivity growth and innovation over the last 20 years.[1] Moreover, empirical evidence has shown that ICT productivity returns are not identical across firms and countries but they may vary depending on different workplace organization and human resource practices (e.g. Bresnahan, Brynjolfsson, and Hitt 2002; Bloom, Sadun, and Van Reenen 2012). Thus, a key conclusion from this evidence is that effective use of ICT should be accompanied with appropriate workplace organization. In particular, workplace practices that allow for decentralized decision making and reward individual effort have turned out to

[1] See for a recent literature review, e.g. Draca, Sadun, and Van Reenen (2007), Bertschek (2012) and Cardona, Kretschmer, and Strobel (2013).

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improve the effective use of ICT. However, most of the empirical evidence is from large firms, mainly due to data availability, and it remains an open question whether the findings on effective implementation of ICT can be generalized for smaller firms. Generally, firms of different size may differ in their ability to employ ICT or they may have made different levels of complementary organizational investments (Tambe and Hitt 2012).

In this chapter, I test the hypothesis on the complementarity between information technology (IT) and decentralized and incentive-based workplace organization for small and medium-sized firms (SMEs) and I compare the results from the sample of smaller firms to those from larger firms. The empirical analysis sheds light on the relationship between IT use, work organization practices and productivity for firms of different size. The data used in this chapter are a unique sample of 3288 SMEs and 595 larger firms from the manufacturing and service sector in Germany. It is an unbalanced panel covering the years 2004, 2007 and 2010. For the empirical analysis of the relationship between IT and workplace organization and their productivity contributions, I proceed in two steps. First, I analyse by conditional correlation regressions whether firms with decentralized and incentive-based workplace practices are more IT intensive. Second, I examine the productivity impacts of these two factors by estimating a Cobb-Douglas production function that is augmented by IT and workplace organization as additional inputs and that allows for interaction effects between these two inputs.

My main measure for firms' IT intensity is the firms' usage intensity of enterprise software systems. The enterprise software systems considered are enterprise resource planning (ERP), supply chain management (SCM) and customer relationship management (CRM), which are generally among the most widely diffused enterprise software systems. Such systems assist firms in collecting, storing and using information in the value creation process. Therefore, they can be viewed as good proxies to capture the improved information availability through modern IT. Additionally, firms' IT intensity is taken account of by the share of employees using mainly computers for work. Decentralized workplace organization is measured by the existence of a business unit with own profit and loss responsibility and self-responsible team work. Moreover, firms' use of performance pay is considered as another measure whether firms set incentives and remunerate good performance.

To the best of my knowledge, the empirical analysis in this chapter presents the first analysis on complementarity between IT and decentralization that compares findings from smaller firms to those from larger firms. Even though Tambe and Hitt (2012) compare IT returns between midsize and large firms, they cannot include workplace organization in their productivity analysis due to data limitations. The comparison between SMEs and larger firms allows an examination of whether findings from large firms are valid for firms of smaller size, too. There might be reasons to expect the complementarity of IT and decentralization not to be present for small firms because of different IT usage ability and different levels of IT-related complementary investments across firm size, such as skills or appropriate workplace organization (Tambe and Hitt 2012; Giuri, Torrisi, and Zinovyeva 2008). Small firms might on average have lower demand for IT-related complements, for instance, due to a smaller amount of information that has to be processed and coordinated (Giuri, Torrisi, and Zinovyeva 2008). Moreover, the chapter contributes to a better understanding of the role of IT, workplace organization and their interactions in explaining productivity differences among firms of smaller size, given that there is little evidence on the productivity contributions of combining these two factors for smaller firms.

My results show that in line with the complementarity hypothesis, SMEs with a decentralized workplace organization and performance pay use IT more intensively. Large firms are only significantly more IT intensive when using performance pay. Although both, IT and decentralization, are individually associated with higher SME productivity, the results do not reveal robust evidence for a productivity contribution from combining IT and decentralization. Only the combination of IT and performance pay is weakly associated with higher productivity for SMEs. In contrast, the results for large firms show a significant productivity contribution for the combination of IT and decentralization as it has already been found in prior research. The comparison of the results for SMEs and larger firms suggests that only larger firms benefit from combining IT and decentralized workplace organization.

The remainder of this chapter is organized as follows: The next section 2.2 gives an overview of the key insights from the literature on IT productivity. The focus is on the complementary relation between IT and organizational practices and on enterprise software systems. The third section 2.3 presents the data and descriptive statistics. Section 2.4 illustrates the empirical methods to test for complementarity. Section 2.5 discusses the empirical results, conducts robustness checks and shows results separately for manufacturing and service firms. Section 2.6 concludes with suggestions for future research.

2.2 Literature and background discussion

ICT productivity returns have been shown to vary across countries and firms, and this has been summarized in the so-called "productivity puzzle" of ICT.[2] One explanation for the measured heterogeneity in the productivity contributions of ICT is seen in different levels of complementary organizational investments, such as workplace organization, particularly decentralization and incentive-setting, and business process re-engineering across firms and countries. This interdependence between ICT and appropriate workplace practices and organization is summarized in the hypothesis on complementarity between ICT and workplace organization. According to the seminal paper on production complementarities by Milgrom and Roberts (1990), organizational factors are defined to be complements when there are nonconvexities with respect to the output function in a firm's decision whether to adopt any or all of a group of activities that complement new technologies.[3]

Generally, an organizational structure can be characterized as decentralized if the top management not only has decision making authority but also employees at lower levels of the hierarchy so that decision making is spread more evenly throughout the firm in contrast to a centralized firm where decisions are only made at the top of the organizational hierarchy.[4] Possible benefits of decentralization are the reduction of information transfer and communication costs and increased speed of reacting to market changes. Since modern IT reduces information access and processing costs, it is seen as one determinant for decentralization.[5] This view is empirically supported by Bloom et al. (2014) who show that information technology increases worker and plant manager autonomy. A complementary relationship between IT and a decentralized workplace organization is optimal if knowledge, that is valuable for firm performance, is held by employees but is difficult to transmit, and information overload puts a constraint on the amount of information that can be processed by decision makers at the top of the hierarchy (Hitt and Brynjolfsson 1997). Decentralization of decision rights implies decentralization of information processing and especially large firms may implement it, given limited capacity of individuals for information-processing and decision making (Radner 1993).

[2] For a short discussion about that argument, see, e.g., Bloom, Sadun, and Van Reenen (2010).

[3] See Brynjolfsson and Milgrom (2013) for an overview of the theory behind organizational complementarities, a definition and empirical studies analysing complementarities between IT and workplace variables.

[4] For an overview about the concept of decentralization in economics, see, e.g., Bloom, Sadun, and Van Reenen (2010). The following discussion about decentralization and its relationship to ICT is based on it.

[5] The mechanism of reduced information costs causing firms to decentralize is theoretically formalized by Garicano (2000). In his model, the firm is conceptualized as a cognitive hierarchy that has to solve problems of varying difficulty and optimally decentralizes with decreasing information costs.

Several studies highlight the importance of decentralized workplace organization and incentive setting for good performance in order to derive the full potential of IT. One of the first empirical studies on the relationship between IT and workplace organization is by Bresnahan, Brynjolfsson, and Hitt (2002) who find that the productivity of IT in large U.S. firms is higher if firms also use workplace practices that allow for decentralized decision making by teams and employees. Black and Lynch (2001) show that U.S. plant productivity is improved the higher is the share of non-managers using the computer is. Tambe, Hitt, and Brynjolfsson (2012) find that the combination of IT, decentralization and external focus, which captures a firm's intensity of focus on observing the market environment and efforts to uncover market opportunities, is associated with significantly higher productivity for moderate-sized and large U.S. firms. Bloom, Sadun, and Van Reenen (2012) argue that the U.S. advantage in IT-related productivity effects in comparison to Europe, that has been observed from the mid-1990s, can be attributed to differences in work and human resource practices between the U.S. and Europe: They show that people management practices, which foster individual target setting, promotions and rewards, are complementary to IT capital and that U.S.-owned firms employ such practices more intensively than European firms. Mahr and Kretschmer (2010) show that German manufacturers with an explorative learning type have higher IT productivity returns with greater degree of decentralization.

Evidence on ICT productivity returns and organizational complementarities in SMEs is still scare. Tambe and Hitt (2012) find higher long-run IT returns on average for large than for midsize U.S. firms. No evidence for complementarity between ICT and decentralized workplace practices is found for Swiss firms, mainly SMEs (Arvanitis 2005). Bugamelli and Pagano (2004) argue that the lack of complementary investments in organizational capital and human capital have acted as barriers to investment in ICT for Italian manufacturing firms, among them mainly SMEs. Also for Italian firms, mainly SMEs from the manufacturing sector, Giuri, Torrisi, and Zinovyeva (2008) find no evidence for productivity gains from combining IT and organizational change.

Enterprise software systems are a particular type of information technology applications. Enterprise resource planning (ERP), supply chain management (SCM) and customer relationship management (CRM) are three widely employed systems. While ERP is a general purpose software aimed at managing information from various business processes inside the firm more efficiently, SCM and CRM software provide support for specific business processes of the value chain. SCM software capabilities help organizing the value chain and operations management in contact to suppliers or buyers. CRM software provides tools to systemize customer relationship management with the aim to improve customer satisfaction and customer loyalty. These software systems have changed drastically how firms can store, access, share, exchange and analyse information relevant for business operations. In particular, these systems have increased the speed of information gathering and availability and they feature an integrated database. Consequently, the improved information basis should support firms in making more solid decisions and in particular, in reacting in a more timely way to problems and market trends.[6]

Few econometric studies assess the performance effects of enterprise software systems using firm-level data from a larger sample of firms.[7] The existing evidence is mixed, although, pointing towards a positive relationship between the use of some of the systems and performance (e.g. Shin 2006; Aral, Brynjolfsson, and D. Wu 2006; Engelstätter 2013). Considering also workplace organization, López (2012) finds that CRM use and organizational change are complementary in Spanish firms from the manufacturing and service sector, while no significant productivity increase is found for the combination of ERP use with organizational change. Aral, Brynjolfsson, and L. Wu (2012) show that the combination of human resource practices, which monitor employees' performance, and performance pay complements special software for human capital management, which is often part of an ERP system.

2.3 Data and variable construction

The data used for the analysis come from three waves of the ICT survey collected from the Centre for European Economic Research (ZEW).[8] The ICT survey is a firm-level survey with the focus on the diffusion and the use of ICT of firms from the manufacturing and service sector located in Germany for firms with five or more employees. Moreover, the survey provides detailed information about further firm characteristics, like skill composition or export activities and performance measures like total sales. The survey has been until now conducted six times: for the first time in 2000, then in 2002, 2004, 2007, 2010 and in 2014. For each wave roughly 4400 firms were surveyed by telephone and the data are stratified according to industries, to three size classes and to two regions (East/West Germany). As the survey is constructed as an unbalanced panel, some firms were sur-

[6] See, e.g., Hendricks, Singhal, and Stratman (2007), Engelstätter (2013) and Bloom et al. (2014) (for ERP) for more information about properties and benefits of enterprise software systems. The discussion about enterprise software systems in this chapter is based on these papers.

[7] However, there is a large literature, generally from the Information Systems (IS) and business studies literature, on qualitative assessments of enterprise software systems and case study based evidence, often for one specific enterprise software system. This literature is not discussed here.

[8] The data are accessible at the ZEW Research Data Centre: http://kooperationen.zew.de/en/zew-fdz/home.html

veyed in each wave, others only in certain waves and others only once.[9] With respect to the topics and questions asked, some questions are repeated in each wave, while others were only asked in some of the waves.

For the analysis in this chapter, I use data from the waves of 2004, 2007 and 2010 because from 2004 onwards information on both, enterprise software use intensity and workplace organization, is available. The time frame of the data represents the diffusion of ICT after 2000, where at least basic ICT, such as the personal computer, might be already more widely diffused among firms. Firms may also have made different choices of complementary investments so that many combinations of IT and workplace organization might exist. Due to non-response on particular items affecting variables used in the empirical analysis and an unbalanced panel structure, there are 3883 firms in my estimation sample and an overall number of observations of 5250 is obtained.[10] Thus, in spite of having a panel data set, the majority of firms in the sample participated only once in the survey.[11]

Since one goal of the chapter is to compare results from smaller firms to those from larger firms, I divide the estimation sample according to employment size. Based on international classifications, the maximum employment level for a firm to be an SME is not more than 250.[12] Therefore, all firms with at most 250 employees are classified as SMEs. Those firms with exactly 250 employees are included because the descriptive statistics indicate that a large number of firms claim to have 250 employees, which in a telephone-based survey might be an answer given by the interviewee if she does not know the exact number but thinks 250 employees to be a a decent guess.[13] Based on this classification, 3288 firms are classified as SMEs with an overall number of 4487 observations. Thus, on average roughly 85 percent of the surveyed firms belong to the category of SMEs. The remaining 595 firms are classified as large firms with totally 763 observations. Table 2.14 in the appendix shows the sector composition of the estimation samples in comparison to

[9] The sample selection criteria for the ICT survey is that, in principle, each firm, that has been selected from the pool of addresses and has agreed to participate, is contacted again in the next consecutive survey. However, since participation is voluntary firms may decide not to participate again. Depending on the number of panel firms that agreed to answer the survey, new firms are contacted to reach a balanced industry composition for the surveyed industries within the cross section until roughly 4400 firms in total have been surveyed.

[10] This sample is based on a data set that excludes productivity outliers keeping only firms within the first and 99th percentile of the labour productivity distribution. Labour productivity is measured by total sales over the number of employees. In total, 51 observations are dropped.

[11] That is why the panel data structure is not exploited in the main empirical analysis presented in Section 2.4 and 2.5. A brief discussion of the results using panel data methods is given in the Appendix 2.7.4.

[12] See, e.g., the definition of SMEs by the European Commission: http://ec.europa.eu/enterprise/policies/sme/facts-figures-analysis/sme-definition/

[13] The empirical results presented in Section 2.5 do not change qualitatively when firms with exactly 250 employees are considered in the sample of large firms.

the totally available data of firms within the ICT survey both for those firms with 250 employees at most and for larger firms. Since the distribution across industries is very similar for the estimation samples and the complete data set, it can be assumed that the samples used are representative with respect to the industries covered. Moreover, Table 2.14 in the appendix shows that descriptive statistics for the main variables are very similar for firms in the estimation sample and for those firms that cannot be included due to item non-response. Tests on the equality of means by industry between these two data sets can mostly not be rejected, providing further confidence that the firms left out from the estimation sample due to item non-response, are missing at random.[14]

2.3.1 IT variables

The section on enterprise software systems in the survey covers whether firms use an ERP, a SCM or a CRM software asking the firms for no (0), minor (1) or broad (2) use. Table 2.1 shows the frequency distributions, means and standard deviations for the software use intensity of each software and correlations between them. Regarding the average use of the three software systems, i.e. without distinguishing between usage intensity, across all years 62 percent of the firms in the SMEs sample use ERP, followed by 43 percent using CRM and 35 percent using SCM. This order is plausible because ERP is the most general software among the three systems. For the sample of large firms, almost all firms use ERP (93 percent), and also CRM (72 percent) and SCM (72 percent) are widely diffused (Table 2.1). There is heterogeneity across large firms in the usage intensity. The mean usage intensity by large firms is slightly higher for all three software systems in comparison to the small firms. However, at least for SCM and CRM the variation in usage intensity according to the standard deviation is fairly similar for firms of both size categories.

To measure firms' IT intensity, an IT intensity indicator based on the usage intensity of these three enterprise software systems is constructed. Each factor is standardized individually through z-scoring and then the standardized factors are summed up and this sum is standardized again. The standardization S is obtained by subtracting the mean μ_x of the respective variable x within the overall sample and by dividing by the sample standard deviation SD_x of the variable. The following equation summarizes the construction of the IT intensity indicator:

[14]The results of the tests on the equality of means are reported in Table 2.15 in the appendix.

$$IT = S(S(ERP) + S(SCM) + S(CRM)) \tag{2.1}$$

$$S \cong \frac{x - \mu_x}{SD_x}$$

The standardized individual software values are aggregated into an aggregate IT indicator, which implies that each factor gets equal weight in the indicator. This is because the hypothesis for equality of coefficients among the three standardized software values cannot be rejected after a productivity regression when the standardized values are considered in regressions individually.[15] The standardization provides a normalized measure of enterprise software systems usage intensity for each firm that relates the individual firm's software intensity to the overall sample mean value and its dispersion. Firms with identical enterprise software use intensity for all three systems have the same value with respect to this indicator and higher values reflect that firms use more of the three systems considered and use the systems more intensively.

Table 2.1: Descriptive statistics of enterprise software use intensity

	Frequency distributions in %					Correlations		
Use intensity	ERP	SCM	CRM	Variable	Mean	ERP	SCM	CRM
				SMEs (N=4487)				
0 - No use	37.51	64.68	57.48	ERP	1.03	1		
	(1683)	(2902)	(2579)		(0.88)			
1 - Minor use	21.86	20.48	24.92	SCM	0.50	0.33	1	
	(981)	(919)	(1118)		(0.74)			
2 - Broad use	40.63	14.84	17.61	CRM	0.60	0.28	0.36	1
	(1823)	(666)	(790)		(0.77)			
				Large Firms (N=763)				
0 - No use	6.82	27.79	28.31	ERP	1.72	1		
	(52)	(212)	(216)		(0.58)			
1 - Minor use	14.02	37.48	44.17	SCM	1.07	0.25	1	
	(107)	(286)	(337)		(0.79)			
2 - Broad use	79.16	34.73	27.52	CRM	0.99	0.18	0.29	1
	(604)	(265)	(210)		(0.75)			

Data source: ZEW ICT Panel 2004, 2007, 2010. N stands for the number of observations; this abbreviation is also used in the subsequent tables. In parentheses: Total number of observations for use intensity (left part of the table), standard deviation for the mean values (right part of the table).

[15] The test for equality of coefficients is based on coefficient estimates from the regression specification in Table 2.6 for SMEs and Table 2.9 for large firms, column (3).

Regarding the interpretation of the indicator, this IT measure provides a picture of the intensity of a firm's reliance on information for decision making and for business process organization. Since enterprise software systems facilitate the gathering and analysis of information, they support decision making about product characteristics or strategic considerations, as well as helping to organize business processes more efficiently. Thus, this IT indicator captures the improved information availability enabled through IT, which is also part of the theoretical arguments behind the complementarity hypothesis between IT and workplace organization. Improved information use combined with workplace organization, which allows decentralized decision making and sets incentives for good performance, should be particularly beneficial for firms because information can be used in a timely way to recognize problems and trends. For instance, the information can be used to develop new products or services, which might increase productivity. Moreover, IT allows performance to be observed more easily.

Although this IT indicator only considers enterprise software use and so only captures a specific part of the firm's IT use explicitly, the advantage of its narrow scope is its economic interpretation as proxy for a firm's intensity of technology-supported use of information as an input into the production process. Even if this IT measure based on the enterprise software systems mismeasures a firm's IT intensity as well as the extent of the use of information in business processes, the measurement error is likely to bias the estimates downward for this indicator.[16] Moreover, firms with higher values of this indicator will likely also have a higher overall IT capital stock including hardware, all kind of software and telecommunication equipment, which will be needed to make the enterprise software systems work effectively. Therefore, this indicator can be interpreted as a proxy for a firm's aggregate IT intensity, too.

Nonetheless, it still might be that firms with low enterprise software use intensity are IT intensive (Type II error) when they use other types of IT intensively, such as the personal computer (PC). Since the data include information on a firm's share of employees working mainly at the computer, this information is used as an additional measure for a firm's overall IT intensity. The share of employees working mainly with the PC can be interpreted as a measure for IT capital or alternatively for labour heterogeneity (Bertschek and Meyer 2009). This IT measure captures part of a firm's hardware and software equipment as well as the extent of the firm's dependence on the computer as a working tool within its business model.

[16]See Tambe, Hitt, and Brynjolfsson (2012), p. 847, for a similar argument for their measure of external focus.

2.3.2 Workplace organization

To capture decentralized and incentive-based workplace practices that might be complementary to IT, I use binary information of three variables from the ZEW ICT survey, which are similar to variables used in prior work. First, I include the existence of a business unit with own profit and loss responsibility (BU), such as a profit centre. This measure of decentralization is helpful to capture formal delegation of power (Bloom, Sadun, and Van Reenen 2010). It refers particularly to the extent of decision autonomy and responsibility at the manager level below the central management board and it provides a measure of decentralization with respect to overall firm organization.[17] A similar measure for decentralization is used by Acemoglu et al. (2007) who define a firm as decentralized when its business units are organized as profit centres.[18] Second, information on the use of self-responsible team work (TW) is included, which reflects the transfer of decision autonomy to individuals and groups, and not only to managers. Firms' use of team work has also been employed in prior research to measure decentralized and team-oriented workplace practices (e.g. Bresnahan, Brynjolfsson, and Hitt 2002; Tambe, Hitt, and Brynjolfsson 2012). Third, performance pay (PP) is considered as a measure that indicates the firm's use of incentive setting to remunerate good performance. Even though, performance pay is not informative about whether firms decentralize decision rights to lower levels of the hierarchy, it captures that firms provide motivation for high performance. Optimally, incentive setting allows the employees at least some decision autonomy in how they do their work, for instance the pace of work. Moreover, Bloom, Sadun, and Van Reenen (2012) find a complementary relationship between IT and their measure of "people management", which includes a question on rewarding high-performance.[19] These work organization variables capture different levels and notions of decentralized workplace organization, decision autonomy and incentives, but they all have in common that employees are, at least to a certain degree, responsible for the outcomes of their work.

Since the organizational practices variables were not asked in the wave of the 2007 survey, the information collected in the 2010 survey is used to replace them in 2007 to not lose information on software use and firm performance from 2007. When this information is not available, due to item non-response or the unbalanced panel structure, the 2007

[17]This last point was raised by an anonymous referee.

[18]Acemoglu et al. (2007) provide a description of the decision authority that managers of business units, which are organized as profit centres, have. In particular, managers of profit centres have the responsibility to monitor revenues and costs. See pp. 1773ff.

[19]Recent research shows empirical evidence for complementarity of decentralization, measured in terms of the delegation of decision rights from principals to middle management, with performance pay (e.g. Hong, Kueng, and Yang 2015). In this chapter, I do not account for a possible complementarity between decentralization and performance pay.

values are replaced with information from 2004. This replacement strategy relies on the assumption of organizational factors being quasi-fixed in the short-run, which is usually made in empirical analyses on the effects of organizational practices when only cross-sectional information on those practices is available (e.g. Bresnahan, Brynjolfsson, and Hitt 2002; Bloom, Sadun, and Van Reenen 2012). The workplace organization variables I use are close to time-invariant in both estimation samples as it is indicated by transition probabilities and persistence statistics for those firms with multiple participation in the survey.[20] Thus, the assumption of the work organization practices being quasi-fixed in the period of analysis can be supported by the data.

Table 2.2 shows descriptive statistics for the three workplace organization variables. Across all years, 59 percent of the SMEs use self-managed teams, 53 percent use performance pay, and 28 percent of them have a business unit with own profit and loss responsibility. As for the enterprise software use intensity, the average use of the workplace practices is higher in the sample of large firms with 70 percent having a business unit with own profit and loss responsibility, 76 percent with self-managed teams and even 85 percent of the large firms use performance pay.

Table 2.2: Descriptive statistics of workplace organization variables

Variable	Mean	SD	Min.	Max.	Correlations		
					Business unit	Team work	Performance pay
					SMEs (N=4487)		
Business unit	0.28	0.45	0	1	1		
Team work	0.59	0.49	0	1	0.19	1	
Performance pay	0.53	0.50	0	1	0.21	0.15	1
					Large firms (N=763)		
Business unit	0.70	0.46	0	1	1		
Team work	0.76	0.43	0	1	0.17	1	
Performance pay	0.85	0.36	0	1	0.13	0.12	1

Data source: ZEW ICT Panel 2004, 2007, 2010. SD stands for standard deviation; this abbreviation is also used in the subsequent tables.

Just as the IT indicator measures only part of a firm's IT use, the variables to measure decentralized and incentive-based workplace organization capture only a small part of a firm's workplace organization.[21] Thus, they might mismeasure firms' decentralization degree and if so, the estimates are downwardly biased. The mismeasurement problem

[20] The results of the transition probabilities and persistence statistics are reported in Table 2.16 in the appendix.

[21] An anonymous referee pointed out that particularly the business unit variable might be a weak proxy for decentralization of work for SMEs because given their firm size they do not need self-responsible business units; nonetheless, their employees may use decentralized work routines. Moreover, it was pointed out that it is probable that only multi-product firms have formal self-responsible business units so that this variable indicates firms' product diversification, too. This notion could also explain the low mean value of this variable for SMEs in comparison to the sample of larger firms. Unfortunately, the data set does not have any information about firms' product mix. However, although information

refers in particular to the intensity of the use of the work practices considered because the information on workplace practices is only binary and the data do not include any information about how many employees and from which skill group within the firm are affected by these workplace measures or what is the scope of the decision autonomy that employees have. Additionally, the workplace organization variables do not capture precisely some aspects that are also understood as 'decentralization' in the literature, such as worker control over the pace of work and the allocation of tasks as it used in Bresnahan, Brynjolfsson, and Hitt (2002) or Tambe, Hitt, and Brynjolfsson (2012). All these points might indicate that my variables underestimate the firms' degree of decentralization. Nevertheless, those firms that use the workplace practices observed in the data might on average probably be more likely to also use other work practices that allow decentralized decision making and reward performance than those firms not using any of the workplace variables considered.

2.3.3 Further firm characteristics

Besides information on ICT, the ICT survey covers information on general firm characteristics, such as total sales, investment and human capital composition of the workforce. Table 2.3 provides descriptive statistics of further variables used in the empirical analysis for SMEs and large firms. Firm performance is captured by deflated value added. Since the data set does not contain exact information, neither on firms' materials and intermediate inputs nor on firm-specific prices, I use industry-wide information on gross value added together with information on the price evolution from the German National Statistics Agency (Destatis) and combine it with firms' reported total sales from the survey to obtain a proxy for real value added. Labour input is measured by the number of employees and capital input is obtained by constructing a capital stock from the available gross investment data.[22] In the appendix, I explain in detail the construction of my measures for value added and for the capital stock (see Subsection 2.7.1 and 2.7.2, respectively).

Moreover, control variables cover information on the share of highly skilled employees (degree from university, university of applied sciences or university of cooperative education), export status, presence of a works council and whether a change in management happened in the year before the survey period (Table 2.17 in the appendix).

about self-responsible business units does not capture all degrees of decentralization, it measures for those firms which have it, control of decision making processes at the manager level. Moreover, with the team work variable, I capture another aspect of decentralized workplace organization. The mean value of this variable is also for SMEs more similar to the one for the large firms.

[22] Table 2.18 in the appendix shows logarithmic values of labour, capital stock and value added.

Table 2.3: Descriptive statistics of production function variables

Variable	Mean	SD	Median	Min.	Max.
			SMEs (N=4487)		
Number of employees	52	57.15	28	5	250
Capital stock	183	8920	3	0.006	584 000
Total sales	10.60	26.10	3.40	0.06	650
Value added (deflated)	3.39	7.83	1.15	0.02	152
% Firms located in former East Germany	0.33	0.47	0	0	1
% Multi-plant group	0.28	0.45	0	0	1
Labour productivity (sales per employee)	0.19	0.34	0.11	0.008	5.59
Value added per employee (deflated)	0.06	0.11	0.04	0.001	2.73
			Large firms (N=763)		
Number of employees	1 158	2 756.26	550	253	39355
Capital stock	349	969	105	0.04	12 400
Total sales	259	745	95	3.79	10 000
Value added (deflated)	82.30	271	29.60	1.34	5 550
% Firms located in former East Germany	0.17	0.37	0	0	1
% Multi-plant group	0.72	0.45	1	0	1
Labour productivity (sales per employee)	0.22	0.27	0.16	0.008	4.44
Value added per employee (deflated)	0.07	0.06	0.05	0.002	0.97

Data source: ZEW ICT Panel 2004, 2007, 2010. The values of capital stock, sales, value added and the respective per capita values are expressed in millions of euros. Deflated values are in prices of 2005.

2.4 Empirical methods

Correlation and productivity analyses are the two most widely used empirical methods to study organizational complementarities.[23] These two methods complement each other because each test has the highest statistical power if the other is weakest (Brynjolfsson and Milgrom 2013). For the correlation analysis and the productivity analysis, I apply pooled ordinary least squares (OLS) with robust standard errors clustered across firms to account for multiple participation in the survey, thereby exploiting variation across firms to obtain the coefficient estimates. The results from the correlation and productivity analysis reflect empirical relationships. They cannot be interpreted as causal because the data do not contain information neither on the date of the enterprise software adoption nor on the timing of the implementation of the workplace organization variables considered.

[23]Athey and Stern (1998) are among the first to discuss an empirical framework to measure organizational complementarities empirically. See Brynjolfsson and Milgrom (2013) for a survey on the theory and econometrics of studying complementarities in organizations.

2.4.1 Correlation analysis

As in prior work (e.g. Bloom, Sadun, and Van Reenen 2012; Tambe, Hitt, and Brynjolfsson 2012), a conditional correlation analysis between IT (IT) as dependent variable and the three measures for workplace organization (BU, TW and PP) is conducted in order to study whether firms with self-responsible business units, self-managed teams or performance pay are also more IT intensive:

$$IT_{it} = \omega_{BU} BU_{it} + \omega_{TW} TW_{it} + \omega_{PP} PP_{it} + \delta_l log(firmsize_{it}) + \lambda' X_{it} + u_{it} \tag{2.2}$$

where i stands for the individual firm and t for the time period.

Even though correlations are neither necessary nor sufficient evidence of complementarities (Athey and Stern 1998), significant and positive ω_{BU}, ω_{TW} and ω_{PP} coefficients can be interpreted as support for complementarity between IT measured by enterprise software systems and workplace organization because they reflect that work practices allowing for decentralized decision making and individual authority are associated with more intensive use of enterprise software systems.

In the most basic specification, the regression controls for firm size by the logarithm of the number of employees $log(firmsize)$, for multi-establishment group, for region by a dummy variable if located in East Germany and for a full set of time-interacted industry fixed effects included in the control vector X.[24]

In further regression specifications, the control vector includes other firm characteristics that may be correlated with IT intensity and workplace organization. The share of highly skilled employees is to take into account the firm's human capital composition since it has been shown that IT and highly skilled human capital are complementary and are an important factor in explaining heterogeneity in IT returns (e.g. Bresnahan, Brynjolfsson, and Hitt 2002; Draca, Sadun, and Van Reenen 2007 for a survey). The share of employees working mainly with the computer is an alternative measure to the enterprise software indicator for firms' overall IT intensity. It will likely be positively correlated with decentralized and incentive-based workplace practices if more IT-intensive firms also adopt more of such work methods. Moreover, firms with a higher share of employees

[24]This regression specification does not suggest any direction of causality between IT and decentralization in light of the view in the literature that IT facilitates and thus causes decentralization. Given the properties of my data, I follow Bresnahan, Brynjolfsson, and Hitt (2002) who estimate firms' short-run demand equations for IT as a function of work organization and human capital. They justify this specification by arguing that IT is the more easily variable factor within the complementary system than the relatively fixed factors of work organization and human capital and that the correlation coefficients provide evidence about complementarities.

working mainly at the computer are also likely to use enterprise software systems more intensively.

Firm's exporting activities account for the impact of international activities and exposure to foreign competition as exporters have been shown to be more technology intensive and more productive than non-exporters (e.g. Bernard et al. 2012; Bertschek, Hogrefe, and Rasel 2015). Moreover, increased foreign import competition has been found to be associated with more decentralization and performance-based pay in U.S. firms (Guadelupe and Wulf 2008). Existence of a works council is considered as control variable as a measure for employees' voice in decision making and a change in management might have led to higher IT and/or decentralization intensity.

2.4.2 Productivity analysis

As it is widely used in the IT productivity literature[25] and in work on the complementarity relation between IT and organization (e.g. Bresnahan, Brynjolfsson, and Hitt 2002; Bloom, Sadun, and Van Reenen 2012), I employ a Cobb-Douglas specification that is augmented for IT (IT) and decentralized workplace organization ($WO = \{BU, TW, PP\}$). The following regression equation formalizes the empirical model:

$$\begin{aligned} y_{it} = \alpha_c + \alpha_l l_{it} + \alpha_k k_{it} + \alpha_{IT} IT_{it} + \alpha_{WO_j} \sum_j WO_{jit} \\ + \alpha_{IT*WO_j} \sum_j IT_{it} * WO_{jit} + \lambda' X_{it} + u_{it} \end{aligned} \tag{2.3}$$

where $j \epsilon \{BU, TW, PP\}$, i stands for the individual firm and t for the time period. The dependent variable y is logarithmized real value added. A firm's capital stock is represented by k and labour by l, both inputs are in logarithmic values. α_c represents the constant and u an idiosyncratic error term, which captures all unobserved factors. Both, IT and the workplace organization variables, are entered in levels individually as well as their interactions. The regression specification features that IT (IT), workplace organization (WO_j) and their interaction terms ($IT * WO_j$) are allowed to shift a firm's production frontier, i.e. they are modelled as part of the multi-factor productivity. A positive and significant interaction term α_{IT*WO_j} can be interpreted as support for complementarity between IT and workplace organization. It reflects whether the IT productivity contribution depends on workplace organization, and thus whether these factors are interrelated with respect to productivity.

[25]For a summary of the econometric framework of IT productivity returns, see, e.g., Cardona, Kretschmer, and Strobel (2013).

Overall, the control variables are the same as in the correlation analysis. All control variables aim at reducing endogeneity concerns due to omitted variables by capturing organizational factors that will likely be relevant for observed firm heterogeneity in IT use, workplace organization and value added. In the productivity analysis, the computer work share, as another measure for a firm's IT intensity than the measure based on enterprise software, accounts also for the possibility that the enterprise software variables do not merely capture the productivity effect of computer work if firms with higher enterprise software use also have higher shares of employees working mainly with the computer.

2.5 Empirical results

2.5.1 Correlation analysis for SMEs

Table 2.4 shows correlations between the IT indicator and the workplace organization variables. Column (1) presents a baseline estimate for the intensity of the correlation between IT and the existence of a self-responsible business unit controlling only for firm size, regional location, multi-establishment group and industry-interacted year fixed effects. The coefficient estimate of this measure for decentralized workplace organization is highly significant indicating that firms with a self-responsible business unit use enterprise software systems more intensively. This result remains robust controlling for additional factors of firm heterogeneity (column (2)). Among the control variables, the share of employees working predominantly with the PC and exporting increase a firm's IT intensity significantly. It might seem surprising that the share of high-skilled employees is not significantly positively related to IT intensity, given prior findings on complementarity between IT and high-skilled human capital. This result is mainly due to the high pairwise correlation between this share and the share of employees working mainly at the PC (0.62***). Where the computer work share is excluded from the regression, the IT intensity as measured by the software indicator and the share of high-skilled employees are significantly and positively correlated (column (8)). These findings reflect that the computer work share captures a significant fraction of a firm's skill intensity.

Columns (3) and (4) show conditional correlations between IT intensity and whether firms use team work. Firms with team work are also more IT intensive. Equally, firms offering performance pay use IT more intensively (columns (5) and (6)). The positive correlation between IT and the different workplace organization variables stays significant in a specification including all organizational variables (columns (7) and (8)). The coefficient of team work to IT (0.129) is smallest in size, followed by the one for performance pay

(0.147) and the one for a self-responsible business unit (0.288, column (7)).

Table 2.4: Correlations between enterprise software intensity and workplace organization for SMEs

All industries, dependent variable: Enterprise software - IT intensity	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Self-responsible business unit (BU)	0.380***	0.330***					0.288***	0.313***
	(0.037)	(0.036)					(0.036)	(0.037)
Team work (TW)			0.217***	0.180***			0.129***	0.144***
			(0.031)	(0.030)			(0.030)	(0.030)
Performance pay (PP)					0.225***	0.190***	0.147***	0.155***
					(0.031)	(0.030)	(0.030)	(0.031)
log(employment)	0.267***	0.246***	0.307***	0.277***	0.287***	0.264***	0.230***	0.218***
	(0.015)	(0.018)	(0.015)	(0.017)	(0.015)	(0.017)	(0.018)	(0.018)
% Empl. working with PC		0.641***		0.666***		0.674***	0.618***	
		(0.063)		(0.063)		(0.063)	(0.062)	
% Highly skilled empl.		-0.057		-0.042		-0.047	-0.091	0.213***
		(0.085)		(0.086)		(0.086)	(0.085)	(0.080)
Export activity		0.200***		0.202***		0.198***	0.190***	0.213***
		(0.033)		(0.033)		(0.034)	(0.033)	(0.033)
Works council		0.045		0.060		0.051	0.050	0.050
		(0.043)		(0.043)		(0.043)	(0.042)	(0.043)
Change in management		-0.003		0.007		-0.002	-0.000	0.015
		(0.036)		(0.036)		(0.036)	(0.035)	(0.036)
Constant	-1.220***	-1.438***	-1.391***	-1.585***	-1.323***	-1.535***	-1.498***	-1.331***
	(0.091)	(0.090)	(0.090)	(0.089)	(0.091)	(0.089)	(0.088)	(0.090)
Control variables	yes	yes	yes	yes	yes	yes	yes	yes
Number of observations	4487	4487	4487	4487	4487	4487	4487	4487
Number of firms	3288	3288	3288	3288	3288	3288	3288	3288
Adjusted R^2	0.2013	0.2355	0.1869	0.2241	0.1878	0.2250	0.2444	0.2243

Significance levels: $*$: 10% $**$: 5% $***$: 1%. Control variables include industry dummy variables based on two-digit classification interacted with a full set of year fixed effects, a dummy variable for location equal to one if the firm is in one new German Bundesland (member state), i.e. formerly East Germany, and a dummy variable if the firm belongs to a multi-plant group. Robust standard errors clustered at the firm level in parentheses.

Overall, the correlation analysis provides evidence that firms with workplace practices that allow decentralized decision making and emphasize individual incentives tend to use enterprise software more intensively. Therefore, in line with the hypothesis on the complementarity between IT and decentralization, it holds for SMEs that firms with higher IT intensity are more likely to have also adopted a decentralized and incentive-based work organization. However, it cannot be completely ruled out that unobserved factors, such as management ability, bias the estimates or are the true driving force behind the results, even though the estimation controls for a large amount of relevant unobserved heterogeneity. Moreover, the values on the adjusted R-squared of the correlation regressions are only all around 0.19 to 0.24. These rather low values indicate that only a small fraction of the variation in enterprise software use intensity is explained by workplace organization and the other firm characteristics considered. In the next section, I examine with productivity analyses whether combining IT and decentralized, incentive-based workplace organization is associated with higher performance.

2.5.2 Productivity analysis for SMEs

Table 2.5 shows the results from different specifications of the productivity regressions used to analyse the productivity of IT and decentralized and incentive-based workplace organization and whether these organizational factors are complementary. Column (1) provides baseline estimates for a standard Cobb-Douglas production function with labour and capital inputs. The coefficients for labour and capital are statistically significant and plausible in magnitude. Column (2) introduces a baseline estimate for the average productivity contribution of IT measured by enterprise software usage intensity for the time periods 2004, 2007 and 2010. The point estimate is about 0.095 and highly significant reflecting that firms with more intense enterprise software use are more productive. Column (3) controls for the share of employees working mainly at the PC as additional measure for a firm's IT intensity. The coefficient of the enterprise software indicator decreases slightly in size to 0.061 but remains highly significant. This significantly positive coefficient supports the hypothesis that firms with higher intensity of technology-supported use of information within the value creation process are more productive. As found in prior analysis (e.g. Bertschek and Meyer 2009), the estimate for the share of employees working mainly at the computer is significantly positive, too. Altogether, firms with higher IT intensity, either through enterprise software use or employees working mainly with the computer, turn out to be the more productive ones.

In column (4), the workplace organization measures for the existence of a self-responsible business unit, self-managed teams and the use of performance pay are added to the empirical specification. In contrast to other evidence of a positive relationship between group-based work organization variables and productivity (e.g. Bresnahan, Brynjolfsson, and Hitt 2002), the coefficient of self-managed teams is statistically not significant from zero. More similar to my results is the result of Black and Lynch (2001, 2004) who analyse the relationship between the proportion of workers in self-managed teams and labour productivity and who do not find a significant relationship, neither. The other two variables both have a significantly positive coefficient with a large magnitude. Having a self-responsible business unit is associated with approximately 15.6 percent higher productivity (coefficient: 0.156) and using performance pay with roughly 9.7 percent higher productivity (coefficient: 0.097).[26] These coefficients, although not completely equivalent, are similar to prior coefficient estimates on decentralization or performance pay (e.g. Tambe, Hitt, and Brynjolfsson 2012; Aral, Brynjolfsson, and L. Wu 2012, respectively). These results underline the view that decentralization and high-performance workplace

[26]The coefficients for self-responsible business unit and performance pay are similar in separate regressions where only one measure is considered. The coefficient of the team work variable turns positive but is still insignificant; the corresponding results are shown in Table 2.19 in the appendix.

Table 2.5: Productivity regressions of IT and workplace organization for SMEs

	All industries, dependent variable: log(value added)								
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
IT - Index(ERP+CRM+SCM)		0.095***	0.061***	0.046***	0.040*	0.041*	0.036	0.061***	0.040***
		(0.013)	(0.013)	(0.013)	(0.023)	(0.023)	(0.023)	(0.023)	(0.013)
Self-responsible business unit (BU)				0.156***	0.160***	0.158***	0.154***	0.168***	0.151***
				(0.030)	(0.030)	(0.030)	(0.030)	(0.031)	(0.029)
Team work (TW)				-0.018	-0.020	-0.022	-0.018	-0.009	-0.017
				(0.025)	(0.025)	(0.025)	(0.025)	(0.025)	(0.025)
Performance pay (PP)				0.097***	0.100***	0.097***	0.093***	0.096***	0.090***
				(0.025)	(0.025)	(0.025)	(0.025)	(0.026)	(0.025)
IT * BU					-0.025	-0.026	-0.022	-0.021	
					(0.027)	(0.027)	(0.027)	(0.028)	
IT * TW					-0.018	-0.019	-0.018	-0.023	
					(0.025)	(0.025)	(0.025)	(0.026)	
IT * PP					0.043*	0.043*	0.040	0.040	
					(0.025)	(0.025)	(0.025)	(0.026)	
log(employment)	0.914***	0.891***	0.910***	0.888***	0.888***	0.888***	0.856***	0.839***	0.856***
	(0.018)	(0.018)	(0.018)	(0.018)	(0.018)	(0.018)	(0.019)	(0.020)	(0.019)
log(capital stock)	0.126***	0.119***	0.114***	0.111***	0.111***	0.111***	0.105***	0.108***	0.106***
	(0.012)	(0.012)	(0.011)	(0.011)	(0.011)	(0.011)	(0.011)	(0.011)	(0.011)
% Empl. working with PC			0.622***	0.595***	0.595***	0.556***	0.542***		0.542***
			(0.057)	(0.057)	(0.057)	(0.063)	(0.062)		(0.062)
% Highly skilled empl.						0.134	0.108	0.369***	0.106
						(0.083)	(0.084)	(0.080)	(0.084)
Export activity							0.125***	0.140***	0.125***
							(0.028)	(0.028)	(0.028)
Works council							0.119***	0.117***	0.121***
							(0.035)	(0.035)	(0.035)
Change in management							0.037	0.051	0.040
							(0.031)	(0.031)	(0.031)
Constant	9.066***	9.266***	9.088***	9.140***	9.150***	9.157***	9.244***	9.394***	9.236***
	(0.149)	(0.151)	(0.146)	(0.146)	(0.146)	(0.146)	(0.146)	(0.149)	(0.146)
Control variables	yes	yes	yes	yes	yes	yes	yes	yes	yes
Number of observations	4487	4487	4487	4487	4487	4487	4487	4487	4487
Number of firms	3288	3288	3288	3288	3288	3288	3288	3288	3288
Adjusted R^2	0.7251	0.7288	0.7408	0.7440	0.7441	0.7443	0.7466	0.7389	0.7466

Significance levels: $*$: 10% $**$: 5% $***$: 1%. Control variables include industry dummy variables based on two-digit classification interacted with a full set of year fixed effects, a dummy variable for location equal to one if the firm is in one new German Bundesland (member state), i.e. formerly East Germany, and a dummy variable if the firm belongs to a multi-plant group. Robust standard errors clustered at the firm level in parentheses.

practices matter for productivity.[27] The inclusion of the workplace organization variables decreases the estimates of the software and computer work intensity measures slightly but leaves them significant. This reduction in the magnitude of the IT coefficients, when workplace organization is taken into account in the productivity analysis, is consistent with the results from the correlation analysis that more IT-intensive firms tend to have a decentralized workplace organization, too. Thus, when omitting workplace organization in the regression specification, IT captures part of its productivity contribution.

Column (5) presents results for three pairwise interaction terms between enterprise software use and the three workplace organization variables considered in order to test for complementarity. The inclusion of the interaction terms reduces the significance of the coefficient on enterprise software, whereas the coefficients for self-responsible business

[27]For an empirical analysis of productivity impacts of workplace innovation, see, e.g., Black and Lynch (2004) for U.S. firms.

unit and performance pay remain highly significant. This suggests that the return to enterprise software depends on workplace organization. The coefficients of the interaction between IT and self-responsible business unit and IT and team work are, surprisingly, negative, even though not significant. In contrast, the interaction term between IT and performance pay is positive and weakly significant, as column (5) shows.

Controlling also for the share of highly skilled employees to account for skilled human capital (column (6)) does not change the previous results. Specification (7) takes account of additional factors of firm heterogeneity which might drive the results by incorporating exporting activity, the existence of a works council and whether a change in management took place in the survey period. The consideration of these additional control variables lowers the IT coefficient and turns it insignificant, while the individual coefficients on self-responsible business units and performance pay remain significant. This result provides confidence that the workplace organization variables do not pick up effects of alternative factors that are also positively related to productivity. However, the combination of performance pay and enterprise software use turns insignificant. The coefficient estimates on exporting and on works council are significantly positive, which is in line with prior findings for a positive relationship between productivity and export activities or a works council.

In specification (8), the share of computer employees is omitted to see how the coefficients evolve, given that this measure reflects IT intensity and also partly labour heterogeneity. The coefficients on enterprise software intensity and the share of highly skilled employees increase in size and both become significant. This illustrates that computer work intensity captures a large part of a firm's IT intensity and also skill intensity as found already in the correlation analysis. Specification (9) excludes the interaction terms between IT and workplace organization to analyse what are the productivity contributions without accounting for combination effects. The coefficient estimates are similar to those in column (5) or (6). Overall, these results show that more IT-intensive firms and firms with decentralized and incentive-based workplace practices are more productive. However, there is no robust evidence of complementarity between IT and decentralized workplace organization and only weak support for a complementary relationship between IT and performance pay.

2.5.3 Robustness checks for SMEs

To gauge the sensitivity of the results to the construction of the enterprise software use indicator and the workplace organization variables, I conduct the productivity analysis as of Table 2.5 with differently constructed indicators and the individual software variables. Table 2.6 shows the results for the specification with all control variables as in specification (7), Table 2.5. Column (1) presents the results when the dummy variables for all workplace organization variables are added in a count indicator for workplace organization and a corresponding interaction term between IT and this indicator is included. The coefficient on this workplace organization indicator is positively significant, whereas the interaction term with IT is not statistically significant. Given that across specifications the coefficients of the team work variable are negative, although insignificant (see Table 2.5), I construct a count variable including only self-responsible business unit and performance pay. The coefficient of this workplace organization index is, as expected, larger in magnitude but the interaction term is still insignificant (column (2)).

In columns (3) and (4), once the individually standardized software values and once the dummy variables for ERP, SCM and CRM are considered in the regressions. In isolation, both ERP (with weak significance) and SCM raise productivity. This finding is similar to the productivity contributions of these three systems for Korean firms where only SCM raises productivity significantly (Shin 2006). I also conducted the regressions with the standardized individual software and the binary values including interaction terms between them and the three workplace organization variables.[28] None of the interaction terms is significant. Since SCM is a special software that not all firms need, column (5) shows results including only ERP and CRM in the enterprise software indicator. As for the main indicator of IT intensity, the combination of IT and performance pay is again weakly significant and the other coefficients do not change qualitatively.

One further important factor to explain current productivity is likely to be past productivity, which also might have an impact on firms' decisions on current input factors.[29] Column (6) shows coefficient estimates accounting for lagged productivity with a time lag of three years because the used data were gathered in 2004, 2007 and 2010. Since the estimation sample for the main analysis is based on an unbalanced panel with the majority of firms having participated only once in the survey, the estimation sample I can use to control for past productivity is smaller. There remain only 982 SMEs, which have participated at least twice in the survey. Accounting for lagged productivity, the coefficient

[28] The corresponding results are omitted for reasons of brevity; they are available upon request from the author.
[29] This point was made by an anonymous referee.

Table 2.6: Productivity regressions of IT and workplace organization for SMEs - Different measures and lagged values

	Dependent variable: log(value added)						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
IT - Index(ERP+CRM+SCM)	0.031	0.041*				-0.005	0.026
	(0.022)	(0.022)				(0.031)	(0.030)
IT - Index(ERP+CRM)					0.023		
					(0.022)		
S(ERP)			0.022*				
			(0.013)				
ERP-dummy				0.024			
				(0.027)			
S(SCM)			0.029**				
			(0.013)				
SCM-dummy				0.060**			
				(0.025)			
S(CRM)			0.003				
			(0.014)				
CRM-dummy				0.001			
				(0.027)			
BU+TW+PP	0.068***						
	(0.014)						
BU+PP		0.115***					
		(0.019)					
Self-responsible business unit (BU)			0.152***	0.155***	0.159***	0.101**	0.044
			(0.029)	(0.029)	(0.030)	(0.043)	(0.042)
Team work (TW)		-0.016	-0.017	-0.017	-0.016	0.023	-0.002
		(0.025)	(0.025)	(0.025)	(0.025)	(0.035)	(0.033)
Performance pay (PP)			0.092***	0.093***	0.094***	0.031	0.038
			(0.025)	(0.025)	(0.025)	(0.035)	(0.035)
IT(ERP,SCM,CRM)*BU						-0.080*	-0.004
						(0.043)	(0.037)
IT(ERP,SCM,CRM)*TW		-0.020				0.017	-0.014
		(0.025)				(0.035)	(0.031)
IT(ERP,SCM,CRM)*PP						0.033	-0.006
						(0.036)	(0.033)
IT(ERP, SCM, CRM)*(BU+TW+PP)	0.007						
	(0.012)						
IT(ERP, SCM, CRM)*(BU+PP)		0.015					
		(0.016)					
IT(ERP,CRM)*BU					-0.030		
					(0.026)		
IT(ERP, SCM)*TW					-0.013		
					(0.024)		
IT(ERP,CRM)*PP					0.043*		
					(0.024)		
log(employment)	0.863***	0.857***	0.855***	0.857***	0.858***	0.396***	0.399***
	(0.019)	(0.019)	(0.019)	(0.019)	(0.019)	(0.040)	(0.041)
log(capital stock)	0.106***	0.106***	0.106***	0.106***	0.106***	0.055***	0.057***
	(0.011)	(0.011)	(0.011)	(0.011)	(0.011)	(0.017)	(0.017)
% Empl. working with PC	0.543***	0.544***	0.545***	0.552***	0.548***	0.263***	0.263***
	(0.063)	(0.062)	(0.063)	(0.062)	(0.063)	(0.072)	(0.073)
% Highly skilled empl.	0.106	0.105	0.108	0.106	0.107	0.033	0.033
	(0.084)	(0.084)	(0.083)	(0.083)	(0.084)	(0.094)	(0.094)
Export activity	0.125***	0.125***	0.124***	0.126***	0.127***	0.070*	0.071*
	(0.028)	(0.028)	(0.028)	(0.028)	(0.028)	(0.040)	(0.040)
Works council	0.126***	0.121***	0.119***	0.121***	0.119***	-0.030	-0.035
	(0.035)	(0.035)	(0.035)	(0.035)	(0.035)	(0.050)	(0.050)
Change in management	0.044	0.039	0.039	0.040	0.037	0.010	0.007
	(0.031)	(0.031)	(0.031)	(0.031)	(0.031)	(0.047)	(0.047)
Productivity (t-3)						0.572***	0.572***
						(0.037)	(0.038)
Constant	9.183***	9.230***	9.240***	9.185***	9.220***	3.501***	3.469***
	(0.146)	(0.146)	(0.147)	(0.144)	(0.146)	(0.433)	(0.442)
Control variables	yes	yes	yes	yes	yes	yes	yes
Number of observations	4487	4487	4487	4487	4487	1199	1199
Number of firms	3288	3288	3288	3288	3288	982	982
Adjusted R^2	0.7454	0.7464	0.7466	0.7463	0.7464	0.8300	0.8290

Significance levels: $*$: 10% $**$: 5% $***$: 1%. Control variables include industry dummy variables based on two-digit classification interacted with a full set of year fixed effects, a dummy variable for location equal to one if the firm is in one new German Bundesland (member state), i.e. formerly East Germany, and a dummy variable if the firm belongs to a multi-plant group. Robust standard errors clustered at the firm level in parentheses. In column (7), IT and the workplace organization variables are included as lagged values, i.e. t-3.

estimates of the input factors are generally decreased in size. Only existence of a self-responsible business unit, the share of employees working mainly at the PC, labour and capital, of which the coefficient estimates are reduced by roughly a half, are significantly linked with higher productivity. The coefficient estimate of lagged productivity is large suggesting that lagged productivity is a relevant factor to explain current productivity. In column (7), I take three years lagged values for enterprise software use intensity and the workplace variables in order to account for possible coefficient biases due to simultaneity between productivity and these factors. The results show that only lagged productivity in addition to labour and capital but neither lagged IT nor do workplace organization or any of the combination effects raise productivity significantly. However, given correlations between input factors and lagged productivity and the large positive coefficient of lagged productivity, it might be that lagged productivity takes up most of the factors that explain heterogeneity in productivity. The results with lagged values suggest that omitting lagged productivity is likely to bias the other inputs coefficient estimates upward, in a similar way to the omission of firm fixed effects.[30]

Overall, the conclusion from the different specifications about how combinations of IT and decentralized and incentive-based workplace organization are related to productivity is that SMEs with higher computer work intensity and the use of decentralized workplace organization and performance pay are more productive. This result remains robust considering also alternative sources of better performance, such as skill composition or exporting. In general, however, the results suggest that the combination of the measures of IT and workplace organization used here is not associated with higher productivity for SMEs.

2.5.4 Results for large firms

Prior research finds evidence for complementarity between IT and decentralized, incentive-based workplace organization for large firms, mainly from the U.S.. This section illustrates the results with the sample of large firms within the ZEW ICT panel, here classified as firms with more than 250 employees. Overall, there are 595 such firms. The results from the correlation analysis reflect some differences in comparison to those from SMEs. While using self-responsible team work and offering performance pay are significantly correlated with higher enterprise software use intensity, having a self-responsible business unit is not (Table 2.7). Moreover, the share of employees working mainly with the PC as another measure for a firm's IT intensity is only weakly positively related to software use

[30]See Subsection 2.5.5 for a discussion of the results.

intensity in a regression with self-responsible business units as work organization variable (column (2)) or performance pay (column (6)), whereas the positive relation between the share of high-skilled employees and IT is stronger for the large firms than for the SMEs. This positive association between IT and highly skilled employees is consistent with complementarity between IT and human capital.

Table 2.7: Correlations between enterprise software intensity and workplace organization for large firms

All industries, dependent variable: Enterprise software - IT intensity								
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Self-responsible business unit (BU)	0.064	0.026					-0.017	-0.007
	(0.086)	(0.087)					(0.086)	(0.086)
Team work (TW)			0.237**	0.212**			0.196**	0.200**
			(0.096)	(0.093)			(0.092)	(0.092)
Performance pay (PP)					0.276**	0.243**	0.220**	0.223**
					(0.112)	(0.109)	(0.106)	(0.107)
log(employment)	0.187***	0.166***	0.183***	0.161***	0.173***	0.154***	0.150***	0.145***
	(0.043)	(0.044)	(0.043)	(0.043)	(0.044)	(0.044)	(0.044)	(0.044)
% Empl. working with PC		0.303*		0.289		0.297*	0.283	
		(0.179)		(0.178)		(0.179)	(0.178)	
% Highly skilled empl.		0.459*		0.435*		0.480*	0.455*	0.590**
		(0.261)		(0.259)		(0.260)	(0.261)	(0.237)
Export activity		0.258**		0.249**		0.244**	0.236**	0.239**
		(0.119)		(0.118)		(0.120)	(0.119)	(0.121)
Works council		-0.060		-0.057		-0.061	-0.058	-0.050
		(0.136)		(0.136)		(0.135)	(0.135)	(0.137)
Change in management		0.194***		0.197***		0.182**	0.186***	0.191***
		(0.072)		(0.071)		(0.071)	(0.071)	(0.072)
Constant	-1.175***	-1.455***	-1.261***	-1.528***	-1.297***	-1.559***	-1.618***	-1.519***
	(0.324)	(0.325)	(0.323)	(0.326)	(0.329)	(0.330)	(0.333)	(0.331)
Control variables	yes	yes	yes	yes	yes	yes	yes	yes
Number of observations	763	763	763	763	763	763	763	763
Number of firms	595	595	595	595	595	595	595	595
Adjusted R^2	0.0823	0.1056	0.0914	0.1135	0.0906	0.1125	0.1166	0.1143

Significance levels: * : 10% ** : 5% *** : 1%. Control variables include industry dummy variables based on two-digit classification interacted with a full set of year fixed effects, a dummy variable for location equal to one if the firm is in one new German Bundesland (member state), i.e. formerly East Germany, and a dummy variable if the firm belongs to a multi-plant group. Robust standard errors clustered at the firm level in parentheses.

The results from the productivity analysis differ, too. As for the SMEs sample, without taking account of possible interactions between IT and workplace organization, more intensive enterprise software use raises productivity significantly. However, the productivity return to software is almost twice that enjoyed by SMEs (specification (3), Table 2.8 for large firms; specification (3), Table 2.5 for SMEs). This finding suggests that larger firms seem to benefit more from enterprise software than smaller firms. In contrast to the results from SMEs, workplace organization does not increase productivity significantly for large firms.[31] Given that the majority of firms in the sample offers performance pay (85 percent) and also has self-responsible team work (76 percent) and self-responsible business units (70 percent), it is plausible that these workplace organization practices do not explain productivity differences significantly.

[31]The work organization variables do not increase productivity significantly in regressions with each work

Table 2.8: Productivity regressions of IT and workplace organization for large firms

	All industries, dependent variable: log(value added)								
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
IT - Index(ERP+CRM+SCM)		0.121***	0.114***	0.117***	0.002	-0.007	-0.011	-0.010	0.108***
		(0.025)	(0.025)	(0.026)	(0.057)	(0.057)	(0.056)	(0.056)	(0.026)
Self-responsible business unit (BU)				0.059	0.063	0.052	0.051	0.057	0.046
				(0.054)	(0.054)	(0.053)	(0.053)	(0.053)	(0.053)
Team work (TW)				-0.012	-0.007	-0.013	-0.012	-0.010	-0.018
				(0.058)	(0.058)	(0.057)	(0.056)	(0.056)	(0.057)
Performance pay (PP)				-0.072	-0.051	-0.041	-0.047	-0.046	-0.071
				(0.068)	(0.071)	(0.071)	(0.072)	(0.073)	(0.070)
IT * BU					0.099**	0.098**	0.091*	0.092*	
					(0.049)	(0.049)	(0.048)	(0.048)	
IT * TW					-0.004	-0.004	0.002	0.006	
					(0.054)	(0.054)	(0.053)	(0.053)	
IT * PP					0.065	0.070	0.070	0.068	
					(0.056)	(0.056)	(0.055)	(0.055)	
log(employment)	0.847***	0.840***	0.846***	0.847***	0.841***	0.838***	0.823***	0.818***	0.828***
	(0.042)	(0.041)	(0.040)	(0.040)	(0.040)	(0.040)	(0.040)	(0.040)	(0.040)
log(capital stock)	0.159***	0.145***	0.143***	0.143***	0.143***	0.145***	0.145***	0.147***	0.145***
	(0.025)	(0.024)	(0.025)	(0.025)	(0.025)	(0.024)	(0.024)	(0.024)	(0.024)
% Empl. working with PC			0.292**	0.282**	0.282**	0.181	0.168		0.169
			(0.121)	(0.120)	(0.119)	(0.120)	(0.119)		(0.120)
% Highly skilled empl.						0.494***	0.505***	0.584***	0.501***
						(0.182)	(0.183)	(0.179)	(0.184)
Export activity							0.105	0.106	0.107
							(0.081)	(0.081)	(0.082)
Works council							0.161	0.166	0.167
							(0.107)	(0.108)	(0.109)
Change in management							0.011	0.014	0.012
							(0.046)	(0.046)	(0.046)
Constant	9.006***	9.309***	9.204***	9.236***	9.231***	9.212***	9.060***	9.100***	9.063***
	(0.338)	(0.337)	(0.342)	(0.346)	(0.345)	(0.341)	(0.349)	(0.347)	(0.350)
Control variables	yes	yes	yes	yes	yes	yes	yes	yes	yes
Number of observations	763	763	763	763	763	763	763	763	763
Number of firms	595	595	595	595	595	595	595	595	595
Adjusted R^2	0.6836	0.6942	0.6973	0.6970	0.6984	0.7020	0.7035	0.7029	0.7023

Significance levels: ∗ : 10% ∗∗ : 5% ∗ ∗ ∗ : 1%. Control variables include industry dummy variables based on two-digit classification interacted with a full set of year fixed effects, a dummy variable for location equal to one if the firm is in one new German Bundesland (member state), i.e. formerly East Germany, and a dummy variable if the firm belongs to a multi-plant group. Robust standard errors clustered at the firm level in parentheses.

Another central difference is that the combination of IT and existence of a self-responsible business unit raises productivity significantly (specifications (5) to (8), Table 2.8). This positive interaction term is consistent with complementarity between IT and decentralization. The productivity premium between IT and decentralized workplace organization is significant for the alternative IT and work organization indicators, too (specifications (1), (2) and (5), Table 2.9). This result underlines that large firms that combine technology with appropriate workplace organization perform particularly well, whereas workplace organization in isolation does not explain productivity differences significantly. Given that the correlation between IT and existence of a self-responsible business unit is not significant, the positive and significant interaction term between IT and this organizational practice indicates that firms with a self-responsible business unit, which also use enterprise software intensively, are more productive. These opposing results from the correlation and productivity analysis with respect to the conclusion for complementarity underline the different statistical power properties of each method for testing the existence

organization variable considered separately, either; the results are shown in Table 2.20 in the appendix.

of organizational complementarities.[32]

Another difference from the results from SMEs is that the share of employees working mainly at the PC does not raise productivity significantly, whereas the share of high-skilled employees does. This result might reflect that the majority of large firms has reached their optimal level of PC-based employees, so that differences in this share do not explain productivity differences, in contrast to different levels of skilled human capital employed by the firm. As for SMEs, including lagged productivity and taking lagged values of IT and workplace organization, lagged productivity has a large and positive coefficient. The other coefficient estimates are reduced in size and the estimates of the capital coefficient and the interaction term between IT and workplace organization also turn insignificant (columns (6) and (7), Table 2.9).

The findings support prior evidence on complementarity between IT and decentralization which has been found for rather large firms. The comparison of the results between smaller and larger firms is compatible with the results in Tambe and Hitt (2012). They argue that large firms derive larger productivity returns from IT than firms of smaller size, which is consistent with advantages in economies of scale for larger firms. Moreover, the results from the productivity analysis in this chapter support their argument that large firms may have advantages in benefitting from IT-related complements, such as decentralization. Nevertheless, the results can only be interpreted as reflecting robust correlations and should not be viewed as causal. It might be that the positive interaction term between IT and decentralization reflects the impact of an unobservable factor that is correlated with both IT and decentralization, which is the true relevant factor for improved productivity.

[32]See Section 2.4 for this argument.

Table 2.9: Productivity regressions of IT and workplace organization for large firms - Different measures and lagged values

All industries, dependent variable: log(value added)	(1)	(2)	(3)	(4)	(5)	(6)	(7)
IT - Index(ERP+CRM+SCM)	-0.022	-0.023				0.057	0.064
	(0.058)	(0.058)				(0.085)	(0.088)
IT - Index(ERP+CRM)					-0.025		
					(0.055)		
S(ERP)			0.043				
			(0.028)				
ERP-dummy				0.168			
				(0.108)			
S(SCM)			0.063**				
			(0.025)				
SCM-dummy				0.120**			
				(0.053)			
S(CRM)			0.048*				
			(0.026)				
CRM-dummy				0.076			
				(0.057)			
BU+TW+PP	0.006						
	(0.032)						
BU+PP		0.014					
		(0.044)					
Self-responsible business unit (BU)			0.046	0.036	0.053	-0.061	-0.049
			(0.053)	(0.053)	(0.053)	(0.089)	(0.094)
Team work (TW)		-0.012	-0.019	-0.016	-0.003	0.056	0.027
		(0.056)	(0.057)	(0.057)	(0.056)	(0.085)	(0.094)
Performance pay (PP)			-0.070	-0.065	-0.049	0.057	-0.004
			(0.070)	(0.069)	(0.070)	(0.141)	(0.183)
IT(ERP,SCM,CRM)*BU						0.096	-0.040
						(0.090)	(0.096)
IT(ERP,SCM,CRM)*TW		0.002				0.067	0.002
		(0.053)				(0.080)	(0.117)
IT(ERP,SCM,CRM)*PP						-0.139	-0.011
						(0.100)	(0.150)
IT(ERP, SCM, CRM)*(BU+TW+PP)	0.058**						
	(0.025)						
IT(ERP, SCM, CRM)*(BU+PP)		0.087***					
		(0.033)					
IT(ERP,CRM)*BU					0.113**		
					(0.050)		
IT(ERP, SCM)*TW					0.012		
					(0.054)		
IT(ERP,CRM)*PP					0.036		
					(0.052)		
log(employment)	0.822***	0.823***	0.827***	0.831***	0.823***	0.343***	0.400***
	(0.040)	(0.040)	(0.040)	(0.040)	(0.040)	(0.107)	(0.113)
log(capital stock)	0.146***	0.145***	0.144***	0.146***	0.150***	0.025	0.021
	(0.024)	(0.024)	(0.024)	(0.025)	(0.025)	(0.031)	(0.031)
% Empl. working with PC	0.169	0.173	0.168	0.171	0.178	0.021	-0.043
	(0.119)	(0.120)	(0.119)	(0.120)	(0.120)	(0.198)	(0.204)
% Highly skilled empl.	0.518***	0.519***	0.507***	0.528***	0.489***	0.778**	0.892**
	(0.182)	(0.183)	(0.184)	(0.185)	(0.187)	(0.360)	(0.361)
Export activity	0.108	0.103	0.105	0.105	0.116	0.055	0.112
	(0.081)	(0.080)	(0.083)	(0.084)	(0.082)	(0.101)	(0.111)
Works council	0.163	0.161	0.170	0.164	0.150	0.197	0.169
	(0.107)	(0.107)	(0.108)	(0.110)	(0.107)	(0.116)	(0.145)
Change in management	0.011	0.009	0.013	0.017	0.016	-0.114	-0.077
	(0.045)	(0.045)	(0.046)	(0.046)	(0.046)	(0.078)	(0.083)
Productivity (t-3)						0.640***	0.616***
						(0.086)	(0.100)
Constant	9.014***	9.034***	9.067***	8.713***	8.963***	3.243***	3.478***
	(0.345)	(0.349)	(0.351)	(0.356)	(0.349)	(1.103)	(1.179)
Control variables	yes	yes	yes	yes	yes	yes	yes
Number of observations	763	763	763	763	763	168	168
Number of firms	595	595	595	595	595	142	142
Adjusted R^2	0.7041	0.7039	0.7015	0.6988	0.7013	0.7856	0.7756

Significance levels: $*$: 10% $**$: 5% $***$: 1%. Control variables include industry dummy variables based on two-digit classification interacted with a full set of year fixed effects, a dummy variable for location equal to one if the firm is in one new German Bundesland (member state), i.e. formerly East Germany, and a dummy variable if the firm belongs to a multi-plant group. Robust standard errors clustered at the firm level in parentheses. In column (7), IT and the workplace organization variables are included as lagged values, i.e. t-3.

2.5.5 Discussion of the results

There are several possible explanations as to why the combination of IT and decentralized workplace organization is not significantly linked with higher productivity for SMEs in contrast to the results for large firms which emerged here and in prior empirical work based on samples of mainly large firms. First, it might be that synergies from combining IT and decentralization are not that strong for smaller firms in comparison to larger firms. Giuri, Torrisi, and Zinovyeva (2008) argue that given differences in characteristics between small and large firms related to complexity and flexibility of work routines, financial capabilities, amount of information or skill composition that originate from the different size, there might be reasons to believe that complementarities between IT and organizational change are generally less present in SMEs. For instance, since large firms have to coordinate more information, tasks and people, they will have greater demand for ICT and complementary investments such as workplace reorganization and should also benefit more from implementing the complementary system. The incremental gain from combining IT with decentralized workplace organization might be smaller for SMEs than for larger firms, for instance, because of a smaller market share and a smaller sales volume. An alternative explanation could be that employees in SMEs can specialize less in their tasks than employees in large firms because of the smaller workforce. Even if SMEs decentralize formally, for instance by having self-responsible business units, employees might still have to multi-task. Consequently, in light of constraints on human information processing capabilities, they might benefit less from an improved information basis enabled by IT. Generally, firms of different size might have different abilities to use IT effectively and empirical evidence has shown that small firms derive smaller marginal products from IT investments than large firms, which is consistent with the hypothesis that large firms are better equipped to benefit from IT-related complementary investments (Tambe and Hitt 2012).

Another possibility leading to an insignificant interaction term might be that the indicators used in the empirical analysis to measure IT intensity and decentralization suffer from measurement error and capture only specific channels of the economic effects of IT, decentralization and incentive-setting.[33] In particular, the variables for workplace organization are only binary variables, so they do not capture any intensive margin of decentralization and incentive-setting as broader decentralization indicators do that are used in prior work with other data sets. If measurement error is present, the estimates are downwardly biased. Although this possibility cannot be completely ruled out, the positive

[33] See Section 2.3 for a discussion of the economic interpretation of the IT indicator and the workplace organization variables.

and significant coefficient estimates for IT and decentralized workplace organization in isolation, even when controlling for other relevant sources of firm heterogeneity, provide credibility that the measures capture at least to some extent firms' IT and decentralization intensity.

A third possibility why IT combined with decentralization is not significantly related to higher productivity might be that the benefits of this combination depend on other firm characteristics. These factors are possibly intangibles since prior research has demonstrated the role of the corporate learning type (Mahr and Kretschmer 2010) or external focus (Tambe, Hitt, and Brynjolfsson 2012) for the productivity effects of IT and decentralization, and of human resource analytics for the effects of IT and performance pay (Aral, Brynjolfsson, and L. Wu 2012). Finally, Tambe, Hitt, and Brynjolfsson (2012) find an insignificant interaction term between IT and decentralization, while their coefficients on IT and decentralization are individually significant. They argue that it might be that most IT-intensive firms have adopted decentralized work practices in recent years, so that there are minimal marginal effects on productivity from this combination. This argument might be valid for SMEs, too, given that the time period of the data starting in 2004 is fairly recent and can be seen as rather late for IT equipment adoption, such as enterprise software. However, given that only 28 percent of the SMEs in the sample have an own business unit in contrast to 70 percent in the large firms sample, this argument might be less valid for the sample of SMEs used for the empirical analysis.

Given the nature of the data and the econometric techniques I can apply, there are some limitations to the interpretation of the results. I can control for a large part of alternative firm heterogeneity that is likely to be relevant for higher levels of IT and decentralized workplace organization as well as higher productivity levels. This allows to rule out some alternative explanations for the positive association between IT, workplace organization and productivity and to reduce endogeneity concerns due to omitted variable bias. One potential source of remaining relevant firm heterogeneity are unobserved individual firm fixed effects that capture quasi-fixed organizational factors such as management ability. However, part of the individual time-invariant firm heterogeneity is captured already by taking explicitly account of workplace organization. Under the additional assumption that the work organization practices considered are positively correlated with management ability, the measures for workplace organization can be seen as a proxy for management ability so that the bias from omitted management ability will be alleviated.

A direct method with panel data to check the impact of omitted variable bias on the coefficient estimates of the explanatory variables due to firm fixed effects would be to control for them using fixed effects estimation. The fixed effects estimator is valid under the assumption that the unobserved heterogeneity is correlated with the explanatory variables.[34] This assumption is likely to be the case in my analysis, in particular for IT and decentralization as my main variables of interest. A property of the fixed effects estimator is that it does not provide estimates for fully time-invariant variables and only very imprecise estimates for rather stable variables (Cameron and Trivedi 2009). Since the IT and organizational variables are close to time-invariant within the sample period for an individual firm with multiple participation and the majority of firms in the sample is only surveyed once, the fixed effects estimator does not seem to be an appropriate estimator for the available data. In general, fixed effects estimated IT coefficients have turned out to be lower than estimates from pooled OLS, where the latter do not consider individual time-invariant firm heterogeneity. One reason for this is that the fixed effects estimator eliminates any IT benefits that are persistent over time at the firm level (Cardona, Kretschmer, and Strobel 2013).

Another source for biased coefficient results might be endogeneity due to simultaneity. If firms with a positive productivity shock adjust their IT levels correspondingly or if more productive firms are more likely to adopt IT and decentralized and incentive-based work organization, the coefficients on IT and work organization will be upward biased.[35] This is particularly likely for the enterprise software coefficient in light of results by Aral, Brynjolfsson, and D. Wu (2006) who find that firms with successful ERP adoption keep on adopting SCM and/or CRM.

Since the majority of firms in the estimation sample participated only in one wave of the ICT survey, the data set is not rich enough to apply panel data techniques because such techniques require generally at least a minimum of three periods for each firm. So I cannot use estimators that allow to control for simultaneity or reverse causality, such as estimators by Olley and Pakes (1996), Levinsohn and Petrin (2003), Arellano and Bond (1991), or the Blundell and Bond (2000) System-GMM estimator do.[36] Tambe and Hitt (2012) could apply such techniques and the comparison of the coefficient estimates across different estimators shows that even though the unadjusted cross-sectional estimates of

[34]For consistency of the estimates, more assumptions are needed, most importantly that the explanatory variables are strictly exogenous. While this assumption may hold in static models, it is violated in dynamic models with lagged dependent variables. Thus, the fixed effects estimator is inconsistent in dynamic models.

[35]Similarly, the labour coefficient will be upward biased under OLS in a setting with a positively transmitted productivity shock and labour as a variable input. Under the assumption that capital is a less flexible input factor than labour, the bias of the capital coefficient depends on the correlation between capital and the transmitted productivity shock in comparison to the corresponding correlation between the shock and variable inputs (see Levinsohn and Petrin 2003, pp. 332f.).

[36]In 2.7.4 in the appendix, dynamic panel data results are presented for a subsample of the total estimation sample for which information from three waves is available.

IT productivity are slightly upward biased, overall, the IT productivity estimates seem to suffer from a relatively small endogeneity bias. In view of those findings, the OLS-based IT coefficient estimates in this chapter are likely to be upward biased but the endogeneity bias is likely to be rather small, too.

2.5.6 Results for manufacturing and services separately

Table 2.10 and Table 2.11 show the results from correlation and productivity analyses separately for manufacturing and service SMEs, respectively. The correlation analysis shows that manufacturing as well as service SMEs with decentralized and incentive-based workplace organization use the enterprise software systems considered more intensively. One difference between the sectors is that while in manufacturing the share of highly skilled employees is significantly positively related to IT, it is negatively correlated for service firms.[37] For large firms, in manufacturing only self-managed teams are positively related to higher enterprise software use intensity, while for service firms, only performance pay is linked with higher software use intensity (Table 2.10).

The separate productivity analysis shows some differences between the two sectors, too (Table 2.11). For SMEs in manufacturing, the marginal productivity effect of enterprise software intensity is only significantly positive in a basic production function set-up with labour and capital inputs (column (1)). When taking account of workplace organization and the share of computer employees, enterprise software intensity does no longer raise productivity significantly (column (2)). This indicates that for manufacturing SMEs with a similar workplace organization and computer work intensity, differences in enterprise software use intensity do not explain productivity differences. This might be because most manufacturing firms who can benefit from enterprise software systems may have already implemented those systems before the time period of the sample, leading no longer to extra productivity improvements from them in the sample time period. However, the coefficient of the share of employees working mainly at the computer is significant and large in magnitude, and more than two times larger than in services. For service SMEs, more intensive enterprise software use as well as a higher share of employees working mainly at the computer are associated with a higher productivity level (columns (9) to (12)). Decentralized workplace organization measured by a self-responsible business unit and performance pay are significantly positively related to productivity for manufacturing

[37]However, this result is not significant without controlling for the share of computer workers (column (4), Table 2.10). Thus, the negative coefficient for the share of high-skilled employees should be interpreted in the way that for a given computer work intensity, human capital intensive firms use enterprise software less intensively than otherwise similar firms but not that in general, highly skilled human capital is negatively related to IT intensity.

Table 2.10: Correlations between enterprise software intensity and workplace organization - Manufacturing versus services for SMEs and large firms

Dependent variable: Enterprise software - IT intensity					
	Manufacturing		Services		
	SMEs	Large	SMEs		Large
	(1)	(2)	(3)	(4)	(5)
Self-responsible business unit (BU)	0.244***	-0.101	0.349***	0.367***	0.174
	(0.050)	(0.104)	(0.053)	(0.054)	(0.151)
Team work (TW)	0.174***	0.261**	0.067	0.090*	0.047
	(0.038)	(0.118)	(0.046)	(0.047)	(0.151)
Performance pay (PP)	0.150***	0.164	0.138***	0.147***	0.317*
	(0.040)	(0.147)	(0.047)	(0.047)	(0.162)
log(employment)	0.270***	0.197***	0.184***	0.167***	0.104
	(0.024)	(0.054)	(0.026)	(0.027)	(0.074)
% Empl. working with PC	0.658***	0.102	0.520***		0.451*
	(0.094)	(0.267)	(0.084)		(0.236)
% Highly skilled empl.	0.279**	0.896**	-0.250**	-0.38	0.028
	(0.140)	(0.376)	(0.104)	(0.101)	(0.399)
Export activity	0.206***	0.201	0.154***	0.151***	0.274*
	(0.044)	(0.203)	(0.049)	(0.049)	(0.149)
Works council	0.014	0.208	0.042	0.036	-0.223
	(0.053)	(0.174)	(0.069)	(0.070)	(0.181)
Change in management	0.035	0.229***	-0.052	-0.044	0.060
	(0.045)	(0.087)	(0.057)	(0.056)	(0.131)
Constant	-1.743***	-2.190***	-0.925***	-0.719***	-1.492***
	(0.098)	(0.442)	(0.123)	(0.121)	(0.545)
Control variables	yes	yes	yes	yes	
Number of observations	2442	499	2045	2045	264
Number of firms	1825	397	1515	1515	205
Adjusted R^2	0.2714	0.0990	0.2121	0.2074	0.0850

Significance levels: * : 10% ** : 5% * * * : 1%. Control variables include industry dummy variables based on two-digit classification interacted with a full set of year fixed effects, a dummy variable for location equal to one if the firm is in one new German Bundesland (member state), i.e. formerly East Germany, and a dummy variable if the firm belongs to a multi-plant group. Robust standard errors clustered at the firm level in parentheses.

and services. Unlike the results from the total sample, the interaction term between IT and self-responsible business unit is weakly significantly negative for manufacturing SMEs.

Similar to the results for the total SMEs sample, for both, manufacturing and service firms, three years lagged productivity is a relevant factor to explain current productivity (columns (6) and (7) for manufacturing firms, columns (13) and (14) for service firms). Equally as for the total sample, most coefficient estimates of the other variables reduce in magnitude and partly also turn insignificant when accounting for lagged productivity.[38]

For large firms, increasing enterprise software intensity combined with a self-responsible business unit is associated significantly with higher productivity for large service firms only (Table 2.12, columns (8) and (9)). For manufacturing large firms, the respective interaction term is not significant. This shows that the positive combination effect found

[38] See Subsection 2.5.3 for further comments on the implications of accounting for lagged values.

with the total sample of large firms is mainly from heterogeneity in productivity between service firms with different combinations of IT and this workplace organization decision. Without controlling for interactions between IT and work organization, more intensive IT use raises productivity for manufacturing and service firms where the positive relation is stronger for service firms (coefficient: 0.179***, column (10)) than for manufacturing firms (coefficient: 0.065***, column (5)). However, a higher share of high-skilled employees is associated with higher productivity only for manufacturing firms. Otherwise, the results from the separate industry analysis for large firms do not provide qualitatively different results in comparison to the results for the total sample together. In particular, none of the individual workplace organization variables is significantly linked with higher productivity.[39]

Comparing the results of large firms with SMEs, the ranking remains that large firms have a higher enterprise software marginal productivity than SMEs, whereas the relationship between the computer work intensity and productivity is stronger for SMEs.

[39] There is no empirical analysis conducted separately for large manufacturing and service firms that takes account of lagged values because the remaining samples would be too small for allowing meaningful conclusions of the results: There are 102 manufacturing large firms left, and 59 service firms. The sample reduces because of the unbalanced panel data structure with the majority of firms having participated only once in the survey.

Table 2.11: Productivity regressions of IT and workplace organization - SMEs: Manufacturing versus services

	All industries, dependent variable: log(value added)													
	Manufacturing							Services						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
IT - Index(ERP+CRM+SCM)	0.078***	0.012	-0.001	-0.011	0.003	-0.070	-0.048	0.107***	0.068***	0.074**	0.074**	0.066***	0.045	0.077*
	(0.017)	(0.017)	(0.031)	(0.030)	(0.017)	(0.046)	(0.042)	(0.020)	(0.019)	(0.034)	(0.034)	(0.019)	(0.039)	(0.041)
Self-responsible business unit (BU)		0.100**	0.118***	0.115***	0.098**	0.059	0.029		0.212***	0.206***	0.199***	0.206***	0.114*	0.035
		(0.039)	(0.040)	(0.040)	(0.039)	(0.058)	(0.064)		(0.043)	(0.044)	(0.044)	(0.043)	(0.063)	(0.056)
Team work (TW)		-0.005	-0.007	-0.002	0.000	0.054	-0.000		-0.022	-0.024	-0.028	-0.026	-0.001	0.041
		(0.031)	(0.031)	(0.031)	(0.031)	(0.046)	(0.045)		(0.040)	(0.040)	(0.040)	(0.040)	(0.050)	(0.050)
Performance pay (PP)		0.104***	0.107***	0.101***	0.097***	0.078	0.101**		0.087**	0.087**	0.084**	0.083**	-0.029	-0.013
		(0.032)	(0.032)	(0.032)	(0.032)	(0.051)	(0.050)		(0.038)	(0.038)	(0.038)	(0.038)	(0.049)	(0.049)
IT * BU			-0.066*	-0.062*		-0.064	-0.014			0.033	0.033		-0.035	0.029
			(0.038)	(0.038)		(0.057)	(0.055)			(0.038)	(0.038)		(0.062)	(0.052)
IT * TW			0.008	0.008		0.057	0.047			-0.055	-0.056		-0.031	-0.072
			(0.033)	(0.033)		(0.049)	(0.043)			(0.038)	(0.038)		(0.048)	(0.044)
IT * PP			0.046	0.046		0.028	0.027			0.027	0.026		-0.000	-0.067
			(0.032)	(0.032)		(0.050)	(0.046)			(0.038)	(0.039)		(0.052)	(0.047)
log(employment)	0.923***	0.939***	0.937***	0.898***	0.899***	0.513***	0.513***	0.848***	0.832***	0.831***	0.813***	0.813***	0.355***	0.358***
	(0.024)	(0.023)	(0.023)	(0.026)	(0.026)	(0.072)	(0.076)	(0.026)	(0.026)	(0.026)	(0.027)	(0.027)	(0.045)	(0.045)
log(capital stock)	0.123***	0.104***	0.104***	0.099***	0.100***	0.042	0.037	0.113***	0.110***	0.110***	0.107***	0.107***	0.072***	0.075***
	(0.015)	(0.015)	(0.014)	(0.014)	(0.014)	(0.026)	(0.027)	(0.018)	(0.017)	(0.017)	(0.017)	(0.017)	(0.022)	(0.022)
% Empl. working with PC		0.925***	0.924***	0.805***	0.807***	0.380***	0.368***		0.332***	0.330***	0.310***	0.312***	0.073	0.081
		(0.081)	(0.081)	(0.097)	(0.097)	(0.126)	(0.127)		(0.077)	(0.077)	(0.082)	(0.082)	(0.089)	(0.089)
% Highly skilled empl.				0.222	0.218	0.439**	0.402**				0.075	0.073	-0.027	-0.054
				(0.173)	(0.173)	(0.210)	(0.204)				(0.087)	(0.087)	(0.111)	(0.112)
Export activity				0.150***	0.149***	0.094	0.107*				0.073*	0.073*	0.061	0.058
				(0.038)	(0.038)	(0.063)	(0.062)				(0.041)	(0.041)	(0.052)	(0.053)
Works council				0.102**	0.105**	-0.036	-0.050				0.118*	0.119*	-0.057	-0.048
				(0.040)	(0.041)	(0.063)	(0.062)				(0.062)	(0.062)	(0.081)	(0.080)
Change in management				0.077*	0.079**	-0.001	0.011				-0.025	-0.021	0.008	0.023
				(0.040)	(0.040)	(0.066)	(0.068)				(0.050)	(0.049)	(0.064)	(0.064)
Productivity (t-3)						0.529***	0.528***						0.563***	0.565***
						(0.061)	(0.062)						(0.048)	(0.050)
Constant	9.094***	8.977***	8.983***	9.085***	9.082***	3.785***	3.899***	9.332***	9.216***	9.216***	9.297***	9.297***	3.583***	3.504***
	(0.182)	(0.177)	(0.176)	(0.175)	(0.176)	(0.724)	(0.760)	(0.223)	(0.213)	(0.214)	(0.219)	(0.219)	(0.516)	(0.527)
Control variables	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Number of observations	2442	2442	2442	2442	2442	617	617	2045	2045	2045	2045	2045	530	530
Number of firms	1825	1825	1825	1825	1825	517	517	1515	1515	1515	1515	1515	429	429
Adjusted R^2	0.7557	0.7785	0.7787	0.7819	0.7818	0.8525	0.8517	0.6842	0.6949	0.6950	0.6959	0.6958	0.8069	0.8072

Significance levels: * : 10% ** : 5% *** : 1%. Control variables include industry dummy variables based on two-digit classification interacted with a full set of year fixed effects, a dummy variable for location equal to one if the firm is in one new German Bundesland (member state), i.e. formerly East Germany, and a dummy variable if the firm belongs to a multi-plant group. Robust standard errors clustered at the firm level in parentheses. In column (7) and (14), IT and the workplace organization variables are included as lagged values, i.e. t-3.

Table 2.12: Productivity regressions of IT and workplace organization - Large firms: Manufacturing versus services

	All industries, dependent variable: log(value added)									
	Manufacturing					Services				
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
IT - Index(ERP+CRM+SCM)	0.092***	0.086***	0.045	0.045	0.065**	0.170***	0.175***	-0.072	-0.077	0.179***
	(0.030)	(0.030)	(0.054)	(0.053)	(0.029)	(0.042)	(0.046)	(0.148)	(0.145)	(0.045)
Self-responsible business unit (BU)		0.093	0.095	0.077	0.076		-0.051	-0.023	-0.040	-0.065
		(0.062)	(0.062)	(0.060)	(0.059)		(0.110)	(0.115)	(0.114)	(0.110)
Team work (TW)		0.013	0.010	0.015	0.017		-0.066	-0.054	-0.061	-0.073
		(0.065)	(0.065)	(0.064)	(0.063)		(0.110)	(0.111)	(0.110)	(0.110)
Performance pay (PP)		-0.001	0.013	0.007	-0.000		-0.182	-0.142	-0.130	-0.177
		(0.076)	(0.077)	(0.079)	(0.077)		(0.131)	(0.145)	(0.147)	(0.135)
IT * BU			0.028	0.023				0.208**	0.200**	
			(0.064)	(0.062)				(0.098)	(0.100)	
IT * TW			-0.036	-0.022				-0.019	-0.017	
			(0.067)	(0.064)				(0.089)	(0.088)	
IT * PP			0.057	0.025				0.133	0.146	
			(0.067)	(0.064)				(0.116)	(0.115)	
log(employment)	0.867***	0.859***	0.860***	0.843***	0.843***	0.807***	0.826***	0.823***	0.818***	0.818***
	(0.052)	(0.054)	(0.053)	(0.050)	(0.051)	(0.068)	(0.065)	(0.066)	(0.065)	(0.064)
log(capital stock)	0.131***	0.132***	0.132***	0.134***	0.133***	0.168***	0.167***	0.161***	0.161***	0.168***
	(0.029)	(0.030)	(0.029)	(0.028)	(0.028)	(0.043)	(0.043)	(0.044)	(0.044)	(0.042)
% Empl. working with PC		0.361**	0.367***	0.166	0.162		0.209	0.204	0.176	0.181
		(0.140)	(0.141)	(0.143)	(0.142)		(0.195)	(0.193)	(0.192)	(0.193)
% Highly skilled empl.				0.794***	0.797***				0.198	0.175
				(0.232)	(0.231)				(0.278)	(0.280)
Export activity				0.225	0.236*				0.038	0.031
				(0.136)	(0.137)				(0.102)	(0.104)
Works council				0.298*	0.298*				0.085	0.109
				(0.164)	(0.163)				(0.136)	(0.139)
Change in management				0.045	0.046				-0.079	-0.070
				(0.053)	(0.053)				(0.090)	(0.090)
Constant	9.434***	9.249***	9.237***	8.809***	8.806***	8.544***	8.559***	8.582***	8.582***	8.562***
	(0.411)	(0.412)	(0.415)	(0.451)	(0.449)	(0.574)	(0.607)	(0.591)	(0.593)	(0.610)
Control variables	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Number of observations	499	499	499	499	499	264	264	264	264	264
Number of firms	397	397	397	397	397	205	205	205	205	205
Adjusted R^2	0.6839	0.6885	0.6873	0.7009	0.7025	0.7114	0.7123	0.7162	0.7137	0.7099

Significance levels: $*$: 10% $**$: 5% $***$: 1%. Control variables include industry dummy variables based on two-digit classification interacted with a full set of year fixed effects, a dummy variable for location equal to one if the firm is in one new German Bundesland (member state), i.e. formerly East Germany, and a dummy variable if the firm belongs to a multi-plant group. Robust standard errors clustered at the firm level in parentheses.

2.6 Conclusion

The goal of this chapter was to increase the knowledge about the relationship between IT and decentralized and incentive-based workplace organization and about their productivity contributions in SMEs in comparison to larger firms. Given that SMEs play an important role for employment and the creation of economic value in Germany, examining which factors contribute to productivity for firms of this size is relevant for policymakers to understand determinants of the economy's productivity performance. Moreover, the comparison of the findings between SMEs and larger firms allows similarities and differences to be analysed in light of arguments for different IT usage capabilities for firms of different size.

Indeed, the empirical results presented in this chapter show different productivity contributions from combining IT and decentralization for SMEs than for large firms. For SMEs, the combination of IT and decentralized workplace organization is not robustly related to higher productivity. However, IT and decentralized and incentive-based workplace organization are individually linked with higher productivity. In contrast, the results for large firms support prior evidence of higher productivity from combining IT and decentralization. In spite of the different results for combination effects between IT and workplace organization for SMEs and larger firms, the results are consistent with the hypothesis that firms which use IT to organize their production and business processes are more productive. Moreover, the results underline the relevance of workplace organization for firm outcomes.

Given that there is little evidence on complementarity between IT and decentralization for SMEs, the results cast doubt on whether productivity-enhancing interaction effects from IT and decentralized work practices have ever been present for smaller firms. In small firms, coordination issues between different subunits and the optimal use of information are probably on average easier to handle regardless of their decentralization degree than in large firms. Thus, small firms might on average have lower demand for formal decentralization as they might benefit less from it. Alternatively, they might be less adept than large firms in employing IT and accompanying it with complementary investments. These could be explanations why the results do not show that the productivity of IT in SMEs depends positively on decentralized workplace organization as for large firms. The comparison of results across firm size suggests that findings on IT returns from larger firms cannot necessarily be generalized to smaller firms.

There are some limitations to the interpretation of the results that leave important questions open for future research. Most importantly, only a small number of work organization practices could be included, capturing only a small part of a firm's workplace organization. More empirical evidence on IT returns and the role of IT-related intangibles in SMEs, such as work reorganization or training, would be helpful to understand the impact of IT in smaller firms better and to see whether there are differences between small and large firms as found in this chapter and by recent research (e.g. Tambe and Hitt 2012). Moreover, my findings raise questions about possible reasons for different levels of IT intensity and workplace organization. Are there financial barriers preventing firms from investing more in IT, or do firms lack internal IT knowledge to implement advanced IT solutions? In light of an ongoing digitization of economic processes, using information as an input to the value creation process and to gain competitive advantage will remain important for firm success. A better understanding why firms of similar size use different IT levels and workplace organization practices and which barriers of adoption they face could help policymakers designing supportive policy measures, for instance, by providing access to facilitated funding or special IT training sessions for SMEs.

2.7 Appendix

2.7.1 Data from the Federal Statistical Office of Germany

I use information from the German National Accounts from 2012 ("Volkswirtschaftliche Gesamtrechnung 2012" Fachserie 18, Reihe 1.4) provided by the Federal Statistical Office of Germany and published in September 2013 to construct a measure for real value added from total sales that are available in the ICT survey and to deflate gross investment. For real value added, I create a correction factor equal to the ratio of price-adjusted value added over the nominal total production value in euro by two-digit industry (WZ 2008 industry values) and year. The year 2005 serves as the base year for the deflation of the nominal values. This correction factor *CFVA* provides a measure for the yearly j average share of real value added in the nominal total production value at the two-digit industry level j:

$$\text{CFVA}_{jt} = \frac{\text{price-adjusted value added}_{jt}}{\text{nominal total production value}_{jt}}$$

Then, firms' total sales, where i indicates each firm, are multiplied with this correction factor to obtain an approximation for the firms' real value added in the respective year. The following equation summarizes the construction of real value added:

$$\text{deflated value added}_{it} = \text{nominal sales}_{it} * \text{CFVA}_{jt}$$

To obtain deflated gross investment, a correction factor *CFINV* is created that measures the average share of price-adjusted gross investment over nominal gross investment at the year and two-digit industry level. Then, firms' yearly gross investment is multiplied with this correction factor. The calculations are formalized in the following two equations:

$$\text{CFINV}_{jt} = \frac{\text{price-adjusted gross investment}_{jt}}{\text{nominal gross investment}_{jt}}$$

$$\text{deflated gross investment}_{it} = \text{nominal gross investment}_{it} * \text{CFINV}_{jt}$$

If firms reported zero investment, in order to not lose these observations, I replace gross investment with the 10th percentile of gross investment per employee in the corresponding industry multiplied by the firm's number of employees. For some industries also the 10th percentile of gross investment is zero so that in this case the 15th percentile value is used.

2.7.2 Construction of the capital stock

The capital stock is based on the deflated gross investment (see above) and constructed using the perpetual inventory method (PIM) (see, e.g., Hall and Mairesse (1995) for an application of the PIM to construct a knowledge capital stock). The PIM specifies how to estimate an initial capital stock value and the continuation values for the period of available information on investment. According to the PIM, an initial capital stock value can be estimated by the following equation:

$$K_1 = \frac{I_1}{g + \delta}$$

where I_1 stands for investment in the first period, g for the annual average growth rate of investment and δ for the average depreciation rate of capital within the period of the available data. In case of the ICT survey, the information on gross investment is at most available for five periods, although for the majority of observations rather less times due to the unbalanced panel structure. Instead of taking the initial investment data to compute an estimate of the initial capital stock, I use the average investment level of the data points, which are available, in order to minimize the influence of outliers on the estimate of the initial capital stock. Thus, the formula for the initial capital stock becomes:

$$K_1 = \frac{\text{mean}(I)}{g + \delta}$$

The average depreciation rate δ is computed using the average industry-wide depreciation rate from 1999 until 2009 provided by the national accounts data. The time frame covers the time period of the available ICT survey data. The growth rate of capital g is set to the value 0.05 based on Hall and Mairesse (1995).

The continuation values of the capital stock that take account of the yearly capital accumulation are specified as follows:

$$K_t = (1 - \delta)K_{t-1} + I_t$$

where t represents the time period. Since the ICT survey is constructed as an unbalanced survey, the capital accumulation equation must be adjusted for the period differences between the data points of the years that are available for each firm. For instance, a firm may only have been surveyed in 2002 and 2010. Then, there is only information on investment for these years. Consequently, the capital stock accumulation must consider the time lag of eight years for the depreciation rate of capital and the growth rate of investment. These considerations are summarized in the following formula:

$$K_t = (1-\delta)^{t-n} K_n + I_n \sum_{s=1}^{t-n-1} (1-\delta)^{t-n-s} (1+g)^s + I_t$$

where $n < t$. For the example of data available only for 2002 and 2010, n is equal to 2002 and t to 2010. This formula is obtained from recursive substitution of the last period's available capital accumulation equation.

2.7.3 Additional tables

Table 2.13: Industry distribution in full sample and the complete data set from 2004, 2007, 2010

Industry	N	% of sample	N	% of data set	N	% of sample	N	% of data set
		SMEs				*Large firms*		
Manufacturing sector								
Consumer goods	527	11.73	941	11.56	89	11.66	184	10.47
Chemical and pharmaceutical industry	221	4.93	425	5.22	36	4.72	111	6.38
Other raw materials	340	7.58	647	7.95	69	9.04	145	8.33
Metal industry	347	7.73	611	7.51	57	7.47	129	7.41
Electrical engineering	473	10.54	846	10.40	85	11.14	207	11.89
Machine construction	326	7.27	538	6.61	80	10.48	162	9.30
Vehicle construction	208	4.64	399	4.90	83	10.88	167	9.59
Service sector								
Retail trade	311	6.93	633	7.78	37	4.85	91	5.23
Wholesale trade	233	5.19	421	5.17	29	3.80	78	4.48
Transportation	319	7.11	617	7.58	59	7.73	142	8.16
Media services	156	3.48	250	3.07	29	3.80	63	3.62
IT and other information services	383	8.54	667	8.20	45	5.90	100	5.74
Business consultancy and advertising	142	3.16	253	3.11	14	1.83	33	1.90
Technical services	375	8.36	633	7.78	30	3.93	69	3.96
Other business services	126	2.81	256	3.15	22	2.88	60	3.45
Total number of observations	4487	100	8137	100	763	100	1741	100

Data source: ZEW ICT Panel 2004, 2007, 2010.

Table 2.14: Descriptive statistics of main variables for firms in the estimation sample and for firms excluded due to item non-response of variables

	Estimation sample				Not in estimation sample			
Variable	N	Mean	SD	Median	N	Mean	SD	Median
				SMEs				
ERP	4487	1.03	0.88	1	3424	1.00	0.89	1
SCM	4487	0.50	0.74	0	3472	0.48	0.74	0
CRM	4487	0.60	0.77	0	3461	0.61	0.78	0
BU	4487	0.28	0.45	0	2478	0.23	0.42	0
TW	4487	0.59	0.49	1	2498	0.59	0.49	1
PP	4487	0.53	0.50	1	2471	0.50	0.50	1
Employment	4487	52	57.15	28	3650	60	64.10	30
Capital stock	4487	183	8920	3.00	116	202	1810	2.18
Value added (deflated)	4487	3.39	7.84	1.15	3650	4.5	134	1.29
				Large firms				
ERP	763	1.72	0.58	2	1041	1.68	0.64	2
SCM	763	1.07	0.79	1	1036	1.09	0.82	1
CRM	763	0.99	0.75	1	1029	1.08	0.80	1
BU	763	0.70	0.46	1	804	0.69	0.46	1
TW	763	0.76	0.43	1	786	0.77	0.42	1
PP	763	0.85	0.36	1	796	0.82	0.38	1
Employment	763	1158	2756.26	550	1050	1960	5496.08	634
Capital stock	763	349	969	105	285	864	5160	124
Value added (deflated)	763	82.3	271	29.6	1050	200	832	36.4

Data source: ZEW ICT Panel 2004, 2007, 2010. The values of capital stock and value added are expressed in millions of euros. Deflated values are in prices of 2005.

Table 2.15: Tests of equality of means by industry

Industry	ERP	SCM	CRM	Business unit with own P&L	Self-responsible team work	Performance pay	Employment	Capital stock	Value added (deflated)
					SMEs				
Manufacturing sector									
Consumer goods	0.405	0.628	0.167	0.020**	0.305	0.530	0.558	0.228	0.954
Chemical and pharmaceutical industry	0.425	0.092*	0.009***	0.626	0.868	0.296	0.014**	0.277	0.302
Other raw materials	0.005***	0.560	0.254	0.007***	0.001***	0.004***	0.064*	0.099*	0.590
Metal industry	0.935	0.367	0.552	0.655	0.092*	0.856	0.005***	0.299	0.203
Electrical engineering	0.034**	0.042**	0.953	0.169	0.475	0.227	0.568	0.613	0.961
Machine construction	0.640	0.858	0.797	0.160	0.654	0.380	0.285	0.008***	0.254
Vehicle construction	0.049**	0.063*	0.094*	0.187	0.506	0.152	0.585	0.606	0.352
Service sector									
Retail trade	0.872	0.876	0.897	0.185	0.797	0.238	0.002***	0.716	0.025**
Wholesale trade	0.507	0.086*	0.149	0.041**	0.131	0.260	0.002***	0.589	0.599
Transportation	0.476	0.017**	0.181	0.373	0.002***	0.558	0.140	0.507	0.052**
Media services	0.349	0.630	0.688	0.827	0.006***	0.643	0.097*	0.670	0.181
IT and other information services	0.915	0.483	0.259	0.619	0.619	0.088*	0.016**	0.832	0.000
Business consultancy and advertising	0.228	0.529	0.596	0.177	0.871	0.472	0.078*	0.797	0.094*
Technical services	0.667	0.415	0.393	0.914	0.415	0.293	0.000***	0.658	0.010**
Other business services	0.353	0.980	0.272	0.244	0.564	0.505	0.006***	0.111	0.018**
					Large firms				
Manufacturing sector									
Consumer goods	0.65	0.967	0.627	0.005***	0.207	0.627	0.362	0.892	0.823
Chemical and pharmaceutical industry	0.945	0.723	0.762	0.791	0.111	0.760	0.244	0.139	0.221
Other raw materials	0.858	0.261	0.174	0.366	0.15	0.833	0.040**	0.402	0.213
Metal industry	0.813	0.652	0.107	0.224	0.113	0.452	0.179	0.018**	0.217
Electrical engineering	0.121	0.655	0.546	0.963	0.681	0.084	0.283	0.311	0.051*
Machine construction	0.257	0.910	0.759	0.852	0.651	0.741	0.515	0.828	0.669
Vehicle construction	0.052*	0.285	0.106	0.1854	0.989	0.835	0.080*	0.855	0.139
Service sector									
Retail trade	0.380	0.504	0.662	0.278	0.205	0.620	0.237	0.001***	0.150
Wholesale trade	0.873	0.563	0.387	0.1867	0.904	0.671	0.266	0.305	0.362
Transportation	0.894	0.199	0.450	0.179	0.125	0.817	0.954	0.937	0.330
Media services	0.335	0.794	0.004***	0.000***	0.102	0.947	0.374	0.618	0.106
IT and other information services	0.061*	0.239	0.080*	0.749	0.011	0.544	0.073*	0.684	0.047**
Business consultancy and advertising	0.962	0.670	0.269	0.012	0.126	0.368	0.450	0.579	0.579
Technical services	0.314	0.565	0.722	0.941	0.520	0.060*	0.327	0.085*	0.184
Other business services	0.410	0.878	0.863	0.861	0.662	0.526	0.230	0.491	0.080*

Data source: ZEW ICT Panel 2004, 2007, 2010. Each cell includes the p-value of a test on the equality of means of the corresponding variable by industry between the mean of the firms included in the estimation sample and the mean of the firms non-included in the estimation due to item non-response for the main set of variables used in the empirical analysis.

Table 2.16: Transition probabilities and persistence statistics for the workplace organization variables

	Transition probabilities				Within summary	
	0→0	0→1	1→0	1→1	0	1
	SMEs					
Business unit	96.41	3.59	16.20	83.80	97.96	94.77
Team work	85.37	14.63	9.62	90.38	94.42	96.28
Performance pay	90.28	9.72	10.62	89.38	95.95	96.41
	Large firms					
Business unit	89.50	10.42	6.09	93.91	95.68	98.38
Team work	78.38	21.62	7.14	92.86	94.55	97.90
Performance pay	85.19	14.81	2.94	97.06	95.16	99.12

Data source: ZEW ICT Panel 2004, 2007, 2010. Transition probabilities are from one period to the next. For instance, the value in the cell for 0→0 shows how many of the firms in the sample with multiple participation, which did not have a certain workplace organization practice, do not have this workplace practice in the next period, either. The within summary statistics indicates for the value 0 how many of the firms with multiple participation never had a certain work organization practice and for the value 1 how many of them always had a certain practice.

Table 2.17: Descriptive statistics of further firm characteristics

Variable	Mean	SD	Mean	SD	Min.	Max.
	SMEs (N=4487)		*Large firms* (N=763)			
% Empl. working with PC	0.45	0.34	0.41	0.27	0	1
% Highly skilled employees	0.21	0.26	0.19	0.20	0	1
% Exporters	0.51	0.50	0.74	0.44	0	1
% Works council	0.23	0.42	0.89	0.32	0	1
% Change in management	0.18	0.39	0.46	0.50	0	1

Data source: ZEW ICT Panel 2004, 2007, 2010.

Table 2.18: Descriptive statistics of logarithmic production function variables

Variable	Mean	SD	Min.	Max.	Mean	SD	Min.	Max.
	SMEs (N=4487)				*Large firms* (N=763)			
log(employment)	3.40	1.08	1.61	5.52	6.49	0.82	5.53	10.58
log(capital stock)	14.95	1.79	8.71	27.09	18.45	1.56	10.47	18.45
log(value added)	14.03	1.40	10.05	18.84	17.34	1.09	14.10	22.44

Data source: ZEW ICT Panel 2004, 2007, 2010.

Table 2.19: Productivity regressions of IT and workplace organization (WO) for SMEs - Separate regressions for WO variables

	All industries, dependent variable: log(value added)								
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
IT - Index(ERP+CRM+SCM)		0.050***	0.048***		0.061***	0.063***		0.055***	0.027
		(0.013)	(0.015)		(0.013)	(0.021)		(0.013)	(0.019)
Self-responsible business unit (BU)	0.181***	0.165***	0.163***						
	(0.029)	(0.030)	(0.030)						
Team work (TW)				0.020	0.009	0.008			
				(0.025)	(0.025)	(0.025)			
Performance pay (PP)							0.120***	0.110***	0.104***
							(0.025)	(0.025)	(0.025)
IT * BU			-0.014						
			(0.026)						
IT * TW						-0.013			
						(0.025)			
IT * PP									0.039
									(0.024)
log(employment)	0.907***	0.896***	0.862***	0.925***	0.910***	0.875***	0.914***	0.901***	0.868***
	(0.018)	(0.018)	(0.019)	(0.018)	(0.018)	(0.019)	(0.018)	(0.018)	(0.019)
log(capital stock)	0.115***	0.112***	0.107***	0.118***	0.114***	0.108***	0.116***	0.113***	0.107***
	(0.011)	(0.011)	(0.011)	(0.011)	(0.011)	(0.011)	(0.011)	(0.011)	(0.011)
% Empl. working with PC	0.632***	0.600***	0.544***	0.662***	0.621***	0.558***	0.649***	0.612***	0.555***
	(0.056)	(0.057)	(0.062)	(0.057)	(0.057)	(0.063)	(0.057)	(0.057)	(0.063)
% Highly skilled empl.			0.117			0.134			0.119
			(0.084)			(0.085)			(0.084)
Export activity			0.127***			0.129***			0.126***
			(0.028)			(0.028)			(0.028)
Works council			0.122***			0.125***			0.123***
			(0.035)			(0.035)			(0.035)
Change in management			0.042			0.043			0.040
			(0.031)			(0.031)			(0.031)
Constant	9.032***	9.135***	9.235***	8.947***	9.085***	9.192***	8.969***	9.090***	9.188***
	(0.143)	(0.145)	(0.145)	(0.144)	(0.147)	(0.147)	(0.144)	(0.147)	(0.147)
Control variables	yes	yes	yes	yes	yes	yes	yes	yes	yes
Number of observations	4487	4487	4487	4487	4487	4487	4487	4487	4487
Number of firms	3288	3288	3288	3288	3288	3288	3288	3288	3288
Adjusted R^2	0.7421	0.7430	0.7457	0.7393	0.7407	0.7436	0.7409	0.7421	0.7449

Significance levels: $*$: 10% $**$: 5% $***$: 1%. Control variables include industry dummy variables based on two-digit classification interacted with a full set of year fixed effects, a dummy variable for location equal to one if the firm is in one new German Bundesland (member state), i.e. formerly East Germany, and a dummy variable if the firm belongs to a multi-plant group. Robust standard errors clustered at the firm level in parentheses.

Table 2.20: Productivity regressions of IT and workplace organization (WO) for large firms - Separate regressions for WO variables

	All industries, dependent variable: log(value added)								
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
IT - Index(ERP+CRM+SCM)		0.114***	0.038		0.115***	0.081*		0.117***	0.030
		(0.025)	(0.037)		(0.026)	(0.044)		(0.026)	(0.045)
Self-responsible business unit (BU)	0.057	0.051	0.043						
	(0.055)	(0.055)	(0.053)						
Team work (TW)				0.015	-0.009	-0.012			
				(0.058)	(0.058)	(0.057)			
Performance pay (PP)							-0.033	-0.067	-0.042
							(0.066)	(0.068)	(0.073)
IT * BU			0.104**						
			(0.048)						
IT * TW						0.034			
						(0.052)			
IT * PP									0.093*
									(0.052)
log(employment)	0.849***	0.842***	0.816***	0.854***	0.846***	0.825***	0.857***	0.851***	0.834***
	(0.042)	(0.041)	(0.040)	(0.041)	(0.040)	(0.040)	(0.041)	(0.040)	(0.039)
log(capital stock)	0.156***	0.143***	0.148***	0.155***	0.143***	0.146***	0.155***	0.142***	0.142***
	(0.025)	(0.025)	(0.024)	(0.025)	(0.025)	(0.024)	(0.025)	(0.025)	(0.024)
% Empl. working with PC	0.325***	0.280**	0.164	0.336***	0.292**	0.171	0.339***	0.293**	0.178
	(0.124)	(0.121)	(0.119)	(0.124)	(0.121)	(0.120)	(0.124)	(0.120)	(0.120)
% Highly skilled empl.			0.505***			0.517***			0.516***
			(0.183)			(0.183)			(0.184)
Export activity			0.099			0.107			0.109
			(0.080)			(0.081)			(0.081)
Works council			0.161			0.166			0.166
			(0.108)			(0.109)			(0.107)
Change in management			0.007			0.010			0.014
			(0.045)			(0.045)			(0.046)
Constant	8.882***	9.183***	9.023***	8.899***	9.207***	9.021***	8.924***	9.251***	9.062***
	(0.345)	(0.346)	(0.351)	(0.339)	(0.340)	(0.344)	(0.342)	(0.345)	(0.349)
Control variables	yes	yes	yes	yes	yes	yes	yes	yes	yes
Number of observations	763	763	763	763	763	763	763	763	763
Number of firms	595	595	595	595	595	595	595	595	595
Adjusted R^2	0.6881	0.6973	0.7042	0.6876	0.6969	0.7021	0.6876	0.6973	0.7033

Significance levels: $*$: 10% $**$: 5% $***$: 1%. Control variables include industry dummy variables based on two-digit classification interacted with a full set of year fixed effects, a dummy variable for location equal to one if the firm is in one new German Bundesland (member state), i.e. formerly East Germany, and a dummy variable if the firm belongs to a multi-plant group. Robust standard errors clustered at the firm level in parentheses.

2.7.4 Panel data analysis

As discussed in Subsection 2.5.5 the coefficient estimates presented in the empirical analysis may be biased because the data do not allow to control adequately for endogeneity due to simultaneity or reverse causality. In the following, I present for a small subsample of the total estimation sample results from a dynamic panel data analysis with the aim to provide some idea about estimates obtained with dynamic panel data estimators. I cannot apply the panel data estimation techniques to the total estimation sample because the majority of the firms surveyed in the ICT survey participated only in one of the waves that are used for the empirical analysis of this chapter. Generally, panel data estimators such as the First Difference-GMM (FD-GMM) estimator in line with Arellano and Bond (1991) or the System GMM (SYS-GMM) estimator as of Arellano and Bover (1995) and Blundell and Bond (2000) require data for a minimum of at least three time periods. Moreover, these dynamic panel data estimators are applicable for situations in which the number of available years (T) is small but the number of firms (N) is large (see, e.g., Blundell and Bond 2000).

In total, 217 SMEs of my original estimation sample of 3288 firms have information for the three time periods considered in the analysis. For the sample of large firms a dynamic model panel data analysis is not reasonably possible because there are only 26 firms with information for three time periods, hence an overall number of 78 observations. This sample size of 217 SMEs across 17 industries for three time periods is likely to be a rather low bound for the number of observations needed so that dynamic panel data estimators will produce consistent estimates.

A consequence of the necessity to have at least three observations for each firm is that the industry distribution of the estimation sample, which is available for a dynamic analysis, does no longer seem to be well comparable to the one of the main estimation sample (see Table 2.21). The reason for these differences across samples is that the ZEW ICT survey is constructed as an unbalanced panel. The sample selection rule for each wave requires only that the cross-sectional data are representative with respect to the covered industries but not necessarily that the data set is still representative along the panel dimension (see also footnote 9, p. 13, for further explanations of the sample selection rule). Given the small sample size and these differences in industry composition, the regression results with this sample will likely not be well comparable with the results derived from the main estimation sample and will only have illustrative character.

Table 2.22 shows regression results for the productivity analysis with the sample that is suitable for a dynamic panel data analysis. Columns (1) to (3) show coefficient estimates using pooled OLS. Without accounting for lagged productivity (column (1)), the estimates for the labour and capital coefficients seem plausible. Performance pay is positively related to productivity and the interaction between IT and a self-responsible business unit is negative. Taking lagged productivity (columns (2) to (3)) into account by using OLS, the magnitude of most coefficient estimates of the input factors is reduced and only performance pay, labour and capital are significantly linked with higher productivity across specifications. Lagged productivity strongly explains current productivity, similar to the results from the larger subsample using lagged variables (see Subsection 2.5.3), which indicates that lagged productivity is a relevant factor to explain current productivity.

Table 2.21: Industry distribution in full sample for dynamic panel data analysis and the main estimation sample from 2004, 2007, 2010 for SMEs

Industry	N	% of sample (dynamic)	N	% of sample (main)
Manufacturing Sector				
Consumer goods	15	6.91	527	11.73
Chemical and pharmaceutical industry	14	6.45	221	4.93
Other raw materials	12	5.53	340	7.58
Metal industry	17	7.83	347	7.73
Electrical engineering	29	13.36	473	10.54
Machine construction	14	6.45	326	7.27
Vehicle construction	7	3.23	399	4.64
Service Sector				
Retail trade	17	7.83	311	6.93
Wholesale trade	13	5.99	233	5.19
Transportation	18	8.29	319	7.11
Media services	10	4.61	156	3.48
IT and other information services	19	8.76	383	8.54
Business consultancy and advertising	7	3.23	142	3.16
Technical services	21	9.68	375	8.36
Other business services	4	1.84	126	2.81
Number of observations	217	100	4487	100

Data source: ZEW ICT Panel 2004, 2007, 2010.

The coefficient estimates from FD-GMM and SYS-GMM are obtained using the xtabond2-command for Stata provided by Roodman (2009). The efficient two-step GMM estimator is taken with the Windmeijer (2005) correction to obtain finite sample corrected standard errors as it has been shown that without this correction, the standard errors tend to be severely downward biased (Roodman 2009). Moreover, the option for small-sample corrections to the covariance matrix estimate provided by the xtabond2-command is used. Estimating a dynamic model in first differences using GMM in the line of Arellano and Bond (1991) drops the workplace organization variables due to collinearity (not reported). Therefore, column (4) shows estimates from FD-GMM without lagged productivity. None of these coefficients is significant. However, due to the weak instruments problem of FD-

GMM estimates, these coefficient estimates may be biased. Blundell and Bond (2000) highlight that even if variable series are only moderately persistent so that the correlation between the first difference and the lagged level will be low, estimates with FD-GMM will be biased due to a weak instruments problem, which is particularly severe the smaller the sample size is. Since the main variables for the analysis in this chapter are rather persistent, particularly the workplace variables, using the FD-GMM estimator will likely yield biased estimates.

Table 2.22: Regressions of IT and workplace organization for SMEs
- Dynamic panel data analysis

All industries, dependent variable: log(value added)						
	OLS			GMM		
	IT and WO, present values		Lagged IT and WO	FD-GMM	SYS-GMM	
	(1)	(2)	(3)	(4)	(5)	(6)
IT - Index(ERP+CRM+SCM)	0.010	0.030	0.041	0.617	-0.184	0.088
	(0.056)	(0.050)	(0.048)	(0.484)	(0.197)	(0.190)
Self-responsible business unit (BU)	0.156**	0.061	0.003	0.216	0.210*	0.019
	(0.074)	(0.062)	(0.060)	(0.267)	(0.112)	(0.190)
Team work (TW)	0.055	0.040	0.074	-0.192	0.079	0.030
	(0.061)	(0.049)	(0.049)	(0.168)	(0.073)	(0.100)
Performance pay (PP)	0.183***	0.091*	0.131**	-0.262	0.157*	0.088
	(0.064)	(0.047)	(0.053)	(0.273)	(0.094)	(0.167)
IT * BU	-0.143**	-0.151**	-0.036	-0.095	-0.111	-0.212
	(0.061)	(0.073)	(0.054)	(1.278)	(0.081)	(0.132)
IT * TW	0.039	0.038	-0.005	0.194	0.141	0.004
	(0.052)	(0.051)	(0.045)	(0.750)	(0.139)	(0.133)
IT * PP	0.092	0.041	-0.053	-1.345	0.190	0.019
	(0.057)	(0.057)	(0.048)	(1.586)	(0.132)	(0.170)
log(employment)	0.814***	0.442***	0.433***	0.497	0.660**	0.707***
	(0.048)	(0.046)	(0.047)	(0.784)	(0.305)	(0.232)
log(capital stock)	0.188***	0.075***	0.088***	0.393	0.243	0.171
	(0.033)	(0.025)	(0.026)	(0.361)	(0.199)	(0.207)
% Empl. working with PC	0.367**	0.088	0.110	0.101	0.359**	0.284
	(0.145)	(0.102)	(0.104)	(0.580)	(0.165)	(0.180)
Productivity (t-3)		0.515***	0.523***			0.264
		(0.051)	(0.052)			(0.179)
Constant	8.043***	3.894***	3.576***		7.728***	4.977*
	(0.471)	(0.537)	(0.535)		(2.329)	(2.876)
Control variables	yes	yes	yes	yes	yes	yes
AR(1) (p-value)	-	-	-	0.123	0.008	-
Hansen J Test (p-value)	-	-	-	0.906	0.244	0.523
Number of observations	651	434	434	434	651	434
Number of firms	217	217	217	217	217	217
Adjusted R^2	0.7818	0.8563	0.8561	-	-	-

Significance levels: $*$: 10% $**$: 5% $***$: 1%. Control variables include industry dummy variables based on two-digit classification, a dummy variable for location equal to one if the firm is in one new German Bundesland (member state), i.e. formerly East Germany, and a dummy variable if the firm belongs to a multi-plant group. For OLS, robust standard errors clustered at the firm level and for GMM, clustered robust standard errors with the Windmeijer finite-sample correction in parentheses.

In order to alienate the weak instruments problem of FD-GMM estimates with persistent series, Blundell and Bond (2000) suggest to use suitably lagged differences for levels equations in addition to the lagged levels for the differenced equations, which results in a SYS-GMM estimator in line of the estimator proposed by Arellano and Bover (1995). Columns (5) and (6) show SYS-GMM estimates. Generally, the coefficient estimates are quantitatively at least in the same direction as the results from OLS. However, the majority of the coefficient estimates are not significant, even not the capital coefficient. This might be a result of the rather small sample size. The estimate for lagged productivity is lower than under OLS. This is in line with previous comparisons of the lagged productivity coefficient across estimation models, which show an upward bias in OLS (e.g. Blundell and Bond 2000).

The bottom section shows p-values of tests for first-order (AR(1)) serial correlation of the first differenced residuals as well as of Hansen tests of overidentifying restrictions for the GMM regressions. The test for AR(1)-serial correlation can be rejected for the SYS-GMM estimates, which is compatible with the assumptions of the model. However, for consistency of GMM estimates, lack of second-order autocorrelation in the first-differenced residuals is needed (Arellano and Bond 1991). In order to test for second-order autocorrelation of the residuals, a minimum of four time periods and for a dynamic model five time periods are needed, which is impossible with this data since there are only three waves. The Hansen test of overidentifying restrictions, which is a consistent test under heteroskedasticity of the error terms, does not reject the validity of instruments.

Chapter 3

Trade and Technology: New Evidence on the Productivity Sorting of Firms*

3.1 Introduction

Analysing the gains from trade has a long tradition in economic research. Melitz and Trefler (2012) recently summarized the potential sources of gains from trade. Besides the classic reasoning that builds on endowment differences or comparative advantage, three additional sources can be defined: First, the availability of a greater variety of products, which increases individuals' utility and firms' input choices; second, a reallocation of firms' market shares with the relatively more productive firms (exporters) expanding, thus raising aggregate productivity; and third, trade-induced process innovation activity implying intra-firm productivity improvements.

The third source has so far received the least attention in the literature. Nevertheless, it has been addressed in some influential recent studies (Bustos 2011; Lileeva and Trefler 2010). The economic mechanism of the innovation-induced gains from trade is based

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on a cost-benefit trade-off: A firm will invest in adopting new productivity-enhancing technologies (i.e. process innovation) as soon as the expected gains from a decrease in marginal costs of production outweigh the fixed costs of adoption. The corresponding zero cut-off profit level is thus directly linked to the volume produced by the firm. Since trade liberalization can be a source of expansion for firms, it could also trigger intra-firm productivity gains from technology adoption. Importantly, according to theory, these extra gains from trade are expected to arise for some firms only: exporting firms that do not yet use the advanced productivity-increasing technology. Note that in contrast to the between-firm reallocation channel in Melitz (2003), where the most productive firms gain most, it is the firms in the middle of the productivity distribution that the gains would accrue to. The most productive firms simply already use the advanced technology. Taken together, the productivity-enhancing mechanism is active only if strict assumptions on the productivity sorting of firms are met. In other words, only if the technology adoption cut-off level of productivity divides the group of exporters into a low-tech and a high-tech subgroup will there be trade-induced process innovation from trade liberalization.[1] The heterogeneity in the distribution of these gains from trade has a certain relevance from a policy perspective.

In this chapter, we test if the proposed firm-level productivity sorting in terms of technology intensity and export status actually fits the data. To this end, we take up the key prediction that in a cross section of firms, exporters using advanced technology are on average more productive than exporters using low-level technology. Additionally, we embed this productivity cut-off for advanced technology adoption into the otherwise familiar ranking of firms in terms of productivity. That is, we compare both groups of exporters to firms selling only domestically.

First evidence on the adequacy of the sorting assumptions for Germany is shown in Wagner (2012) and Vogel and Wagner (2013), who test the productivity sorting proposed by Bustos (2011). With data from German manufacturing industries and business services industries, respectively, they use research and development (R&D) expenditures as an approximate measure for technology. We follow this line of research and complement the analysis by using unique data on actually implemented advanced information technologies (IT), which closely capture the theoretical mechanism underlying the innovation-induced gains from trade.[2] The considered IT systems require a fixed cost investment but ulti-

[1] Note that in common heterogeneous firms models of international trade, firm size and productivity are directly and positively linked (Melitz 2003). The argument that larger firms find it profitable to use the advanced technology is thus equivalent to the statement that the most productive firms will use the high-level technology.

[2] We see some advantages of using actually implemented technologies rather than R&D. First, firms could implement advanced technologies without having invented them themselves, i.e. R&D is not directly

mately reduce the marginal costs of production. Our data contain information about the firms' use of Enterprise Resource Planning (ERP) software and Supply Chain Management (SCM) software, which are widely used complex IT systems. Thus, we are able to explicitly document patterns of technology use, rather than inferring them indirectly from R&D expenditures. The analysis provides new evidence for the applicability of models that show innovation-induced gains from trade and gives guidance to the understanding of the relation between trade, technology and productivity.

Our results are as follows: For manufacturing firms, we confirm the sorting pattern, which is at the heart of recent theoretical models of exporting and technology adoption. We find significant productivity differences between exporters with different levels of technology use. Furthermore, we find purely domestic firms to be relatively less productive and almost exclusively characterized by low-level technology use. For service sector firms, we find a similar pattern of trade and technology intensity. However, the group of domestic firms with advanced technology is non-negligible and co-exists with low-tech service exporters. This finding is not consistent with theoretical derivations that place the advanced technology cut-off productivity level in the group of internationally active firms. We attribute this finding to the specific characteristics of some services compared to manufacturing, such as higher fixed costs of exporting due to intangibility and interactivity. For internationally active service sector firms, we again find service exporters with advanced technology to be more productive than service exporters with low-level technology use. Given this ambiguity in the results for service sector firms, we argue that recent theoretical contributions linking trade and technology adoption seem to particularly fit the manufacturing sector.

The remainder of this chapter is organized as follows: Section 3.2 summarizes briefly the theoretical concept on which the empirical analysis is based. In Section 3.3 we outline the empirical strategy and present the data, followed by Section 3.4 with the empirical results and robustness checks for the manufacturing and service sector separately. Section 3.5 concludes.

linked to the actual implementation. Second, the time-lag between R&D activities and implementation of new technologies could be considerable and would thus be missed in a cross-sectional analysis of sorting patterns. Third, looking at R&D activities usually does not allow differentiation between product and process innovation, the latter of which is closest in spirit to the theoretical mechanism in models such as Bustos (2011) and Lileeva and Trefler (2010).

3.2 Theoretical background

We briefly outline the theoretical mechanism at work in recent models such as the ones in Lileeva and Trefler (2010) and Bustos (2011). We do not repeat the derivations of those models' gains from trade mechanisms, but rather document the implied pattern of productivity cut-offs and the sorting that results from it, which we will subsequently look for in the data. The idea behind the technology adoption decision is that firms face the option of paying a fixed cost, f^t, for the adoption of the advanced technology. This technology allows production with lower marginal cost that differs from initial marginal cost c as c/ϕ, with $\phi > 1$ being a marginal cost reduction parameter. It thus makes the firm more productive. Naturally, the benefits from adopting the technology, $q \times c/\phi$, are greater for larger firms. If these cost savings are larger than the fixed cost of technology adoption, f^t, the firm will innovate, i.e. adopt the process innovation. In standard heterogeneous firm models, size is a function of productivity. Larger firms are simultaneously more productive. With respect to the case considered here, particularly productive – and thus larger – firms will have sufficient scale q to find technology adoption profitable. The model as such does not tell us anything about where this productivity cut-off will be located. We know that it depends on productivity through the effect of firm size, but we do not know whether the necessary size (and thus productivity) for technology adoption is smaller or greater than the size necessary for exporting (or even market entry). Models like Bustos (2011) specify conditions under which the cut-off is located within the group of domestic or within the group of exporting firms but ultimately *assume* it to be within the group of exporting firms. Writing the cut-off productivity for market entry, exporting and the technology adoption cut-off as π, π^x and π^t, respectively, it is thus assumed that $\pi < \pi^x < \pi^t$. Confirming this pattern is equivalent to looking for a sorting of firms which is necessary for the modelled gains from trade to arise. The remainder of this chapter is concerned with identifying a corresponding pattern in the data - and to look for cases that are not compatible with the theory.

3.3 Empirical strategy and data

The general idea for exploring the link between a firm's international market participation, its technology choice and its productivity is to define groups of firms according to their internationalization and technology choice and to compare productivity (and other firm characteristics) across these groups. In terms of the above theoretical considerations, these groups are bounded by the cut-off values of productivity for either domestic market access, international market access or technology adoption. If the theoretical sorting is taken at face value, three out of four possible groups in terms of firms' trade status and technology choice will play a role, depending on the location of the technology adoption cut-off (see Table 3.1). Theories such as the one suggested by Bustos (2011) place the technology cut-off within the group of exporting firms. Consequently, given the usual pattern of increasing productivity across modes of internationalization, there should be no purely domestic high-tech firms (no such firm is large enough to find technology adoption profitable). Furthermore, there will be two groups of exporters, one classified as high-tech (HT) and the other as low-tech (LT). The expected corresponding sorting order for performance measures across technology level and export status is: $Y_{DOMLT} < Y_{EXPLT} < Y_{EXPHT}$. The empirical analysis of this chapter will show whether the hypothetical sorting assumed in papers like Bustos (2011) is indeed a realistic feature of the German economy.

Table 3.1: Combination of firms into groups

	(a) Technology adoption cut-off is in the group of exporting firms	
	internationalization	
technology	domestic	export
low	theory consistent	theory consistent
high	not consistent	theory consistent
	(b) Technology adoption cut-off is in the group of domestic firms	
	internationalization	
technology	domestic	export
low	theory consistent	not consistent
high	theory consistent	theory consistent

In order to test whether the productivity sorting along export status and technology intensity holds, we conduct so-called premia regressions. This is a common method in the international trade literature for assessing whether or not a certain group of firms dominates a suitably defined reference group with respect to specific performance measures or firm characteristics.[3] In this chapter, we are most interested in labour productivity, but also show sorting evidence with respect to firm size, human capital endowment, and R&D activity. Given our objective of verifying whether there is an ascending productivity sorting order across trade status and technology intensity, we conduct premia regressions for groups of varying trade status and technology intensity, showing performance premia with respect to a reference group: domestic low-tech firms. We also control for firm size,

[3] One of the first applications of the premia analysis in the international trade literature is provided by Bernard and Jensen (1999) who compare performance measures of exporters with those of non-exporters.

EMP_i, except when firm size is the dependent variable itself, as well as for industry affiliations $\boldsymbol{\delta}$. We also allow for heteroskedastic error terms. This leads to the following regression specification:

$$Y_i = \beta_{EXPLT} EXPLT_i + \beta_{EXPHT} EXPHT_i + \gamma log(EMP_i) + \boldsymbol{\delta} + \epsilon_i \quad (3.1)$$

where Y is the variable of interest in terms of which the "premia" is measured. Given that there are three groups of firms to be compared (and not only two as in a pure non-exporter versus exporter comparison), the premia regression specification includes two binary indicator variables: one for affiliation to the low-tech exporting group and another for the high-tech exporting group so that the domestic low-tech firms are the reference group. We use Wald tests for equality of coefficients to determine significance of the ascending sorting order.

For our main variable of interest (labour productivity), we furthermore employ the nonparametric two-sample Kolmogorov-Smirnov (KS) test for equality of the overall cumulative distributions. To do so, we calculate logarithmic labour productivity relative to the respective industry mean and compare the distribution of this variable across groups.[4]

The data for the empirical analysis stem from the ZEW ICT Survey 2010 (ZEW 2010), designed by the Centre for European Economic Research (ZEW).[5] Our sample comprises firms from the manufacturing and service sectors with five or more employees and is stratified according to industry, size class and region (East/West Germany). We conduct the empirical analysis separately for manufacturing firms and for service firms from West Germany. In order to minimize the influence of outliers, we drop firms below the 1st percentile and above the 99th percentile of the labour productivity distribution.[6] The resulting sample of firms for which information on sales, export status and technology use are available as our main variables covers 978 firms from the manufacturing sector and 563 from the service sector.

With regard to representativeness, closer inspection reveals the characteristics of firms in our estimation sample to closely resemble the characteristics in the entire ICT survey comprising West German firms. In Table 3.2, we compare the distribution of firms across

[4] For a brief illustration and application of the KS test in a similar context, see, e.g., Kohler and Smolka (2012).

[5] For more information about the survey, see Section 2.3 as well as (only in German) ZEW (2010). The data are available at the ZEW Data Research Centre http://kooperationen.zew.de/en/zew-fdz.

[6] We acknowledge that this method may seem a bit arbitrary and conduct a more careful analysis of the appropriate treatment of outliers in Subsection 3.4.3. Using different methods, including robust regression techniques, we find our results to be highly robust to different treatments of outliers.

industries in the estimation sample with the distribution in the full data set. Table 3.3 shows descriptive statistics of the variables number of employees, labour productivity, share of high-skilled employees and share of exporters from our estimation sample and from the full data set of the ICT survey 2010. The distributions across industries and the descriptives are very similar for both data sets indicating that firms that have to be left out from the estimation sample due to item non-response are missing at random.

Table 3.2: Distribution of firms across industries in the main estimation sample and for all firms surveyed in 2010

Industry	N	% of sample	N	% of data set
Manufacturing Sector				
Consumer goods	236	24.13	337	24.30
Chemical and pharmaceutical industry	87	8.90	124	8.94
Other raw materials	141	14.42	192	13.84
Metal industry	123	12.58	173	12.47
Electrical engineering	163	16.67	235	16.94
Machine construction	145	14.83	208	15.00
Vehicle construction	83	8.49	118	8.51
Total number of observations	978	100	1387	100
Service Sector				
Transportation	74	13.17	155	15.98
Media services	85	15.12	145	14.95
IT and other information services	132	23.49	214	22.06
Real estate and rental services	56	9.96	83	8.56
Business consultancy and advertising	54	9.61	107	11.03
Technical services	96	17.08	157	16.19
Other business services	65	11.57	109	11.24
Total number of observations	562	100	970	100
All industries: Number of observations	1540	100	2357	100

Data source: ZEW ICT Survey 2010. N stands for the number of observations; this abbreviation is also used in the subsequent tables. The numbers of the sample refer to those observation with information on labour productivity.

The considered performance variables are measured as follows: Labour productivity is measured as sales per employee. Firm size is measured by the number of employees, human capital by the proportion of high-skilled employees and R&D activity is an indicator variable equal to one if the firm has positive R&D expenditures. Descriptive statistics are presented in Table 3.4. For R&D, we use a linear probability model of the probability of observing positive investment in R&D. EMP_i is a firm's number of employees and $\boldsymbol{\delta}$ represents a vector of seven industry fixed effects based on the two-digit NACE 2.0 classification for each sector.[7] The manufacturing sector covers consumer goods, chemi-

[7] Classification of industries 2008 as of "Klassifikation der Wirtschaftszweige 2008 (WZ 2008)". See Table 4.16 in the appendix of Chapter 4 for the exact industry classification.

cals and pharmaceuticals, raw materials, metals, electronics, machinery, and automotive construction. In the premia regression, the consumer goods industry is taken as the reference category. The considered service industries are transport, media, telecommunication, renting, consultancy, technical and business services. Transportation services are taken as the reference category. A firm's trade status is defined in accordance with the related literature: The firm is either active on the domestic market only, i.e. is a non-exporter, or it also sells at least some of its products to foreign markets, i.e. is an exporter.

Table 3.3: Descriptive statistics of manufacturing and service firms in the main estimation sample and for all firms surveyed in 2010

Variable	N	Mean	SD	Median	N	Mean	SD	Median
	Estimation sample				Full data set			
Manufacturing Sector								
Labour productivity	978	192.41	189.92	140	1056	232.78	507.45	140
Number of employees	978	502	3203.85	67	1387	498	3074.71	65
% Highly skilled empl.	880	0.14	0.16	0.09	1204	0.14	0.17	0.08
% Exporters	978	0.81	0.39	1	1383	0.77	0.42	1
Service Sector								
Labour productivity	562	166.85	253.73	25	681	228.05	547.12	100
No. of employees	562	490	3103.71	100	970	455	2486.43	35
% Highly skilled empl.	536	0.34	0.31	0.2	902	0.34	0.32	0.25
% Exporters	562	0.43	0.50	0	1383	0.35	0.48	0

Data source: ZEW ICT Survey 2010. SD for standard deviation; this abbreviation is also used in the subsequent tables. Labour productivity is in thousands of euros.

Table 3.4: Descriptive statistics: Average values in the main estimation sample

	Manufacturing			*Services*		
Variable	N	Mean	SD	N	Mean	SD
Labour productivity (in thousands of euros)	978	192.41	189.92	562	166.85	253.73
Number of employees	978	502	3203.85	562	490	3103.71
% Highly skilled empl.	880	0.14	0.16	536	0.34	0.31
% R&D activity	825	0.66	0.48	532	0.42	0.49
ERP use	978	0.81	0.38	562	0.70	0.46
SCM use	978	0.47	0.50	562	0.19	0.40
ERP and SCM use	978	0.45	0.50	562	0.15	0.36
% Exporters	978	0.81	0.39	562	0.43	0.50

Data source: ZEW ICT survey 2010.

Since we intend to investigate the productivity ranking according to a firm's international activities and technology use, we construct an IT indicator based on the firm's combined implementation of two advanced enterprise software systems, Enterprise Resource Planning (ERP) and Supply Chain Management (SCM). ERP is a general purpose software that integrates enterprise functions such as sales and distribution, materials management, production planning, financial accounting, cost control, and human resource management (Aral, Brynjolfsson, and D. Wu 2006). SCM enables IT-based processing of each step of the value chain.[8] Such systems assist the firm in managing its business processes and represent process innovations at the time of adoption – an innovation that requires bearing the fixed cost of implementation, however. We classify the firms into two groups and define the IT indicator as follows: A firm is said to be a "high technology" (high-tech) firm if it uses both ERP and SCM. If the firm uses neither of the two systems or only one system, the firm is grouped into the "low technology" (low-tech) category.[9] The rationale behind the construction of this indicator is derived from the literature on adoption and performance gains from enterprise software systems and the associated definition of advanced technology in recent heterogeneous firm models of trade and technology adoption as, for instance, in Bustos (2011). The installation of such systems is usually very costly and should generally be accompanied by appropriate organizational restructuring and IT-training (Bresnahan, Brynjolfsson, and Hitt 2002). Thus, the adoption of such systems implies high fixed costs. At the same time, empirical evidence suggests that ERP and SCM may increase performance, such as productivity. Based on these arguments, our classification of a high-tech firm, to us, seems like a plausible empirical approximation of its theoretical counterpart. The next section shows the empirical results – first for manufacturing, then for services.

3.4 Empirical results

3.4.1 Manufacturing

We begin with a simple comparison of the number of firms in each group. The numbers borne out by our sample support the theoretical notion that the advanced technology cut-off level indeed lies within the group of exporters. Out of our manufacturing sample of 1017 firms, the domestic high-tech group is the smallest of the four possible groups with

[8] For more information about these enterprise software systems see Section 2.2 and the corresponding literature references.

[9] In order to gauge the sensitivity of the results with respect to the definition of the IT indicator, we conduct several robustness analyses. See Subsection 3.4.3 for details.

a share of roughly 4 percent of the total number of firms. The remaining groups each consist of a considerably larger proportion of firms. Since we are testing theories that by assumption exclude domestic high-tech firms, this group will be dropped from the analysis, following Bustos (2011) and Wagner (2012).[10] The remaining sample comprises 978 firms. Among these firms, the shares of domestic low-tech firms, low-tech exporters and high-tech exporters are 18.71, 36.20 and 45.09 percent, respectively. Across these groups, we now take a closer look at the sorting pattern with respect to several performance measures.

Table 3.5: Premia regressions and equality of coefficients tests for manufacturing firms

	Premia regressions			
	log(labour productivity)	log(employment)	Share of highly skilled	R&D activity
Exporter, low-tech	0.325***	1.081***	0.0255*	0.265***
	(0.0649)	(0.111)	(0.0142)	(0.0463)
Exporter, high-tech	0.485***	2.558***	0.0549***	0.317***
	(0.0765)	(0.111)	(0.0160)	(0.0099)
Observations	978	978	880	825
R-squared	0.188	0.343	0.164	0.235
	Test of equality of coefficients			
Coefficient comparison	log(labour productivity)	log(employment)	Share of highly skilled	R&D activity
	p-value			
β_{EXPLT} vs. β_{EXPHT}	0.0019***	0.0000***	0.0142**	0.1532

Robust standard errors are given in parentheses. The lower table presents the p-values of the test statistics for the linear test that the two compared premia coefficients from the respective premia regression are equal.***, **, and * represent significance at the 1, 5, and 10 percent level, respectively.

The results in Table 3.5 reveal the common finding that internationally active firms are significantly more productive, have a larger workforce, employ more high-skilled individuals and have a higher propensity to conduct R&D activity. For instance, high-tech exporters have a roughly 48.5 percent higher labour productivity than domestic low-tech firms. Consistent with expectation, the premia also increase from the group of low-tech exporters to the high-tech exporters. More importantly, we find significant differences among exporters. The Wald tests for equality of coefficients show that for all firm characteristics besides R&D activity, the premia for the high-tech exporters is significantly higher than the premia for the low-tech exporters. The hypothesized pattern of trade and technology use across firms thus finds considerable support. Additional support comes from the KS tests for equality of distributions. They yield that the hypothesis of equal productivity distributions for high-tech and low-tech exporters, respectively, can clearly be rejected. The p-values for the comparison of the distributions are each 0.0000. Figure 3.1 in the appendix shows the differences in the productivity distributions by plotting the

[10] The majority of domestic firms classified as high-tech are from the machinery or consumer goods industry. These firms are on average smaller than the firms from the other groups with an average firm size of 138 employees compared to 502 employees for the firms of the other groups.

cumulative distribution functions (CDF). The results remain qualitatively similar with alternative IT indicators as outlined in Subsection 3.4.3.

We take the evidence found for manufacturing firms as support for the productivity ranking of firms with different modes of trade and technology use that is assumed in recent heterogeneous firms trade models.

3.4.2 Services

Table 3.6 shows the results of the premia regressions for the sample of service firms. As for manufacturing firms, we find exporting firms to be, on average, more productive, larger and more likely to invest in R&D. Moreover, we find the productivity and size premia for high-tech exporters to be significantly higher than the ones for low-tech exporters – just as required by the aforementioned theories of trade and technology adoption. One notable difference between the results for services and manufacturing is that neither type of exporting service firm has a significantly higher share of university educated employees than domestic service firms.

Table 3.6: Premia regressions and equality of coefficients tests for service firms

	Premia regressions			
	log(labour productivity)	log(employment)	Share of highly skilled	R&D activity
Exporter, low-tech	0.154**	0.303**	0.0480	0.123***
	(0.0722)	(0.154)	(0.0292)	(0.0468)
Exporter, high-tech	0.529***	2.227***	0.0271	0.290***
	(0.108)	(0.236)	(0.0380)	(0.0700)
Observations	562	562	536	532
R-squared	0.173	0.213	0.330	0.277
	Test of equality of coefficients			
Coefficient comparison	log(labour productivity)	log(employment) *p-value*	Share of highly skilled	R&D activity
β_{EXPLT} vs. β_{EXPHT}	0.0004***	0.0000***	0.6119	0.0192**

Robust standard errors are given in parentheses. The lower table presents the p-values of the test statistics for the linear test that the two compared premia coefficients from the respective premia regression are equal. ***, **, and * represent significance at the 1, 5, and 10 percent level, respectively.

A further noteworthy difference between manufacturing and services emerges if one takes a step back to assess the size of the different groups defined according to trade and technology use. While the (dropped) group of domestic high-tech firms is still the smallest of the four possibilities in the service sector, it comprises a little more than 11 percent of all firms. To add robustness to our results, we include the group of domestic high-tech firms in the sample and still find the high-tech exporters to be the most productive both overall and relative to low-tech exporters.[11] However, the domestic high-tech firms show a higher productivity than low-tech exporters. This observation might reflect the different tradability characteristics of some service firms' output. Such a view does not seem entirely inconsistent with characteristics of the service sector. Bustos (2011) points out that the theoretical sorting, according to which the cut-off productivity level required for technology adoption is in the group of exporters, holds only if the (fixed) technology adoption costs are high relative to the fixed exporting costs. Since some services are difficult to trade, it is reasonable to assume that for certain service firms the fixed exporting costs are higher than the technology adoption costs, so there may exist purely domestic, yet IT-intensive firms. Furthermore, inspection of the data shows that the high-tech domestic firms mainly come from the transport sector, media services, IT and telecommunications industries. These services may often have a local focus which requires intense interaction between supplier and client and these activities are usually IT intensive. Finally, some service firms' business models may explicitly be based on advanced IT applications, independent of their size and international activities.

Given the empirical evidence, we are careful to draw conclusions on the sorting patterns within the service sector, in particular with respect to the location of the technology adoption cut-off. It could be the case that the presence of some domestic high-tech firms is due to non-tradability of certain services. Comparing low-tech exporters to high-tech exporters – and therefore firms that trade services – the findings support the theoretical notion that the high-tech exporters are more productive than low-tech exporters. If the above result holds, the applicability of recent theories of exporting and technology adoption seems to be dependent on the heterogeneous trading possibilities of services.

3.4.3 Robustness analyses

Robustness with respect to outliers

Recent research on the exporter premium in international trade has stressed the potential contamination of the estimation sample by outliers (Verardi and Wagner 2012; Vogel and Wagner 2011). It points to the potential dependency of the obtained results on observations for a few firms with either extremely high or extremely low productivity. The problem of OLS estimation is that it assigns a comparably large weight to outlying observations – up to a point where both the coefficient values as well as statistical significance can be severely affected. Rousseeuw and Leroy (2005) categorize outliers in three classic cases. First, there are vertical outliers, for which the underlying observations for the inde-

[11] Results can be found in Table 3.9 in the appendix.

pendent variables are within the regular range of values observed but the estimated model does a poor job explaining the realized value of the dependent variable. Second, there are good leverage points with outlying observations in terms of the independent variables that have, however, an effect well explained by the model. Third, there are bad leverage points characterized by extreme values of the independent variables and a poor fit of the model. While vertical outliers can traditionally be dealt with fairly well using median regression and similar procedures, bad leverage points require slightly more sophisticated approaches – like the so-called MM-estimator (Verardi and Croux 2009).

Given the evidence recently documented in the literature, we provide a discussion of the presence and potential effects of outliers in our estimation sample. We start by looking for outliers according to the method proposed by Verardi and Croux (2009). Only 60 of our 998 observations in the full sample, or 6.11 percent, are identified as outliers and almost all of them (59) correspond to vertical outliers. Importantly, none of them have the characteristics of a bad leverage point. A further noteworthy point is that the outliers are not equally distributed across our groups of firms (domestic low-tech firms, low-tech exporters, and high-tech exporters). More than half of the identified outliers are within the high-tech exporters group. Given that these are expected to be the firms with the highest productivity, the more observations we treat as outliers and the harsher we penalize them in general, the more we reduce the weight of the observations in this specific group.

Table 3.7: Robust estimators: Premia regressions and equality of coefficients tests for manufacturing firms

Premia regressions, dependent variable: log(labour productivity)					
	Regular OLS	Outliers dropped - OLS	Median Regression	M-estimator	MM-estimator
Exporter, low-tech	0.352***	0.327***	0.330***	0.333***	0.318***
	(0.0731)	(0.0566)	(0.0736)	(0.0675)	(0.0706)
Exporter, high-tech	0.555***	0.431***	0.457***	0.479***	0.423***
	(0.0897)	(0.0638)	(0.0824)	(0.0789)	(0.0820)
Observations	998	938	998	998	998
Test of equality of coefficients					
Coefficient comparison			*p-value*		
β_{EXPLT} vs. β_{EXPHT}	0.0005***	0.0173**	0.0364**	0.0030***	0.0356**

Robust standard errors are given in parentheses. The lower table presents the p-values of the test statistics for the linear test that the two compared premia coefficients from the respective premia regression are equal. The median regression is performed with the Stata 12.1 command *qreg* and the M-estimator and MM-estimator based results are obtained using the package *robreg*. ***, **, and * represent significance at the 1, 5, and 10 percent level, respectively.

Table 3.7 shows various approaches that deal with outliers in our sample. For reasons of comparison we first provide simple OLS results in column (1). These are very similar to the ones we obtained in Subsection 3.4.1, where we dropped observations in the first and last percentile of the productivity distribution. We see the familiar sorting of firms and observe a significant difference in the premia for the low-tech and the high-tech exporters. Column (2) shows results obtained after dropping all outliers identified by the method of Verardi and Croux (2009). OLS estimation without these 60 observations reveals no notable change. As expected, the premium for the high-tech exporter is slightly lower. Yet, all the premia are still statistically highly significant and the two groups of exporters again differ significantly from each other as well. In columns (3) and (4) we apply standard robust estimation techniques, known to deal well with vertical outliers – median regression and its generalized counterpart, M-estimation (Huber 1964). Again, we see results that are highly robust. Finally, in column (5) we use the MM-estimator, which provides the highest level of robustness against outliers. We see a slight reduction in the estimated productivity premia but the significance of both the premia themselves and the difference between the two groups of exporters maintains. We also repeat the exercise for the service sector (Table 3.8) and find very similar results to those reported in Subsection 3.4.2.

Table 3.8: Robust estimators: Premia regressions and equality of coefficients tests for service firms

Premia regressions, dependent variable: log(labour productivity)					
	Regular OLS	Outliers dropped - OLS	Median Regression	M-estimator	MM-estimator
Exporter, low-tech	0.228***	0.255***	0.223***	0.251***	0.259***
	(0.0777)	(0.0583)	(0.0767)	(0.0647)	(0.0631)
Exporter, high-tech	0.508***	0.502***	0.509***	0.509***	0.496***
	(0.104)	(0.0809)	(0.0977)	(0.0916)	(0.0947)
Observations	806	743	806	806	806
Test of equality of coefficients					
Coefficient comparison			*p-value*		
β_{EXPLT} vs. β_{EXPHT}	0.0087***	0.0027**	0.0066***	0.0050***	0.0093***

Robust standard errors are given in parentheses. The lower table presents the p-values of the test statistics for the linear test that the two compared premia coefficients from the respective premia regression are equal. The median regression is performed with the Stata 12.1 command *qreg* and the M-estimator and MM-estimator based results are obtained using the package *robreg*. ***, **, and * represent significance at the 1, 5, and 10 percent level, respectively.

Robustness checks for the IT indicator

In order to check the sensitivity of the results with respect to the specification of the IT indicator, henceforth the baseline IT indicator, we run the empirical analysis with three different IT indicators.[12] First, we build a high-tech vs. low-tech classification based on the firms' use of SCM only: A firm is classified as low-tech if it does not use SCM, and consequently, it is classified as high-tech if it does. The motivation for constructing the IT indicator from the information on SCM only is based on theoretical considerations and

[12] Since the technology intensity classification is different with the alternative IT indicators in comparison to the IT baseline index, the sample size varies slightly as the group composition depends on the respective IT index.

empirical evidence that SCM is, on average, installed after the installation of ERP since SCM is a more specialized software than ERP (Aral, Brynjolfsson, and D. Wu 2006). Hence, on average, SCM-using firms will also have installed ERP. However, not all ERP-using firms will have installed SCM. Thus, the information on SCM use can be interpreted as an approximation for technology advancement. The results with this indicator remain robust in comparison to the baseline indicator (see Table 3.10 for the manufacturing sector and Table 3.11 for the service sector in the appendix). As before, for the manufacturing sector, the KS tests (not shown) are all significant at the one percent level, rejecting equality of the productivity distributions across groups. Similarly, for the service sector, the p-values of the KS tests all indicate significance within the conventional bounds.

Second, we build an IT indicator that takes into account a firm's use of Customer Relationship Management (CRM) and Content or Document Management Systems (CDMS) software in addition to ERP and SCM.[13] This measure is an extended proxy for a firm's IT intensity. Based on the number of IT systems, a firm is said to be high-tech if it uses at least two of the considered systems. Otherwise, the firm is grouped into the low-tech category. The results remain generally robust (see Table 3.12 and Table 3.13 in the appendix). For the manufacturing sector, all previous results hold. One exception worth mentioning is that the difference between the low-tech exporter and the high-tech exporter premia for labour productivity is not significant in the service sector. Still, the premia are significant and increasing in magnitude with respect to the low-tech domestic reference group of firms.

Third, we define another IT indicator, based on the share of employees working mainly at the computer (PC). This indicator is often used in IT research to reflect a firm's IT intensity.[14] For its construction, we compute the industry mean of this variable based on the two-digit NACE 2.0 level and then classify a firm as high-tech if its share of employees working mainly at the computer is above the respective industry mean and as low-tech if it is below. We thus implicitly assume a higher share of PC work to be associated with the use of more advanced technology in the spirit of the above analyses. The results using this index are also generally robust (see Table 3.14 and Table 3.15 in the appendix). The only major exception is that, in the service sector, the difference between the premia coefficients for labour productivity of the low-tech and high-tech exporters is no longer significant, although they still increase in magnitude from the low-tech to the high-tech exporters. All three checks thus corroborate a robust and theory consistent sorting in manufacturing, while the evidence for services is somewhat mixed.

[13] See Section 2.2 and Subsection 4.3.1 for further details about these applications.
[14] See Subsection 2.3.1 for further details of this measure.

3.5 Conclusion

In this chapter, we provide empirical evidence for productivity sorting across groups of firms with different modes of trade and different levels of technology intensity. We test sorting patterns arising from the assumptions made in recent theoretical papers such as Bustos (2011) or Lileeva and Trefler (2010). These papers have attracted considerable attention because they highlight a new source for gains from trade - gains that arise from growing firms eventually adopting advanced technologies. However, these gains arise to certain firms only and their theoretical emergence is crucially linked to the models' assumptions of where the technology adoption cut-off is found. According to these papers, only with the cut-off being among internationally active firms will there be novel gains from trade. In this chapter, we thus look for empirical evidence on the implied productivity sorting among German firms. Complementary to previous empirical studies, our analysis measures the implementation of technology by firms' actual use of efficiency-enabling IT systems. Based on a unique German firm-level data set, we find cross-sectional evidence for productivity differences between manufacturing exporters with different levels of technology use. This result is in line with the models presented by Bustos (2011) and Lileeva and Trefler (2010) and empirical evidence for German firms shown by Wagner (2012). Looking at service sector firms, we also find support for the same sorting pattern as Vogel and Wagner (2013) – yet it is somewhat less pervasive. Some firms are high-tech firms without being internationally active – a result that might be explained by the specific characteristics of services, such as the fixed costs of exporting being higher relative to manufacturing. We take the results as supportive of the recent models' implied sorting patterns, but conclude that these recent theories of heterogeneous firms and trade-induced technology adoption seem to better fit manufacturing industries. Of course, this is not to say that there are no possibilities for gains from trade in the service sector, in particular for the more tradable services. Additionally, the usual positive effects, derived from increased varieties and reallocations between firms leading to higher aggregate productivity, arise independently for the entire economy.

3.6 Appendix

3.6.1 Additional tables and figures

Table 3.9: Premia regressions and equality of coefficients tests for service firms including domestic high-tech firms

	Premia regressions			
	log(labour productivity)	log(employment)	Share of highly skilled	R&D activity
Exporter, low-tech	0.146**	0.323**	0.0499*	0.137***
	(0.0719)	(0.154)	(0.0291)	(0.0466)
Domestic, high-tech	0.354***	1.655***	0.0496	0.0602
	(0.116)	(0.257)	(0.0362)	(0.0684)
Exporter, high-tech	0.515***	2.235***	0.0317	0.311***
	(0.108)	(0.235)	(0.0374)	(0.0687)
Observations	632	632	602	595
R-squared	0.193	0.224	0.324	0.247
	Test of equality of coefficients			
Coefficient comparison	log(labour productivity)	log(employment)	Share of highly skilled	R&D activity
		p-value		
β_{EXPLT} vs. β_{EXPHT}	0.0005***	0.6566	0.72902	0.0132**
β_{EXPLT} vs.β_{DOMHT}	0.0819*	0.0000***	0.9953	0.2985
β_{DOMHT} vs. β_{EXPHT}	0.2410	0.0801*	0.6795	0.0031***

Robust standard errors are given in parentheses. The lower table presents the p-values of the test statistics for the linear test that the two compared premia coefficients from the respective premia regression are equal. ***, **, and * represent significance at the 1, 5, and 10 percent level, respectively.

Table 3.10: Premia regressions and equality of coefficients tests for manufacturing firms - Classification with IT indicator based on SCM only

	Premia regressions			
	log(labour productivity)	log(employment)	Share of highly skilled	R&D activity
Exporter, low-tech	0.322***	1.108***	0.0243*	0.265***
	(0.0659)	(0.114)	(0.0145)	(0.0469)
Exporter, high-tech	0.465***	2.487***	0.0506***	0.320***
	(0.0765)	(0.113)	(0.0159)	(0.0508)
Observations	976	976	877	823
R-squared	0.184	0.321	0.162	0.235
	Test of equality of coefficients			
Coefficient comparison	log(labour productivity)	log(employment)	Share of highly skilled	R&D activity
		p-value		
β_{EXPLT} vs. β_{EXPHT}	0.0048***	0.0000***	0.0273**	0.1313

Robust standard errors are given in parentheses. The lower table presents the p-values of the test statistics for the linear test that the two compared premia coefficients from the respective premia regression are equal.***, **, and * represent significance at the 1, 5, and 10 percent level, respectively.

Table 3.11: Premia regressions and equality of coefficients tests for service firms - Classification with IT indicator based on SCM only

	Premia regressions			
	log(labour productivity)	log(employment)	Share of highly skilled	R&D activity
Exporter, low-tech	0.163**	0.354**	0.0472	0.122**
	(0.0744)	(0.158)	(0.0305)	(0.0480)
Exporter, high-tech	0.497***	1.981***	0.00765	0.244***
	(0.101)	(0.230)	(0.0354)	(0.0661)
Observations	549	549	524	519
R-squared	0.175	0.186	0.333	0.284
	Test of equality of coefficients			
Coefficient comparison	log(labour productivity)	log(employment)	Share of highly skilled	R&D activity
		p-value		
β_{EXPLT} vs. β_{EXPHT}	0.0007***	0.0000***	0.3135	0.0726*

Robust standard errors are given in parentheses. The lower table presents the p-values of the test statistics for the linear test that the two compared premia coefficients from the respective premia regression are equal. ***, **, and * represent significance at the 1, 5, and 10 percent level, respectively.

Table 3.12: Premia regressions and equality of coefficients tests for manufacturing firms - Classification with IT indicator based on four IT systems

	Premia regressions			
	log(labour productivity)	log(employment)	Share of highly skilled	R&D activity
Exporter, low-tech	0.308***	0.685***	0.0276**	0.233***
	(0.0748)	(0.124)	(0.0132)	(0.0541)
Exporter, high-tech	0.443***	2.478***	0.0675***	0.367***
	(0.0797)	(0.108)	(0.0149)	(0.0518)
Observations	937	937	838	785
R-squared	0.183	0.336	0.193	0.250
	Test of equality of coefficients			
Coefficient comparison	log(labour productivity)	log(employment)	Share of highly skilled	R&D activity
		p-value		
β_{EXPLT} vs. β_{EXPHT}	0.0358**	0.0000***	0.0046***	0.0034***

Robust standard errors are given in parentheses. The lower table presents the p-values of the test statistics for the linear test that the two compared premia coefficients from the respective premia regression are equal.***, **, and * represent significance at the 1, 5, and 10 percent level, respectively.

Table 3.13: Premia regressions and equality of coefficients tests for service firms - Classification with IT indicator based on four IT systems

	Premia regressions			
	log(labour productivity)	log(employment)	Share of highly skilled	R&D activity
Exporter, low-tech	0.215**	-0.0991	0.0856*	0.169**
	(0.109)	(0.172)	(0.0471)	(0.0719)
Exporter, high-tech	0.298***	1.912***	0.0721*	0.317***
	(0.107)	(0.179)	(0.0369)	(0.0644)
Observations	409	409	393	381
R-squared	0.143	0.262	0.380	0.312
	Test of equality of coefficients			
Coefficient comparison	log(labour productivity)	log(employment)	Share of highly skilled	R&D activity
		p-value		
β_{EXPLT} vs. β_{EXPHT}	0.4805	0.0000***	0.7954	0.0739*

Robust standard errors are given in parentheses. The lower table presents the p-values of the test statistics for the linear test that the two compared premia coefficients from the respective premia regression are equal. ***, **, and * represent significance at the 1, 5, and 10 percent level, respectively.

Table 3.14: Premia regressions and equality of coefficients tests for manufacturing firms - Classification with IT indicator based on the share of employees working mainly at the PC

	Premia regressions			
	log(labour productivity)	log(employment)	Share of highly skilled	R&D activity
Exporter, low-tech	0.307***	1.542***	0.00601	0.301***
	(0.0613)	(0.126)	(0.0107)	(0.0457)
Exporter, high-tech	0.559***	1.809***	0.104***	0.390***
	(0.0673)	(0.131)	(0.0144)	(0.0459)
Observations	976	976	874	821
R-squared	0.221	0.166	0.260	0.265
	Test of equality of coefficients			
Coefficient comparison	log(labour productivity)	log(employment)	Share of highly skilled	R&D activity
		p-value		
β_{EXPLT} vs. β_{EXPHT}	0.0000***	0.0230**	0.0000***	0.0052***

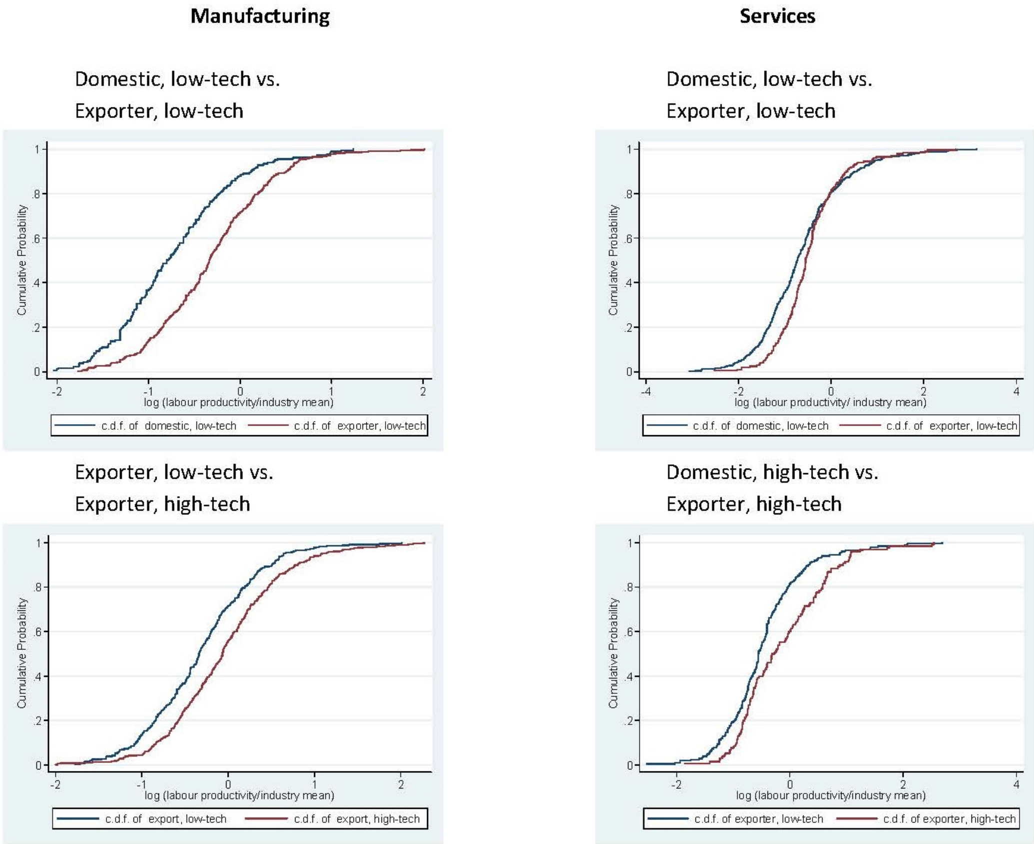
Robust standard errors are given in parentheses. The lower table presents the p-values of the test statistics for the linear test that the two compared premia coefficients from the respective premia regression are equal.***, **, and * represent significance at the 1, 5, and 10 percent level, respectively.

Table 3.15: Premia regressions and equality of coefficients tests for service firms - Classification with IT indicator based on the share of employees working mainly at the PC

	Premia regressions			
	log(labour productivity)	log(employment)	Share of highly skilled	R&D activity
Exporter, low-tech	0.247***	0.906***	-0.0407	0.180***
	(0.0858)	(0.257)	(0.0271)	(0.0608)
Exporter, high-tech	0.301***	0.208	0.222***	0.194***
	(0.0947)	(0.239)	(0.0335)	(0.0626)
Observations	430	430	407	399
R-squared	0.226	0.050	0.498	0.285
	Test of equality of coefficients			
Coefficient comparison	log(labour productivity)	log(employment)	Share of highly skilled	R&D activity
		p-value		
β_{EXPLT} vs. β_{EXPHT}	0.5556	0.0144**	0.0000***	0.8378

Robust standard errors are given in parentheses. The lower table presents the p-values of the test statistics for the linear test that the two compared premia coefficients from the respective premia regression are equal. ***, **, and * represent significance at the 1, 5, and 10 percent level, respectively.

Figure 3.1: Sorting pattern: Cumulative density plots of productivity



The figure presents plots of the empirical cumulative density functions of log-labour productivity by group. Labour productivity is defined as the sales per worker in thousands of euros divided by the respective industry mean based on two-digit NACE 2.0.

Chapter 4

ICT and Global Sourcing - Evidence for German Manufacturing and Service Firms*

4.1 Introduction

Recent advances in information and communication technologies (ICT) are recognized to be an important driver behind the rise in global trade in intermediate inputs. This phenomenon has led to an increased importance of global value chains. As ICT have the potential to reduce costs associated with coordination across distance, it has become easier for firms to source inputs, either goods or services, from abroad. Moreover, ICT have enabled new possibilities of splitting work tasks. For instance, Grossman and Rossi-Hansberg (2007) state, p. 59: “Revolutionary progress in communication and information technologies has enabled an historic (and ongoing) break-up of the production process.” Generally, ICT can reduce communication, information and coordination costs, which in an international context, may be interpreted as trade costs. Furthermore, ICT may also indirectly affect the global sourcing decision through increased firm performance

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given the productivity-enhancing impact of ICT and the argument put forward by Antrás and Helpman (2004) that due to fixed costs of starting to source globally, firms need a certain productivity level to be able to engage in it (Benfratello, Razzolini, and Sembenelli 2015). ICT may particularly be an enabler for trade in services because many services, for instance, accounting services or technical support, have been viewed as non-tradable before. Empirical evidence supports this view by showing that the Internet can be related to growth in service trade at the macroeconomic level in the late 1990s (Freund and Weinhold 2002).

In this chapter, I present new evidence for the relevance of ICT and productivity for the decision to source inputs from abroad for manufacturing and service firms. Prior firm-level studies find primarily that on average more ICT-intensive firms are more likely to outsource inputs and also to import them. However, the empirical evidence for the relevance of ICT for global sourcing decisions is mainly for manufacturing firms only (e.g. Benfratello, Razzolini, and Sembenelli 2015; Fort 2015) or presents average effects for manufacturing and service firms together (Abramovsky and Griffith 2006). To the best of my knowledge, there is no empirical analysis that studies explicitly global sourcing decisions of service firms and the contribution of ICT to it. Thus, it remains an open question whether ICT and other sources of firm heterogeneity, which have been identified as important factors for selection into international trade, such as productivity, have a different marginal impact for service firms' importing decisions than for manufacturing firms. In general, services are more difficult to trade. Moreover, given that prior research has found the impact of ICT on productivity to differ between manufacturing and service firms (e.g. Timmer et al. 2010; Tambe and Hitt 2012) and empirical evidence also shows differences in the productivity sorting across technology intensity between exporters and non-exporters of these two sectors (Bertschek, Hogrefe, and Rasel 2015), the contribution of ICT for global sourcing might be different between these two sectors, too.

The goal of this chapter is to provide new empirical evidence on the relationship between ICT and global sourcing and the role of productivity for global sourcing in the manufacturing as well in the service sector. In particular, the empirical analysis uses a probit model and investigates separately for manufacturing and for service firms whether the global sourcing probability increases with the use of different ICT applications, conditional on other sources of firm heterogeneity. In this chapter, global sourcing is defined as importing inputs, either goods or services, and it is used interchangeably with the term importing.[1] The data set comprises information on ICT use and global sourcing activities

[1] The role of ICT for sourcing inputs from a foreign firm has often been discussed in the offshoring context. A standard definition of offshoring in the literature is "the relocation of jobs and processes to any foreign country without distinguishing whether the provider is external or affiliated with the

of firms from the manufacturing and service sector in Germany from 2009. The firms are mainly small and medium-sized enterprises (SMEs), i.e. firms with at most 250 employees. Many of the service firms in the data set are from industries that offer business-related or knowledge-intensive services, and some of them offer exactly those services that have been often named as being candidates to be offshored, such as information technology services. Firms' ICT intensity is measured by three broad types of ICT: e-commerce activities, enterprise software systems, and the diffusion of computers and Internet access within the firm.

Given the cross-sectional nature of the data, the results reflect empirical correlations between ICT use and global sourcing. To gauge the robustness of the results, I present several robustness checks. First, I consider additional sources of firm heterogeneity; second, I analyse the relevance of ICT for global sourcing for different subsamples of firms; and third, I investigate the role of ICT for firms in industries with higher versus lower upstream supply chain complexity.

The results show some differences between manufacturing and service firms. In the manufacturing sector, the probability of global sourcing is increasing in the share of employees with Internet access. In both sectors, more e-commerce-intensive firms are more likely to import inputs from abroad, in particular in industries with higher upstream supply chain complexity. However, across all industries, the association between e-commerce and global sourcing is only robust for service firms for which it is also stronger than for manufacturing firms. In quantitative terms, the use of an additional e-commerce application is associated with a 5 to 6 percentage points increase in the probability of global sourcing for service firms and with a magnitude of a 1 to 3 percentage points for manufacturing firms. Given that 20.1 percent in the service sector engage in global sourcing compared to 59.5 percent in the manufacturing sector, the economic magnitudes of the relevance of e-commerce for global sourcing in services are much larger than in manufacturing. Further results are that more productive manufacturing as well as service firms are more likely to import inputs. Equally, this relationship is found mainly in industries with higher upstream supply chain complexity.

The empirical study contributes to the literature in three respects. First, the chapter extends the knowledge about the relevance of ICT for outsourcing and global sourcing. In contrast to the prior empirical evidence which mostly considers one or two measures

firm" (Olsen 2006, p. 6). The inputs produced at the foreign location are then imported, i.e. offshored. Global sourcing of inputs might include firms' offshoring activities. Since with the data used in this chapter, I cannot distinguish between the importing of inputs that previously have been produced at the firm and importing of inputs that have always been sourced from abroad, I use the term global sourcing or importing instead of offshoring. See for the measurement of global sourcing in this chapter also Section 4.3.

for firms' ICT use, for instance, ICT investment or Internet ordering (Abramovsky and Griffith 2006), or electronic networks (Fort 2015), this chapter analyses the role of various ICT measures in their relationship to global sourcing. The different measures account for the heterogeneity of ICT and allow to distinguish which kind of ICT might be relevant for firms' global sourcing activities. In particular, to the best of my knowledge, the analysis provides first firm-level evidence on the relationship between enterprise software systems use and global sourcing. Moreover, it provides first empirical evidence about the role of ICT for the probability of global sourcing for service firms since prior studies analyse only the impact of service sourcing on the decision to outsource or offshore (Abramovsky and Griffith 2006) or the effects of service importing on productivity (e.g. Amiti and Wei 2009; Görg, Hanley, and Strobl 2008). The distinction between the manufacturing and service sector allows to investigate similarities and potential differences between the two sectors with respect to the link between importing, ICT use and other firm characteristics.

Second, related to the relevance of technology for global sourcing is the literature on the role of technology for international trade. The existing literature has mainly focused on the export margin (e.g. Lileeva and Trefler 2010; Bustos 2011) and usually finds that manufacturing firms that are active on international markets use more advanced technology. However, the results presented in Chapter 3 of this thesis show that for service firms the group of non-exporting firms that use advanced technology may be large, too (see also Bertschek, Hogrefe, and Rasel 2015). This chapter adds empirical evidence about the ICT intensity of importing firms in comparison to non-importing firms.

Third, the analysis contributes to the literature on international trade in services by showing evidence for service as well as for manufacturing firms. Existing scarce empirical evidence shows many similarities between service and goods trade at the firm level and concludes that heterogeneous firm models of international trade developed for goods trade may be also a good starting point for studying service trade (Breinlich and Criscuolo 2011). This chapter allows examining whether heterogeneous firm models for the importing decision are supported by the data for manufacturing as well as for service firms.

The remaining chapter is structured as follows: Section 4.2 discusses the relevant literature for the empirical analysis. Section 4.3 describes the data and explains the measurement of the central variables followed by the presentation of the econometric implementation. In Section 4.4, the empirical results are presented and discussed, and Section 4.5 concludes.

4.2 Literature and background discussion

Arguments and empirical evidence from various literature strands are relevant for the analysis of this chapter. There is the literature on the benefits of ICT for outsourcing, domestic or international, and offshoring of inputs that stresses how ICT have changed the costs of outsourcing. The worldwide diffusion of the Internet has reduced communication costs across distance. In general, networked ICT can lower the costs of coordinating economic activity inside the firm and with outside market participants (Forman and McElheran 2015). ICT help reducing the costs of outsourcing of business services as they have the potential to lower search and transaction costs directly and as they can decrease the degree of specificity of the transaction since ICT are compatible with general skills, which are easily transferrable across firms (Abramovsky and Griffith 2006): Therefore, firms with a higher ICT investment level are expected to outsource and offshore more services. ICT also enable a change in the task composition of jobs (Autor, Levy, and Murnane 2003), thereby facilitating the fragmentation of production processes across space and consequently, also across borders. The ICT-facilitated fragmentation of production facilitates so-called "trade in tasks", a term suggested by Grossman and Rossi-Hansberg (2008) that highlights the labour content of offshoring manufacturing tasks and business functions. Moreover, ICT may improve the matching of buyers and suppliers of specialized inputs and business services through electronic markets, which may increase outsourcing activities (Grossman and Helpman 2002).

The principal reason for sourcing inputs from abroad is seen in exploiting labour cost differences across countries. Therefore, in theoretical models of global sourcing, wage differences across countries are central elements that determine the decision to source globally (e.g. Antrás and Helpman 2004; Grossman and Rossi-Hansberg 2008). Another reason is the possibility to source new inputs, potentially not available domestically or of better quality (Amiti and Konings 2007).

Besides the ICT-enabled direct cost reduction of communication and of coordination problems and the ICT-facilitated change in the job task composition as drivers for outsourcing inputs, ICT may also indirectly affect a firm's global sourcing decision through ICT-improved firm performance (Benfratello, Razzolini, and Sembenelli 2015). The argumentation for the indirect effect of ICT on the offshoring decision is based on two strands of the literature: On the one hand, by now it is undisputed that ICT may be productivity-enhancing. There is a large literature on the productivity effects of ICT investment.[2] On the other hand, firm heterogeneity in productivity is suggested to be

[2] For an overview, see, e.g., Draca, Sadun, and Van Reenen (2007) and Cardona, Kretschmer, and Strobel (2013).

an important determinant for a firm's global sourcing decision: More productive firms are more likely to engage in global sourcing as they have the resources to overcome the fixed costs of sourcing from abroad (Antrás and Helpman 2004). The fixed (sunk) costs of global sourcing include, for instance, searching for foreign suppliers or making contracts. This theoretical consideration suggests a causal self-selection of already more productive firms into global sourcing prior to starting to source inputs from abroad. Self-selection into entry in international markets based on productivity differences is at the centre of heterogeneous firm models in trade. While the literature has primarily focused on exporting,[3] there are also theories of importing that model fixed costs of sourcing from abroad (e.g. Antrás and Helpman 2004; Antrás, Fort, and Tintelnot 2014).[4]

Empirical evidence supports self-selection into importing based on productivity (e.g. Wagner (2011) for offshoring firms or Vogel and Wagner (2010) for importing firms from Germany) and stresses the role of fixed costs of global sourcing (e.g. Fort 2015; Antrás, Fort, and Tintelnot 2014). Importing firms tend to differ systematically from non-importing firms in other dimensions than productivity, too. Similar to the performance advantage of exporters in comparison to non-exporters,[5] global sourcing firms are larger and pay higher wages (e.g. Wagner (2011) for German offshoring firms; Ariu (2015) for Belgium importers). Moreover, Bernard et al. (2007) find that U.S. importing manufacturers have mainly very similar characteristics to exporting firms and that this similarity can be mainly attributed to the fact that importing firms are often at the same time exporters, too: They are larger, more productive, more capital- and skill-intensive, pay higher wages prior to international market entry than non-exporting and non-importing firms. Furthermore, empirical evidence also finds positive productivity effects from importing of inputs (for goods importing, e.g. Amiti and Konings (2007) or Halpern, Koren, and Szeidl (2015); for service offshoring, e.g. Görg, Hanley, and Strobl (2008)).

Prior firm-level evidence for the relationship between ICT use and global sourcing activity supports a positive correlation: A higher computer intensity is linked with a higher foreign outsourcing intensity for Japanese manufacturers (Tomiura 2005). Using firm-level data from the United Kingdom, Abramovsky and Griffith (2006) find that firms with higher investments in ICT and using the Internet to order goods or services outsource more business services and are more likely to offshore them, too. For Korean manufacturers, an ICT level of at least using the Internet for e-commerce is positively

[3] The model of Melitz (2003) is seen as the baseline model for the relevance of firm heterogeneity in export decisions. See Redding (2011) for a review of theories of heterogeneous firms in international trade.

[4] See Antrás, Fort, and Tintelnot (2014) also for a brief literature review of models of global sourcing and offshoring.

[5] For a survey, see, e.g., Bernard et al. (2012).

related to the offshoring decision, in particular for offshoring from the own foreign affiliate (Hyun 2010). Two firm-level studies for the U.S. and for Italy present more mixed results for the effect of ICT on global sourcing: For U.S. manufacturers, Fort (2015) finds that the use of electronic communication networks has a positively significant effect on production fragmentation and consequently on sourcing from an external supplier. However, this effect of communication technology on sourcing activities is disproportionately larger for domestic than for foreign sourcing, which is argued to be compatible with complementarity between technology and worker skill.[6] For Italian manufacturers, Benfratello, Razzolini, and Sembenelli (2015) show that ICT have a negative effect on offshoring, where the effect is only significant for low-tech firms leading the authors to conclude that ICT may substitute for routine tasks domestically, which are then performed by foreign workers. All these firm-level studies analyse the role of ICT for manufacturing firms' global sourcing decisions and to the best of my knowledge, there is no analysis that studies explicitly also the relevance of ICT for global sourcing activities of service firms.

However, there is some empirical evidence about firms that trade services. Breinlich and Criscuolo (2011) provide characteristics of UK exporters and importers that trade services. They find that only very few firms trade services and, similar to previous evidence for firms trading goods, that service importers are larger in terms of employment and sales, more labour productive, more capital intensive, they pay higher wages and are more likely to be foreign-owned or part of a multinational. The German Central Bank (Deutsche Bundesbank) collects data on international trade in services for the computation of the German Balance of Payments Statistics (Biewen, Blank, and Lohner 2013). Similar to the firm heterogeneity in international services trade for UK firms documented by Breinlich and Criscuolo (2011), the data reflect that many firms import only a very small share, two-way traders[7] import more than exclusive importers, and the majority of firms imports only one service type and mostly only from one country.[8] Ariu (2015) compares firms that trade goods and/or services based on trade transaction data from Belgium. The author finds that service trading firms are fewer and export and import smaller values than goods trading firms. Moreover, some empirical studies examine the impact of material and service offshoring on productivity (e.g. Amiti and Wei 2009; Görg, Hanley, and Strobl 2008).

[6] To support this view, Fort (2015) shows that the effect of communication technology on global sourcing is increasing in the sourcing country's human capital with increasing IT intensity of the production processes. This is interpreted as evidence that firms look for sourcing partners that are technologically advanced enough to cope with the technology requirements.

[7] Two-way traders are firms that export and import.

[8] A more detailed analysis of firm-level characteristics for services trade by German firms based on this Bundesbank data is provided by Kelle and Kleinert (2010).

The goal of this chapter is to provide new empirical evidence on the role of ICT for the probability of sourcing inputs globally, distinguishing between manufacturing and service firms. Based on the arguments for the relevance of ICT for the global sourcing decision as derived in the literature, in general, I expect a positive association between ICT and global sourcing.

4.3 Data and econometric model

The data used for the empirical analysis in this chapter are from the ZEW ICT survey 2010 conducted by the Centre for European Economic Research (ZEW).[9] The global sourcing variable was newly introduced in 2010 so that no panel analysis can be conducted for the purpose of this chapter.[10]

In order to exclude extreme outliers from the estimation sample, observations with a labour productivity below the 1st and above the 99th percentile are dropped.[11] Moreover, the sample is constructed based on the regression specification that includes the main set of control variables, which will be presented below. The resulting sample comprises 1243 firms from the manufacturing sector and 894 from the service sector. The manufacturing sector comprises seven broad industries and the service sector eight industries, among them mainly knowledge-intensive service providers.[12]

Table 4.11 in the appendix shows the distribution of firms across industries for the sample that is used in the empirical analysis as well as for the complete data set that includes all firms that were interviewed in the 2010 wave for these industries. Since the distribution of the estimation sample is not significantly different from the complete data set, it can be assumed that the used sample is representative with respect to the industries.

4.3.1 Measuring global sourcing, ICT and further variables

The dependent variable is a dummy variable for a firm's global sourcing behaviour that indicates whether the firm imported any inputs, goods or services, in 2009. This binary

[9] For more information about the survey, see Section 2.3 as well as (only in German) ZEW (2010). The data set used for this analysis is accessible at the ZEW Research Data Centre: http://kooperationen.zew.de/en/zew-fdz/home.html

[10] The 2014 data are not suited either because the majority of the ICT variables considered in this chapter was not asked in the 2014 survey.

[11] In total, 51 observations are dropped, 25 which are below the 1st and 26 which are above the 99th percentile.

[12] See Table 4.16 in the appendix for an overview of the industry composition.

variable is constructed from the question “Based on all inputs: What is the share that was sourced from abroad in 2009?”, which was only asked to firms if they imported any goods or services at all. The dummy variable is equal to one if the firm has a strictly nonzero global sourcing share, and equal to zero if the firm does not import any goods or services. The data do not allow to distinguish whether firms imported goods or services. Hence, it can be just one type or both. Evidence for Belgium firms shows that firms that trade goods, i.e. export and/or import, are the majority in the manufacturing as well as in the service sector, services are mostly traded in the service sector, whereas the shares of exporters or importers of firms trading both, goods and services, are fairly similar across the manufacturing and service sector (Ariu 2015). The information that the firm sources inputs from abroad allows to conclude that the firm makes use of inputs produced abroad for the own value creation process and that it has business contacts with foreign suppliers. The data do not include information whether the input is sourced from a foreign affiliate, which would be intra-firm trade, or from a foreign external supplier, which would refer to international outsourcing. Thus, the exact ownership of the foreign firm, from which a firm sources inputs, remains unspecific. However, for all firms without a foreign affiliate it can be concluded that if they source inputs from abroad, they engage in international outsourcing and trade across firm boundaries. In order to check whether there is a difference in the relationship between ICT use and global sourcing for purely internationally outsourcing firms and the whole sample of firms comprising also those with a foreign affiliate, in the robustness checks the empirical analysis is conducted exclusively for firms without any foreign location.

Table 4.1 shows global sourcing participation in percent across industries. Around 59.5 percent of manufacturers import inputs, while global sourcing is still less frequent for service firms with only 20.1 percent. A similar pattern of trade participation is found for Belgian firms where export and import participation is higher in the manufacturing sector than in the service sector (Ariu 2015). Across sectors in the manufacturing industry, global sourcing participation is for all except for the metal industry above 50 percent indicating that many manufacturers participate in global value chains. For the service sector, the global sourcing participation distribution looks differently. Global sourcing activities are highest in the sectors media services (31 percent) and IT and other information services (31 percent), whereas in the real estate activities sector only 7 percent import inputs. These average participation shares are consistent with the view that in general, service delivery is often relatively local and that services are more difficult to trade than manufacturing goods. Furthermore, service delivery is usually less input intensive than the production of manufacturing goods.

Table 4.1: Average global sourcing participation across industries

Manufacturing sector (N=1243)	Global sourcing participation in %	*Service sector* (N=894)	Global sourcing participation in %
Consumer goods	53.70	Transportation	19.55
Chemical and pharmaceutical industry	70.19	Media services	30.69
Other raw materials	62.57	IT and other information services	30.77
Metal industry	47.62	Financial and insurance activities	8.25
Electrical engineering	71.65	Real estate activities	7.41
Machine construction	54.95	Business consultancy and advertising	15.79
Vehicle construction	66.30	Technical services	22.54
		Other business services	13.68
Total	59.45	Total	20.13

Data source: ZEW ICT survey 2010. N stands for the number of observations; this abbreviation is also used in the subsequent tables.

The main variable of interest is a firm's ICT intensity. Instead of measuring it with one variable, in the main analysis ICT intensity is captured by various ICT applications, which can be categorized into three broad types of ICT. First, an electronic commerce (e-commerce) count indicator is constructed based on three questions in the survey about the use of the Internet for ordering products or services from suppliers (question 1), and for selling goods or services, either to private end-consumers, i.e. business-to-consumer (B2C) e-commerce (question 2), or to companies, i.e. business-to-business (B2B) e-commerce (question 3). Internet ordering is a form of electronic buying (e-buying) and B2C and B2B e-commerce can be viewed as forms of electronic selling (e-selling). In this chapter, the term e-commerce is used to summarize e-buying and e-selling activities. These e-commerce uses are Internet-enabled business process innovations that may have changed on the one hand, the possibilities how to interact with suppliers and customers, and on the other hand, the costs of interaction. The three e-commerce uses are aggregated into an e-commerce indicator that ranges from zero for no use to three for the use of all of the e-commerce possibilities. The indicator can be interpreted as a proxy for the intensity of the use of Internet-based communication and coordination with suppliers and customers. The aggregation of the three e-commerce options into a count variable also aims at minimizing multicollinearity in the regression because all variables are correlated with each other as it is shown in Table 4.2.

The majority of firms in the manufacturing (50 percent) and service (43 percent) sector uses only one form of e-commerce followed by two forms (Table 4.2). Moreover, if they use e-commerce, mostly they use Internet ordering plus possibly B2B or B2C e-commerce. In the manufacturing sector, 78 percent use Internet ordering from suppliers, 34 percent offer B2B e-commerce and 16 percent B2C e-commerce. In the service sector, the average adoption values are slightly higher with 81 percent for Internet ordering, 39 percent for B2B and 22 percent for B2C e-commerce. This diffusion distribution is consistent with the fact that e-selling usually involves more complex organizational changes and higher adjustment costs than e-buying (McElheran 2015). Given these different adoption costs of e-buying and e-selling, instead of the e-commerce count indicator, in the empirical analysis I also consider the individual e-commerce measures separately in how they are related to global sourcing.

Table 4.2: Descriptive statistics of e-commerce use

	Manufacturing sector (N=1243)								
No. e-commerce applications	0	1	2	3					
	Frequency distributions in %				Mean	SD	Median	Min.	Max.
E-commerce indicator	15.85	50.12	24.70	9.33	1.28	0.84	1	0	3
	Correlations								
	Internet o.	B2B	B2C	-					
Internet ordering	1				0.78	0.42	1	0	1
B2B e-commerce	0.10	1			0.34	0.48	0	0	1
B2C e-commerce	0.10	0.30	1		0.16	0.36	0	0	1
	Service sector (N=894)								
No. e-commerce applications	0	1	2	3					
	Frequency distributions in %				Mean	SD	Median	Min.	Max.
E-commerce indicator	14.43	43.40	27.52	14.65	1.42	0.91	1	0	3
	Correlations								
	Internet o.	B2B	B2C	-					
Internet ordering	1				0.81	0.39	1	0	1
B2B e-commerce	0.24	1			0.39	0.49	0	0	1
B2C e-commerce	0.10	0.34	1		0.22	0.42	0	0	1

Data source: ZEW ICT Survey 2010. SD stands for standard deviation; this abbreviation is also used in the subsequent tables.

Second, four enterprise software systems are considered to reflect a different type of ICT use that focuses on software-enabled information organization: Enterprise Resource Planning (ERP), Content or Document Management systems (CDMS), Supply Chain Management (SCM) and Customer Relationship Management (CRM). ERP is a general purpose software that supports internal information management. It integrates enterprise functions such as sales and distribution, materials management, production planning, financial accounting, cost control, and human resource management (Aral, Brynjolfsson, and D. Wu 2006). CDMS software supports the management of electronic documents as well as it might include functionalities for collaboration with electronic documents. While CRM software focuses on the interaction with customers, SCM software supports ICT-based processing of the different steps of the value chain. The benefits of SCM software might be especially useful for firms with external suppliers.

The principal role of such software solutions is to assist the firm to gather information from various business processes, analyse this information and then to execute on it to increase the performance of the supply chain (Chopra and Meindl 2007). Even though, these software systems focus on different information flows from inside or outside the firm, they have in common that they reduce information and coordination costs, which ultimately may have changed how firms organize their internal work flows as well as their external relationships.[13]

Table 4.3: Descriptive statistics of enterprise software use

	Manufacturing sector (N=1243)									
No. software systems	0	1	2	3	4					
	Frequency distributions in %					Mean	SD	Median	Min.	Max.
Software indicator	15.12	22.61	23.65	19.31	19.31	2.05	1.34	2	0	4
	Correlations									
	ERP	CDMS	SCM	CRM	-					
ERP	1					0.79	0.41	1	0	1
CDMS	0.26	1				0.47	0.50	0	0	1
SCM	0.33	0.35	1			0.42	0.49	0	0	1
CRM	0.30	0.34	0.43	1		0.38	0.48	0	0	1
	Service sector (N=894)									
No. software systems	0	1	2	3	4					
	Frequency distributions in %					Mean	SD	Median	Min.	Max.
Software indicator	14.77	22.48	22.26	26.85	13.65	2.02	1.28	2	0	4
	Correlations									
	ERP	CDMS	SCM	CRM	-					
ERP	1					0.72	0.45	1	0	1
CDMS	0.27	1				0.58	0.49	1	0	1
SCM	0.21	0.24	1			0.24	0.43	0	0	1
CRM	0.29	0.42	0.28	1		0.47	0.50	0	0	1

Data source: ZEW ICT Survey 2010.

Table 4.3 shows basic descriptive statistics of these variables. Like the e-commerce variables, also these variables are all correlated with each other. To reduce multicollinearity, I aggregate them into a count variable ranging from zero for no use of any of the systems to four if all systems are used. This count indicator can be interpreted as a measure for a firm's extent of the use of IT-supported information documentation and analysis. Moreover, it reflects the degree of investment into internal IT capabilities that possibly may also affect external business partners, for instance, in the case of SCM. McElheran (2015) points out that in the 1990s the diffusion of internally-focused IT such as ERP was an important factor for the diffusion of e-commerce solutions.

On average, two of the software systems are used by manufacturing and by service firms. Moreover, in both sectors the firms are roughly evenly distributed across the five frequency possibilities by roughly one fifth in each, even though in the two border groups of zero and five, there are slightly less than one fifth than in the three middle groups. This frequency distribution reflects substantial variation in the enterprise software adoption intensity. With respect to the adoption frequencies of the individual software systems, ERP software is diffused most broadly, followed by CDMS and then either by SCM or CRM software. This diffusion distribution is consistent with the facts discussed above that ERP is a general purpose software whereas the other software systems are aimed at

[13]For more information about ERP, SCM and CRM software, see, e.g., Hendricks, Singhal, and Stratman (2007), Engelstätter (2012) and Section 2.2.

supporting specific business processes and for specific purposes, which not necessarily all firms will need.

Third, two measures of computer and Internet diffusion within the firm are included that reflect the ICT use by employees. On the one hand, the share of employees working predominantly with the personal computer (PC) is considered. This measure can be interpreted as a measure for a firm's overall ICT intensity and alternatively for labour heterogeneity (Bertschek and Meyer 2009). It measures part of a firm's hardware and software equipment as well as it reflects the extent of the firm's use of the computer as a working tool within its business model. On the other hand, the share of employees with Internet access serves as a proxy for the relevance of the Internet for the business activity besides being a measure for the Internet diffusion within the firm. For both measures, the average values are higher in the service than in the manufacturing sector as Table 4.4 shows. Moreover, the share of employees with Internet access (44 percent for manufacturing firms; 77 percent for service firms) is roughly ten percentage points higher than the share of employees working predominantly at the PC (34 percent for manufacturing firms; 68 percent for service firms). The larger diffusion of computer-based work and Internet access across employees in service firms than in manufacturing firms reflects that on average business-related services rely more on computer work than manufacturing production processes for which other types of machinery are relevant, too.

Table 4.4: Descriptive statistics of PC and Internet diffusion

	Manufacturing sector (N=1243)				
	Mean	SD	Median	Min.	Max.
% Empl. working with PC	0.34	0.25	0.28	0	1
% Empl. with Internet access	0.44	0.33	0.30	0	1
	Service sector (N=894)				
	Mean	SD	Median	Min.	Max.
% Empl. working with PC	0.68	0.36	0.85	0	1
% Empl. with Internet access	0.77	0.34	1	0	1

Data source: ZEW ICT survey 2010.

In light of the importance of productivity for the global sourcing decision as documented in the literature on heterogeneous firm models in international trade and on firm importing, labour productivity is considered as another main explanatory variable. It is measured as total sales per employee. More productive firms might also have better financial capacities to afford expensive ICT systems. Furthermore, as ICT have the potential to improve productivity, more ICT-intensive firms are likely to be more productive, too.

The empirical analysis considers various other firm characteristics to control for variables that might have an impact on the global sourcing decision as well as on adopting ICT.[14] Table 4.12 in the appendix presents descriptive statistics of those other firm characteristics. Firm size (logarithmic number of employees) is considered because prior empirical evidence has shown that importing firms are on average larger than non-importing firms (e.g. Bernard et al. 2007; Breinlich and Criscuolo 2011; Vogel and Wagner 2010). Firm size is often interpreted as a measure for a firm's financial capacity to afford complex and often expensive ICT systems, where larger firms are likely to have better access to financial resources than smaller firms.

Further international participation of firms besides sourcing inputs from abroad is included by a dummy variable for exporting activities and a dummy variable for the existence of a foreign location. Empirical findings show that importing firms are often exporters, multinationals or foreign owned (e.g. Bernard et al. 2007; Ariu 2015). Moreover, firms with other foreign contacts may potentially have lower importing costs because they already know business partners abroad or foreign market conditions. Thus, they might find foreign suppliers more easily or even source from own foreign locations. Furthermore, exporters are found to be more capital intensive (e.g. Bernard et al. 2012) and more ICT intensive (e.g. Bertschek, Hogrefe, and Rasel 2015) than non-exporters and use in general more advanced technology (e.g. Bustos 2011). Exporters are also said to face more competitive pressures than non-exporters due to their participation in foreign markets (e.g. Bertschek and Kaiser 2004). Greater competitive pressure may increase the firm's willingness to source inputs globally in order to save costs or to get access to better quality.

Human capital composition is captured by the share of highly skilled employees.[15] In the literature and discussions about offshoring, it has often been discussed that if offshoring costs decrease, especially low-skilled jobs will be relocated abroad and then those tasks and inputs performed by low-skilled workers will be imported from abroad.

[14] For a recent review of the evidence on ICT adoption and firm characteristics, see, e.g., Haller and Siedschlag (2011).

[15] The share of highly skilled employees includes employees with a degree from university, university of applied sciences or university of cooperative education.

In the domestic offshoring firm, a relocation of low-skilled jobs abroad would imply a lower share of low-skilled and a higher share of high-skilled employees so that global sourcing activities and the share of highly skilled human capital would be positively related. Moreover, skilled human capital might be an important factor to manage the international relations, for instance, for negotiating with business partners in a foreign language. A firm's human capital composition of the labour force may also be associated with its ICT use in view of the literature on skill-biased technological change (SBTC) that argues that ICT capital complements skilled labour because ICT raise its relative productivity in comparison to unskilled labour.[16]

To account for the association between internationalization and innovation activities, the innovative capabilities of a firm are captured by a dummy variable for product innovation and a dummy variable for process innovation. The dummy variables are equal to one if the firm has realized a product or process innovation in the period from 2006-2009, respectively. For instance, Criscuolo, Haskel, and Slaughter (2005) find that globally engaged firms (exporters or being part of a multinational) innovate more than purely domestic firms. The authors argue that the innovation advantage can be attributed to a higher number of researchers but also to a more diversified set of inputs, which is available to globally engaged firms through their contacts to suppliers, customers or foreign affiliates. Furthermore, international outsourcing might increase innovation incentives because it reduces production costs through lower prices for the inputs sourced from abroad than domestically available and thereby raises a firm's profits so that the higher profits can be used to increase the innovation rate through increased R&D spending (Glass and Saggi 2001).[17] It might also be that more innovative firms are more likely to import because they need specific inputs that are not domestically available or because they want to save costs for inputs. The innovation variables may also be correlated with the ICT variables since ICT are said to be an enabler for innovation (Brynjolfsson and Saunders 2010) or since more innovative firms are more open to adopt new technologies. For instance, Hollenstein and Wörter (2008) find a positive relationship between the introduction of new products and/or processes and the adoption of e-commerce.

Furthermore, two variables are included that reflect the employees' power in decision making and flexibility of work. On the one hand, a dummy variable for having a works council is considered to control for employees' voice and coordination potential at the employee level with respect to firm-related questions. On the other hand, an indicator

[16] See Violante (2008) for a summary of the SBTC discussion and for a summary of the skill-ICT complementarity hypothesis, see, e.g., Draca, Sadun, and Van Reenen (2007).

[17] For empirical evidence, see, e.g., Görg and Hanley (2011) who find a positive effect of international outsourcing of services on innovative activity using plant-level data from the Republic of Ireland.

for decentralized workplace organization that ranges from zero to five is included.[18] Exporters and multinational plants are found to be better managed (e.g. Bloom, Sadun, and Van Reenen 2012) or exporters will have more layers of management, i.e. be more decentralized, due to a larger firm size than non-exporters (Caliendo and Rossi-Hansberg 2012). Decentralized workplace organization and human resource practices have also been documented to be complementary to ICT (e.g. Bresnahan, Brynjolfsson, and Hitt 2002; Bloom, Sadun, and Van Reenen 2012).[19]

Finally, industry dummy variables based on an industry affiliation that corresponds to the NACE two-digit industry level[20] are included to capture industry-specific effects. Furthermore, a dummy variable for multi-plant association as well as a dummy variable indicating whether the firm is located in East Germany, to account for possible regional effects, are considered.

Since the empirical analysis focuses on the role of ICT for the likelihood of global sourcing, Table 4.5 shows average values for ICT adoption between firms that source inputs globally and those that do not. For all indicators and ICT variables except for B2C e-commerce in the manufacturing sector, importing firms have higher average values than those firms that do not import. Moreover, the differences in firm characteristics between importing and non-importing firms found in the literature are generally reflected. In both sectors, global sourcing firms are on average larger, have a higher labour productivity, are more often exporters as well as more of them have a foreign affiliate than firms without any foreign inputs (Table 4.13 in the appendix). Furthermore, global sourcing firms are more innovative. With respect to labour productivity, in the manufacturing sector the mean value for global sourcing firms is more than 40 percent higher compared to non-importing firms and in the service sector the respective value is more than 25 percent higher.

The descriptive analysis suggests that global sourcing firms differ in their ICT adoption as well as in other important firm characteristics from firms that do not source globally. As expected by theoretical considerations, on average the diffusion of ICT is larger for global sourcing firms than for those without any inputs imported. However, since a pure mean comparison does not control for firm characteristics that might be deterministic for the global sourcing decision as well as for ICT adoption, a univariate probit model

[18]This workplace indicator consists of the sum of the following five dummy variables that are each equal to one if the firm offers this management practice: Self-managed teams, units with own profit and loss responsibility, performance pay, job rotation and work time accounts.

[19]For more information about the evidence for complementarity between ICT and workplace organization, see also Chapter 2.

[20]Classification of industries 2008 as of "Klassifikation der Wirtschaftszweige 2008 (WZ 2008)". See Table 4.16 in the appendix for the exact industry classification.

is chosen that controls for such firm characteristics in order to investigate whether more ICT-intensive firms are more likely to source inputs from abroad, conditional on other sources of firm heterogeneity.

Table 4.5: Average ICT characteristics by global sourcing status

	global sourcing firms		non-global sourcing firms	
ICT variables	Mean	SD	Mean	SD
	Manufacturing sector (N=1243)			
E-commerce indicator	1.33	0.84	1.19	0.84
Internet ordering	0.79	0.41	0.76	0.43
B2B e-commerce	0.39	0.49	0.28	0.45
B2C e-commerce	0.15	0.36	0.16	0.37
Software indicator	2.32	1.31	1.65	1.28
ERP	0.85	0.36	0.70	0.46
CDMS	0.53	0.50	0.38	0.48
SCM	0.50	0.50	0.30	0.46
CRM	0.44	0.50	0.28	0.45
% Empl. working with PC	0.38	0.25	0.28	0.24
% Empl. with Internet access	0.49	0.33	0.37	0.32
	Service sector (N=894)			
E-commerce indicator	1.73	0.84	1.35	0.91
Internet ordering	0.92	0.28	0.78	0.41
B2B e-commerce	0.56	0.50	0.35	0.48
B2C e-commerce	0.26	0.44	0.22	0.41
Software indicator	2.47	1.19	1.91	1.27
ERP	0.81	0.39	0.70	0.46
CDMS	0.68	0.47	0.56	0.50
SCM	0.37	0.48	0.21	0.41
CRM	0.61	0.49	0.44	0.50
% Empl. working with PC	0.70	0.33	0.67	0.37
% Empl. with Internet access	0.81	0.31	0.76	0.35

Data source: ZEW ICT survey 2010.

4.3.2 Econometric implementation

A univariate probit model is chosen to analyse whether firms with certain ICT characteristics and higher ICT intensity as well as higher labour productivity are more likely to source inputs from abroad. The following equation formalizes the estimating equation:

$$P(Y_i = 1|X_i) = \Phi(\alpha + \beta'_{ICT} ICT_i + \gamma log(prod_i) + \delta' X_i) \tag{4.1}$$

where i represents the firm indicator and $\Phi(.)$ the cumulative standard normal distribution given that the probit model assumes the error term to be standard normally distributed. The dependent variable Y_i is a dummy variable for global sourcing activity, ICT_i is a vector that includes the three types of ICT discussed above and $log(prod_i)$ stands for labour productivity included in logarithmic terms.

X_i is a vector of control variables comprising variables that might have an impact on the decision to import inputs as well as on adopting a certain ICT application, as it is discussed above. The probit regressions allow for heteroskedastic error terms by using the robust standard errors estimation.

A potential concern with this empirical approach is that the ICT variables may be endogenous to the global sourcing activity. As the data do not include neither the starting year of importing inputs, nor the adoption year of any of the software systems or the e-commerce solutions, it is impossible to analyse whether ICT can be seen as causing firms to source globally or whether actually global sourcing firms have invested more in ICT solutions because for instance, they assess higher benefits to the use of it. Since this reverse causality problem cannot be addressed with the data, the empirical results are interpreted as correlations between a firm's ICT intensity and global sourcing activity, controlling for firm heterogeneity that may be relevant for both decisions. However, at least for the e-selling activities, which are captured in the e-commerce indicator, the relationship to global sourcing is less obvious given that e-selling supports sales and not sourcing activities. Moreover, the general challenge that e-selling activities depend on the product suitability should on average not depend on the upstream composition of the value chain. Therefore, the e-selling activities that are included in the e-commerce count indicator can be seen as plausibly exogenous to global sourcing.

Besides endogeneity due to reverse causality, omitted variables that are correlated with the explanatory variables may bias the coefficient estimates. For instance, unobservable firm effects, such as management quality, idiosyncratic shocks correlated with ICT and global sourcing or policy changes that do not affect all firms within an industry, so that they would not be appropriately taken into account by the industry dummy variable, might lead to a spurious correlation between ICT and global sourcing. If systematically better performing firms invest on average more in ICT and are also more likely to source globally, then the coefficients of ICT will be upward biased. To alleviate endogeneity due to omitted variables, I include a large set of control variables, such as labour productivity or a firm's human capital composition. Hence, the empirical results reflect whether more ICT-intensive firms with similar other firm characteristics are more likely to source inputs globally. Moreover, in addition to the analysis with the total samples of manufacturing and service firms, I examine the relevance of ICT for global sourcing in different subsamples to analyse where the effect of ICT might be expected to be stronger or lower.

4.4 Empirical results

4.4.1 Main results

Table 4.6 shows the main results of the probit estimations of equation (1) that links a firm's ICT intensity to its global sourcing status. In all tables, the average marginal effects (sample averages of the changes in the variables of interest evaluated for each observation) are presented. In columns (1) to (4) the results for the manufacturing sector and in columns (5) to (8) for the service sector are depicted that originate from various regression specifications, which differ in the set of control variables. Columns (1) and (5) show the correlations between the ICT variables and global sourcing controlling for firm size, industry dummy variables, location in a new state of Germany, i.e. former East Germany, and multi-plant affiliation. In the manufacturing sector, firms with more e-commerce applications as well as more enterprise software systems are weakly significantly more likely to source inputs from abroad. Moreover, manufacturers with a higher share of employees working predominantly at the PC and with a higher share of employees with Internet access are more likely to source globally. In contrast, in the service sector, only those with more e-commerce applications and weakly those with more enterprise software systems are more likely to import inputs.

In columns (2) and (6) labour productivity is included given that models of firm heterogeneity stress the relevance of firm productivity as key selection factor into production fragmentation and importing (e.g. Antrás and Helpman 2004; Antrás, Fort, and Tintelnot 2014). The coefficients of labour productivity show that for manufacturing as well as for service firms, more productive firms are more likely to source globally. This positive relationship between productivity and global sourcing is compatible with the view in models of firm heterogeneity that global sourcing incurs fixed costs that only the more productive ones can overcome. Columns (3) and (7) consider firms' further international activities in terms of exporting and existence of a foreign location. For both, manufacturing and service firms, if they export, they are more likely to import inputs as well. This result seems reasonable given that exporting firms, for instance, have established foreign contacts, which might facilitate finding foreign suppliers or more generally, maintaining contacts with foreign partners.

Table 4.6: Global sourcing probability and ICT - Average marginal effects

	Manufacturing sector				Service sector			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	ICT & firm size	Labour productivity	Interna-tional activities	Further controls	ICT & firm size	Labour productivity	Interna-tional activities	Further controls
E-commerce indicator	0.030*	0.033**	0.022	0.015	0.065***	0.066***	0.059***	0.054***
	(0.016)	(0.016)	(0.015)	(0.015)	(0.015)	(0.015)	(0.014)	(0.015)
Enterprise software indicator	0.024**	0.022*	0.012	-0.001	0.022*	0.019	0.011	0.008
	(0.012)	(0.012)	(0.012)	(0.012)	(0.013)	(0.013)	(0.012)	(0.013)
% Empl. working with PC	0.137*	0.080	0.021	0.026	-0.044	-0.060	-0.044	-0.033
	(0.074)	(0.075)	(0.072)	(0.075)	(0.055)	(0.054)	(0.053)	(0.055)
% Empl. with Internet access	0.170***	0.152***	0.151***	0.148***	0.083	0.062	0.068	0.055
	(0.054)	(0.054)	(0.051)	(0.051)	(0.060)	(0.060)	(0.058)	(0.060)
log(employment)	0.078***	0.067***	0.034***	0.021	0.012	0.010	0.005	0.002
	(0.011)	(0.012)	(0.012)	(0.014)	(0.011)	(0.011)	(0.011)	(0.014)
log(labour productivity)		0.077***	0.047**	0.047**		0.052***	0.041**	0.040**
		(0.020)	(0.020)	(0.020)		(0.019)	(0.018)	(0.018)
Export activity			0.265***	0.264***			0.183***	0.178***
			(0.027)	(0.027)			(0.025)	(0.025)
Foreign location			0.066*	0.060			0.056	0.059
			(0.040)	(0.040)			(0.039)	(0.039)
% Highly skilled empl.				-0.081				-0.031
				(0.093)				(0.054)
Product innovation				0.051*				0.059**
				(0.027)				(0.029)
Process innovation				0.048*				-0.012
				(0.027)				(0.028)
Works council				0.011				0.010
				(0.035)				(0.037)
Workplace organization				0.025**				0.003
				(0.012)				(0.012)
Sector and location dummies	yes	yes	yes	yes	yes	yes	yes	yes
Number of observations	1243	1243	1243	1243	894	894	894	894
Pseudo-R^2	0.1030	0.1124	0.1632	0.1716	0.0952	0.1059	0.1702	0.1757

Significance levels: $*$: 10% $**$: 5% $***$: 1%. Robust standard errors in parentheses. Sector dummy variables include a full set of two-digit industry dummy variables, location defines a dummy variable if the firm is located in a new member state, i.e. in former East Germany. Moreover, all regressions control for multi-plant affiliation.

Columns (4) and (8) add a variety of controls for skill composition, innovation outcomes and workplace organization. Among these control variables, realized product innovations raise the probability of global sourcing for manufacturing and service firms. Manufacturing firms are also significantly more likely to import inputs with realized process innovations and more forms of decentralized workplace organization. With this set of controls, concerning ICT use, in the manufacturing sector only a higher share of employees with Internet access increases the global sourcing likelihood significantly. In the service sector, only e-commerce activities are correlated positively and significantly with the global sourcing probability. The coefficient of the e-commerce indicator in column (8) suggests that being engaged in one more e-commerce-based activity is associated with a 5.4 percentage points increase in the likelihood of global sourcing for service firms.

4.4.2 Robustness checks

Thus far, I have examined the average effect of ICT on the probability of global sourcing, conditional on other sources of firm heterogeneity. In the following, first, I will present some robustness checks with additional control variables or different ICT measures. Second, I will examine the relationship between ICT and global sourcing for different subsamples and third, I will analyse a particular circumstance under which ICT might be particularly relevant for global sourcing. Finally, I will consider SMEs only.

Additional control variables and ICT measures

Table 4.7 shows results for the manufacturing sector with the set of controls as in column (4) of Table 4.6. For all these specifications, the central result from the main analysis for manufacturing firms that the share of employees with Internet access and labour productivity are significantly positively related to global sourcing is robust. In column (1), instead of including two-digit industry dummy variables, three-digit industry dummy variables are considered. They are not used for the main analysis because in some three-digit industries all firms import inputs so that those firms will not be used in the estimation as the three-digit dummy variable predicts global sourcing perfectly. Column (2) includes dummy variables for the second and third tertile of the labour productivity distribution instead of the logarithmic productivity. The reference group are those firms in the first productivity tertile. This strategy is based on Fort (2015) who uses indicators for the productivity distribution in order to allow for potential non-linearities in the effect of productivity. The results show that those firms in the top productivity tertile are on average 8.2 percentage points more likely to source inputs from abroad. Similarly, Fort (2015) finds that the relationship between productivity and global sourcing is stronger for firms in the top of the productivity distribution than for those in the middle group. In column (3), IT outsourcing is taken into account. ICT-intensive firms might be more likely to source out IT and to import inputs. For example, they might import IT support, i.e. the IT outsourcing from abroad. However, the coefficient of IT outsourcing is not significant and all other coefficients do not change neither qualitatively nor quantitatively very much.

Table 4.7: Global sourcing probability and ICT - Robustness checks

	Manufacturing sector					
	(1)	(2)	(3)	(4)	(5)	(6)
	3-digit industry controls	tertiles	IT outsourcing	E-commerce & software indicator	ICT dummy variables	ICT usage intensity indicator
E-commerce indicator	0.013	0.015	0.014			
	(0.016)	(0.015)	(0.017)			
Internet ordering					0.015	
					(0.030)	
B2B e-commerce					0.029	
					(0.029)	
B2C e-commerce					-0.005	
					(0.037)	
E-commerce usage intensity						0.012
						(0.015)
Software indicator	-0.002	-0.000	-0.004			
	(0.012)	(0.012)	(0.013)			
ERP software					0.010	
					(0.034)	
CDMS software					-0.005	
					(0.028)	
SCM software					0.029	
					(0.030)	
CRM software					-0.036	
					(0.031)	
Software usage intensity						0.004
						(0.017)
E-commerce & software indicator				0.006		
				(0.009)		
% Empl. working with PC	0.011	0.031	0.045	0.023	0.027	0.024
	(0.078)	(0.075)	(0.079)	(0.075)	(0.076)	(0.075)
% Empl. with Internet access	0.139***	0.150***	0.141***	0.145***	0.147***	0.145***
	(0.052)	(0.051)	(0.054)	(0.051)	(0.051)	(0.051)
log(employment)	0.032**	0.020	0.011	0.019	0.020	0.020
	(0.015)	(0.014)	(0.015)	(0.014)	(0.014)	(0.014)
log(labour productivity)	0.061***		0.048**	0.047**	0.047**	0.047**
	(0.022)		(0.021)	(0.020)	(0.020)	(0.020)
2. productivity tertile		0.032				
		(0.030)				
3. productivity tertile		0.082**				
		(0.036)				
Export activity	0.240***	0.267***	0.275***	0.263***	0.264***	0.264***
	(0.030)	(0.027)	(0.029)	(0.027)	(0.027)	(0.027)
Foreign location	0.029	0.061	0.060	0.062	0.061	0.061
	(0.039)	(0.040)	(0.041)	(0.040)	(0.040)	(0.040)
% highly skilled empl.	-0.105	-0.081	-0.112	-0.081	-0.082	-0.082
	(0.096)	(0.094)	(0.097)	(0.093)	(0.094)	(0.093)
Product innovation	0.042	0.049*	0.053*	0.051*	0.052*	0.050*
	(0.028)	(0.027)	(0.029)	(0.027)	(0.027)	(0.027)
Process innovation	0.047*	0.051*	0.045	0.047*	0.048*	0.047*
	(0.027)	(0.027)	(0.028)	(0.027)	(0.027)	(0.027)
Works council	-0.018	0.013	0.025	0.010	0.007	0.011
	(0.036)	(0.036)	(0.038)	(0.035)	(0.036)	(0.035)
Workplace organization	0.026**	0.027**	0.018	0.025**	0.025**	0.025**
	(0.012)	(0.012)	(0.012)	(0.012)	(0.012)	(0.012)
IT outsourcing			0.063			
			(0.042)			
Sector and location dummies	yes	yes	yes	yes	yes	yes
Number of observations	1202	1243	1087	1243	1243	1243
Pseudo-R^2	0.2140	0.1710	0.1773	0.1713	0.1731	0.1715

Significance levels: * : 10% ** : 5% *** : 1%. Robust standard errors in parentheses. Sector dummy variables include a full set of two-digit industry dummy variables, location defines a dummy variable if the firm is located in a new member state, i.e. in former East Germany. Moreover, all regressions control for multi-plant affiliation.

Columns (4) to (6) include different variants of ICT indicators. Column (4) considers a count indicator that adds the number of e-commerce and software applications into one indicator. Column (5) includes the individual dummy variables for e-commerce and the software systems. Finally, column (6) introduces indicators based on the usage intensity of the e-commerce activities and of the software systems. The ICT survey 2010 asks the firms about each e-commerce use and enterprise software system whether they do not use it, use it only sporadically or use it broadly. This categorical information from zero to two is used to create a usage intensity indicator by z-scoring the values for each application and then adding the individually z-scored values and using the z-scoring transformation again.[21] None of these various ICT variables is significantly related to global sourcing.

Table 4.8 shows the same set of regression specifications for service firms. The central result from the baseline analysis that an additional e-commerce use raises the global sourcing probability is robust to the different control variables and for the different ICT indicators. The result of column (5), in which each of the ICT applications considered for the indicators, are included as dummy variables, gives some insight which of the e-commerce applications is the most relevant for global sourcing. As consistent with the purpose of this Internet-based transaction, it is the use of Internet ordering whose coefficient has the largest magnitude. According to the result in column (5), firms that use Internet ordering are 12.2 percentage points more likely to source inputs from abroad. Although the results of Abramovsky and Griffith (2006) are not completely comparable to those in this chapter since they only consider business services offshoring, the authors also find that using the Internet to order goods increases the offshoring probability significantly for UK firms. Column (5) also shows that neither B2B nor B2C e-selling is individually significantly related to global sourcing reflecting that it is not e-selling transactions per se that raise the global sourcing probability. To test whether besides e-buying, the intensity of e-selling raises the global sourcing likelihood, column (6) includes a count variable for e-selling based on B2B and B2C e-commerce. The result shows that in addition to Internet ordering, more uses of e-selling are positively associated with global sourcing at the 10-percent significance level. This result suggests that firms that rely on more electronic-based transactions are more likely to be an importing firm, too.

[21]For more information about z-scoring, see Subsection 2.3.1.

Table 4.8: Global sourcing probability and ICT - Robustness checks

	Service sector						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	3-digit industry controls	tertiles	IT outsourcing	E-commerce & software indicator	ICT dummy variables	B2B & B2C indicator	ICT usage intensity indicator
E-commerce indicator	0.062***	0.054***	0.065***				
	(0.016)	(0.015)	(0.015)				
Internet ordering					0.122***	0.121***	
					(0.038)	(0.038)	
B2B e-commerce					0.030		
					(0.027)		
B2C e-commerce					0.039		
					(0.034)		
B2B & B2C indicator						0.034*	
						(0.018)	
E-commerce usage intensity							0.047***
							(0.012)
Software indicator	0.008	0.008	0.003			0.008	
	(0.014)	(0.013)	(0.013)			(0.013)	
ERP software					0.025		
					(0.032)		
CDMS software					-0.012		
					(0.030)		
SCM software					0.008		
					(0.030)		
CRM software					0.015		
					(0.029)		
Software usage intensity							0.009
							(0.017)
E-commerce & software indicator				0.028***			
				(0.009)			
% Empl. working with PC	-0.033	-0.029	-0.031	-0.036	-0.020	-0.024	-0.036
	(0.063)	(0.055)	(0.059)	(0.056)	(0.055)	(0.055)	(0.055)
% Empl. with Internet access	0.060	0.054	0.028	0.048	0.051	0.053	0.050
	(0.063)	(0.060)	(0.065)	(0.061)	(0.061)	(0.060)	(0.060)
log(employment)	0.002	-0.001	0.005	-0.003	0.001	0.002	0.002
	(0.015)	(0.014)	(0.014)	(0.013)	(0.014)	(0.014)	(0.013)
log(labour productivity)	0.043**		0.054***	0.039**	0.039**	0.040**	0.037**
	(0.019)		(0.018)	(0.018)	(0.018)	(0.018)	(0.018)
2. productivity tertile		0.026					
		(0.030)					
3. productivity tertile		0.088**					
		(0.036)					
Export activity	0.179***	0.180***	0.168***	0.178***	0.181***	0.180***	0.178***
	(0.028)	(0.025)	(0.026)	(0.025)	(0.025)	(0.025)	(0.025)
Foreign location	0.056	0.056	0.081*	0.055	0.054	0.054	0.057
	(0.044)	(0.039)	(0.042)	(0.039)	(0.039)	(0.039)	(0.039)
% Highly skilled empl.	-0.044	-0.032	-0.030	-0.038	-0.033	-0.032	-0.037
	(0.064)	(0.054)	(0.057)	(0.054)	(0.054)	(0.054)	(0.054)
Product innovation	0.052	0.061**	0.079***	0.060**	0.063**	0.061**	0.058**
	(0.032)	(0.029)	(0.030)	(0.029)	(0.029)	(0.029)	(0.029)
Process innovation	-0.014	-0.011	-0.020	-0.016	-0.010	-0.010	-0.010
	(0.030)	(0.028)	(0.029)	(0.028)	(0.028)	(0.028)	(0.028)
Works council	0.012	0.017	-0.006	0.009	0.010	0.010	0.013
	(0.041)	(0.037)	(0.038)	(0.037)	(0.037)	(0.037)	(0.037)
Workplace organization	-0.002	0.003	-0.003	0.003	0.002	0.003	0.003
	(0.012)	(0.012)	(0.012)	(0.012)	(0.012)	(0.012)	(0.012)
IT outsourcing			0.062				
			(0.038)				
Sector and location dummies	yes	yes	yes	yes	yes	yes	yes
Number of observations	809	894	781	894	894	894	894
Pseudo-R^2	0.1952	0.1765	0.2113	0.1708	0.1808	0.1799	0.1761

Significance levels: $*$: 10% $**$: 5% $***$: 1%. Robust standard errors in parentheses. Sector dummy variables include a full set of two-digit industry dummy variables, location defines a dummy variable if the firm is located in a new member state, i.e. in former East Germany. Moreover, all regressions control for multi-plant affiliation.

Different subsamples of firms

Second, to gauge whether the results are robust for different subsets of firms and to analyse for which firms ICT seems to be more relevant for global sourcing, Tables 4.9 and 4.10 show results for different subsets of manufacturing and service firms, respectively. Thus far, I have not distinguished between firms without and with a foreign location. Hence, the results have represented the relevance of ICT for sourcing inputs across borders, irrespective of whether the transactions take part within or across firm boundaries. Coordination costs across borders and firm boundaries will probably on average be higher than coordination across borders within firm boundaries so that ICT-facilitated coordination may be particularly useful. Column (1) shows the results for firms without any foreign location. Therefore, in addition to trading across borders, those firms trade across firm boundaries for sourcing their inputs from abroad. Since the results do not differ qualitatively nor quantitatively very much from those including also firms with a foreign location (see Table 4.6, column (4)), in the following, I present the results for firms with and without a foreign location together, if not stated otherwise.

Given the high marginal effect of export activities on the probability of global sourcing, column (2) presents results for the subsample of exporting firms only. Thus, all those firms sell at least part of their output in at least one other country than Germany. Therefore, they will have some knowledge about other foreign markets, which might help them to find international suppliers, too. While in general the results do not change very much in comparison to the results for the total sample, the coefficient of labour productivity decreases in size in comparison to the coefficient for productivity as in the baseline specification (Table 4.6, column (4)) and turns insignificant. This reduction in the contribution of productivity seems plausible because only exporters are considered which according to heterogeneous firm models of international trade are more productive than non-exporters. As those latter are not considered in column (2), the remaining firms are on average already more productive than all firms in the total sample. Since the sorting of the productivity level needed for importing in comparison to exporting has not been yet uniquely established in heterogeneous firm models and prior findings suggest that on average firms that only export services but do not import them are more productive than service importing only firms (Breinlich and Criscuolo 2011), it also seems plausible that increasing labour productivity does not significantly raise the importing likelihood. All those firms had to overcome at least some sort of fixed foreign market entry cost for exporting. Consequently, they might be able to overcome the fixed costs of importing, too, so that productivity is not a central distinguishing factor.

Table 4.9: Global sourcing probability and ICT - For different subsamples of firms

	Manufacturing sector										
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
				Higher upstream industry diversity				*Lower upstream industry diversity*			
	Across firm boundaries	Exporters	Internet ordering	All firms	Across firm boundaries	Exporters	Internet ordering	All firms	Across firm boundaries	Exporters	Internet ordering
E-commerce indicator	0.016	0.002	0.008	0.061**	0.058*	0.050	0.060	-0.003	0.000	-0.019	-0.013
	(0.017)	(0.018)	(0.021)	(0.029)	(0.032)	(0.034)	(0.039)	(0.018)	(0.020)	(0.021)	(0.025)
Software indicator	-0.001	-0.007	0.004	-0.007	-0.022	-0.010	0.009	0.005	0.012	-0.006	0.006
	(0.013)	(0.014)	(0.014)	(0.023)	(0.025)	(0.026)	(0.026)	(0.014)	(0.016)	(0.017)	(0.017)
% Empl. working with PC	0.094	0.015	0.037	0.053	0.132	0.145	0.076	0.032	0.090	-0.035	0.021
	(0.082)	(0.094)	(0.084)	(0.142)	(0.163)	(0.164)	(0.154)	(0.088)	(0.095)	(0.113)	(0.101)
% Empl. with Internet access	0.146***	0.149**	0.095*	-0.004	0.009	-0.011	-0.026	0.199***	0.188***	0.228***	0.134*
	(0.055)	(0.067)	(0.057)	(0.095)	(0.105)	(0.109)	(0.101)	(0.060)	(0.063)	(0.084)	(0.069)
log(employment)	0.028*	0.032*	0.020	0.021	0.051	0.010	0.009	0.017	0.014	0.047**	0.021
	(0.016)	(0.017)	(0.016)	(0.025)	(0.031)	(0.027)	(0.028)	(0.016)	(0.019)	(0.020)	(0.019)
log(labour productivity)	0.058**	0.010	0.026	0.087**	0.100**	0.062	0.063	0.026	0.041	-0.032	0.003
	(0.022)	(0.024)	(0.024)	(0.036)	(0.041)	(0.042)	(0.042)	(0.024)	(0.026)	(0.029)	(0.028)
Export activity	0.256***		0.273***	0.289***	0.281***		0.304***	0.255***	0.250***		0.266***
	(0.029)		(0.030)	(0.053)	(0.056)		(0.057)	(0.031)	(0.033)		(0.036)
Foreign location		0.078*	0.073*	0.058		0.055	0.046	0.071	0.000	0.094*	0.095*
		(0.040)	(0.044)	(0.066)		(0.067)	(0.070)	(0.049)		(0.049)	(0.055)
% Highly skilled empl.	-0.098	-0.173	-0.015	-0.097	-0.036	-0.329*	0.023	-0.038	-0.105	-0.018	-0.002
	(0.104)	(0.114)	(0.108)	(0.160)	(0.182)	(0.178)	(0.180)	(0.112)	(0.123)	(0.145)	(0.132)
Product innovation	0.057*	0.037	0.028	0.050	0.051	0.056	0.014	0.047	0.056	0.022	0.034
	(0.030)	(0.033)	(0.031)	(0.051)	(0.057)	(0.058)	(0.055)	(0.032)	(0.036)	(0.040)	(0.037)
Process innovation	0.045	0.069**	0.044	0.109**	0.075	0.144***	0.116**	0.012	0.023	0.017	0.008
	(0.030)	(0.032)	(0.030)	(0.048)	(0.055)	(0.054)	(0.054)	(0.031)	(0.035)	(0.040)	(0.036)
Works council	0.004	-0.023	0.026	-0.023	-0.064	-0.032	0.011	0.034	0.037	-0.008	0.039
	(0.041)	(0.039)	(0.040)	(0.062)	(0.076)	(0.066)	(0.070)	(0.042)	(0.048)	(0.048)	(0.048)
Workplace organization	0.036***	0.023*	0.031**	0.009	0.026	0.006	0.023	0.037***	0.044***	0.035**	0.035**
	(0.013)	(0.014)	(0.013)	(0.020)	(0.022)	(0.024)	(0.023)	(0.014)	(0.015)	(0.017)	(0.016)
Sector and location dummies	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Number of observations	1035	859	965	378	304	296	299	865	731	563	666
Pseudo-R^2	0.1701	0.0536	0.1723	0.1626	0.1663	0.0800	0.1790	0.1912	0.1844	0.0744	0.1823

Significance levels: $*$: 10% $**$: 5% $***$: 1%. Robust standard errors in parentheses. Sector dummy variables include a full set of two-digit industry dummy variables, location defines a dummy variable if the firm is located in a new member state, i.e. in former East Germany. Moreover, all regressions control for multi-plant affiliation.

Column (3) addresses the potential concern that in the total sample firms who source inputs are compared with firms who produce everything at their plant so that they would not need importing anything from abroad. To make the sample of firms more comparable, in column (3) only firms who indicate to order inputs from suppliers online are considered. Optimally, information about domestic sourcing would suffice to compare firms that source inputs. Since the data do not include information about domestic sourcing but only about foreign sourcing, I use the information about Internet ordering from suppliers to infer that a firm sources at least some inputs from a physically distant supplier, either domestically or from abroad. As the restriction is based on Internet ordering and therefore excludes all firms that source from suppliers without using the Internet, the remaining sample will probably be smaller than conditioning only on input sourcing. Moreover, all those firms have some experience with e-commerce, at least with e-buying. The results show that the marginal effect of the share of employees with Internet access decreases in magnitude but remains significant at the 10-percent level. This result provides some evidence that even among input sourcing firms, more ICT-intensive firms in terms of Internet access diffusion are more likely to import inputs.

Table 4.10, columns (1) to (3), presents the results from the different subsamples for service firms in the same order of restrictions as in Table 4.9, columns (1) to (3). The central finding from the main analysis that more uses of e-commerce increase the global sourcing probability is robust to the different restrictions. The relationship between e-commerce and global sourcing is positive and significant for service firms without a foreign location, among exporting firms only as well as among firms that use Internet ordering.

Upstream industry diversity

A particular circumstance in which the contribution of ICT for global sourcing might be expected to be particularly relevant is when firms source inputs from many different suppliers. This might result in a more complex supply chain so that the coordination costs of firms with multiple suppliers will probably be particularly high. Hence, ICT-facilitated coordination might decrease the coordination costs for these firms disproportionately more than for firms with only very few suppliers. Lacking data on the individual firm's number of different suppliers, I exploit industry variation in the number of different industries from which a particular industry sources inputs. I use information from the input-output (IO) tables from 2009 published by the German Federal Statistical Office in order to compute an industry's ratio of the number of industries with positive inputs sourced domestically and the number of industries with positive inputs from abroad over two times the total number of possible industries to source from. The following formula summarizes the calculation:

$$\text{upstream industry diversity}_j = \frac{\text{no. ind. domestic inputs}_j + \text{no. ind. foreign inputs}_j}{2 * \text{total no. possible input industries}}$$

where j stands for the industry and the total number of possible domestic or foreign input industries is 73 for each based on the German IO tables. For instance, according to the IO tables in 2009, the chemical industry sources inputs from 63 industries domestically and imports inputs from 47 industries. Computing the ratio of this number of industries with positive inputs over two times the total number of possible input industries, i.e. 2*73, yields a ratio of 0.75. Using this ratio, I categorize each industry considered in the ICT survey based on the median value of this measure within the industries in the ICT survey either into the group of industries with many upstream relationships, i.e. higher upstream industry diversity, if the ratio is strictly above the median or into the group with less upstream relationships, i.e. lower upstream industry diversity, if the value is below or equal to the median. As this measure is based on industry-level and not firm-level information and it includes the extent of domestic input sourcing as well as of global sourcing, the categorization of industries into higher and lower upstream industry diversity will likely not represent selection on the firm-level dependent variable global sourcing. The hypothesis is that for firms in industries with higher upstream industry diversity, the marginal effect of ICT for global sourcing is expected to be larger than for firms in an industry with a lower diversity in upstream industries.

This measure of upstream industry diversity also reflects the upstream supply chain complexity of an industry because it measures with how many different industries a particular industry trades upstream. By construction, this measure of upstream industry diversity captures two sources of variation. On the one hand, the number of industries a particular industry sources inputs from domestically. On the other hand, it captures the extent to which the input sourcing is from abroad. Potentially, both sources of variation may contribute to industry-level supply chain complexity. In the following, the terms upstream industry diversity and upstream supply chain complexity are used interchangeably. For more information about the construction of this measure, values for the different industries and alternative measures, see Subsection 4.6.2 in the appendix.

Table 4.10: Global sourcing probability and ICT - For different subsamples of firms

				Service sector						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
				Higher upstream industry diversity				*Lower upstream industry diversity*		
	Across firm boundaries	Exporters	Internet ordering	All firms	Across firm boundaries	Exporters	Internet ordering	All firms	Across firm boundaries	Internet ordering
E-commerce indicator	0.053***	0.096***	0.042**	0.069***	0.058***	0.122***	0.053*	0.045**	0.055***	0.044
	(0.015)	(0.036)	(0.021)	(0.021)	(0.021)	(0.044)	(0.029)	(0.020)	(0.020)	(0.028)
Software indicator	0.004	0.017	0.009	0.016	0.014	0.024	0.019	0.000	-0.009	-0.007
	(0.013)	(0.031)	(0.015)	(0.018)	(0.018)	(0.036)	(0.019)	(0.018)	(0.019)	(0.023)
% Empl. working with PC	-0.038	0.130	-0.013	-0.127	-0.117	-0.039	-0.148*	0.069	0.042	0.152*
	(0.054)	(0.140)	(0.064)	(0.080)	(0.078)	(0.173)	(0.088)	(0.072)	(0.069)	(0.088)
% Empl. with Internet access	0.035	0.115	0.054	0.120	0.120	0.150	0.116	0.010	-0.016	-0.002
	(0.059)	(0.153)	(0.071)	(0.101)	(0.100)	(0.205)	(0.110)	(0.071)	(0.069)	(0.088)
log(employment)	0.004	0.009	-0.004	0.007	-0.002	0.028	-0.001	0.005	0.021	0.002
	(0.014)	(0.034)	(0.016)	(0.020)	(0.021)	(0.040)	(0.022)	(0.018)	(0.018)	(0.021)
log(labour productivity)	0.032*	0.187***	0.030	0.081***	0.063**	0.180***	0.084***	0.009	0.008	-0.012
	(0.019)	(0.050)	(0.022)	(0.027)	(0.029)	(0.058)	(0.029)	(0.022)	(0.022)	(0.027)
Export activity	0.165***		0.201***	0.168***	0.157***		0.190***	0.197***	0.188***	0.218***
	(0.026)		(0.029)	(0.034)	(0.034)		(0.038)	(0.038)	(0.038)	(0.046)
Foreign location		0.135*	0.094**	0.080		0.171*	0.124**	0.006	0.000	0.020
		(0.077)	(0.046)	(0.051)		(0.088)	(0.058)	(0.063)		(0.080)
% Highly skilled empl.	-0.000	-0.313***	-0.041	-0.033	-0.014	-0.247*	-0.034	0.021	0.070	0.028
	(0.057)	(0.119)	(0.064)	(0.069)	(0.073)	(0.129)	(0.078)	(0.095)	(0.094)	(0.118)
Product innovation	0.065**	0.063	0.076**	0.065	0.072	0.087	0.099**	0.049	0.052	0.037
	(0.029)	(0.073)	(0.033)	(0.045)	(0.045)	(0.091)	(0.050)	(0.037)	(0.036)	(0.044)
Process innovation	-0.015	-0.023	-0.005	0.012	0.009	0.015	0.025	-0.049	-0.053	-0.054
	(0.028)	(0.073)	(0.033)	(0.039)	(0.039)	(0.077)	(0.044)	(0.041)	(0.041)	(0.050)
Works council	0.017	-0.145	0.028	-0.017	0.044	-0.266**	-0.012	0.018	-0.015	0.046
	(0.039)	(0.093)	(0.044)	(0.058)	(0.062)	(0.108)	(0.065)	(0.046)	(0.048)	(0.057)
Workplace organization	0.002	0.017	-0.000	-0.005	-0.008	0.024	-0.011	0.011	0.011	0.015
	(0.012)	(0.029)	(0.014)	(0.016)	(0.018)	(0.034)	(0.019)	(0.016)	(0.016)	(0.021)
Sector and location dummies	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Number of observations	801	257	724	482	418	182	405	412	383	319
Pseudo-R^2	0.1536	0.1248	0.1636	0.1765	0.1451	0.1425	0.1805	0.1981	0.1979	0.1876

Significance levels: * : 10% ** : 5% *** : 1%. Robust standard errors in parentheses. Sector dummy variables include a full set of two-digit industry dummy variables, location defines a dummy variable if the firm is located in a new member state, i.e. in former East Germany. Moreover, all regressions control for multi-plant affiliation. The results for the subsample of exporting firms with lower upstream industry diversity are not reported as the sample size is too small for meaningful interpretations; the results are available upon request from the author.

Subject to this definition of upstream industry diversity, in the manufacturing sector, the chemical and pharmaceutical industry, the machine construction, and the vehicle construction industries are classified into the group of higher upstream industry diversity, and consequently the other industries (consumer goods, other raw materials, metal industry, electrical engineering) into the group of lower upstream industry diversity.[22] Columns (4) to (7) in Table 4.9 show the results for the former, and columns (8) to (11) for the latter group by restricting in columns (5) and (9) also on firms without foreign location, in columns (6) and (10) on exporting firms and in columns (7) and (11) on firms who use e-buying from suppliers. This sample splitting yields that in the group of firms with higher industry-level upstream industry diversity, there is some evidence that more uses of e-commerce increase the global sourcing probability, although with weak significance, while the share of employees with Internet access is not significantly related to global sourcing (columns (4) and (5)). This result is similar to the findings for the role of e-commerce in the service sector. In contrast, for firms with lower upstream industry diversity this result is reversed and is similar to the results for the total manufacturing sector. The results from this sample splitting suggest that similar to the service sector, in manufacturing industries with high upstream supply chain complexity, e-commerce activities are positively associated with global sourcing of inputs. In those industries with a large number of industries with positive inputs, the differences in the share of employees with Internet access between importers and non-importers is smaller than in the other manufacturing industries, which explains partly why for them the relationship between the Internet access share and importing is insignificant.

In the service sector, according to the definition of upstream industry diversity as explained above, the IT and other information services, the business consultancy and advertising, the technical services and the other business services industries are categorized into the group with higher upstream industry diversity.[23] As hypothesized, for firms in industries with higher upstream supply chain complexity (Table 4.10, columns (4) to (7)), the marginal effect of an additional e-commerce activity is larger than for firms with a lower intensity (Table 4.10, columns (8) to (10)).[24] These results support the conclusion that in industries with complex supply chains in terms of the number of diverse

[22] Those industries reflect also highest upstream industry diversity, i.e. a ratio above the total sector median, when the number of the domestic industries with positive input values, the number of industries with positive imports or the number of industries with either domestic or foreign inputs are considered in comparison to the total number of possible input industries. For further information, see Subsection 4.6.2 in the appendix.

[23] The same industries are identified when considering alternative counts of the number of industries with positive inputs; see also Subsection 4.6.2 in the appendix.

[24] The results for the subsample of exporting firms in industries with lower upstream industry diversity are not presented because the sample size is only 75 firms for four industries so that no reasonable conclusions can be made.

upstream industries, e-commerce is particularly relevant for global sourcing and that Internet-enabled coordination across distance may lower the associated costs.

Furthermore, in both sectors, only for those industries with higher upstream industry diversity, the association between labour productivity and global sourcing is significant, which might be because a high productivity level is needed to source from different industries. This result is compatible with the heterogeneous firm model for global sourcing decisions by Antrás, Fort, and Tintelnot (2014). In this model, the authors establish a positive relationship between firm productivity and the number of countries a firm can import from because the increasing productivity level is needed to overcome the fixed costs of each additional import market entry. The results suggest that in industries with lower upstream industry diversity, productivity is not a critical factor, upon which importing firms differ from non-importing firms.

4.4.3 SMEs

Finally, the analysis is conducted for the subsample of SMEs only. Even though 86 percent of the manufacturing sector sample and 88 percent of the service sector sample are SMEs, it might be that the results for this subsample of firms differ from the total sample including large firms because prior evidence has found that smaller firms benefit less from IT (e.g. Tambe and Hitt 2012), which is also discussed in Chapter 2. However, for the relationship between ICT and global sourcing, the results for SMEs do not differ qualitatively nor quantitatively a lot from the results with the total sample neither in the manufacturing sector (Table 4.14 in the appendix) nor in the service sector (Table 4.15 in the appendix).[25]

4.4.4 Discussion of the results

The results reflect some similarities and differences in the relevance of particular ICT for global sourcing between manufacturing and service firms. As already suggested by the descriptive statistics, service importers and non-importers do not differ significantly in the average computer work and Internet access shares, while manufacturing firms do. The descriptive statistics and the empirical results from the probit regressions are compatible with the fact that the task composition of the services provided by the service firms considered in this analysis are often highly dependent on computer and Internet work, so

[25]The results for large firms are not presented as the resulting samples are too small to make meaningful conclusions based on them.

that computer-based work and levels of access to the Internet are no distinguishing factors between importers and non-importers in the service sector. However, for manufacturing firms, in which a large fraction of workers work with machines or other technical devices than the computer,[26] the results show that manufacturing firms, in which more employees have access to the Internet, are more likely to import. The positive relationship between Internet access diffusion among employees and global sourcing is especially found in industries with a lower upstream industry diversity. This result might reflect that those firms require a larger back office than non-importers in order to manage the firm and in particular the import and input transactions.

Another potential explanation could be that those importing manufacturing firms have more computer-based work processes. Moreover, such a technology diffusion pattern that documents differences between internationally active and domestically operating firms is consistent with heterogeneous firm models in exporting that establish that exporting firms can invest into higher levels of advanced technology because they have the necessary productivity level not only for exporting but also for buying more advanced technologies (e.g. Lileeva and Trefler 2010; Bustos 2011). In the case of Internet access, it might be that importing firms can afford to equip a larger fraction of their employees with Internet access.

In contrast, in the service sector, firms with a higher e-commerce intensity are more likely to import inputs. The marginal effect of the use of an additional e-commerce application is particularly high in industries with higher upstream industry diversity. Under that circumstance, there is some weak evidence for a positive marginal effect of e-commerce intensity on global sourcing in the manufacturing sector, too. However, in general, the results of the association between e-commerce and global sourcing are much stronger in services than in manufacturing. On the one hand, this is reflected by larger marginal effects with values of a 5 to 6 percentage points increase in the service sector in comparison to a 1 to 3 percentage points increase in the manufacturing sector (Table 4.6). On the other hand, the base rate of global sourcing in the service sector is with an average global sourcing participation of 20.1 percent nearly three times smaller than the average global sourcing participation in manufacturing of 59.5 percent. Consequently, the marginal effects relative to the base are even stronger in services. For example, column (2) of Table 4.6 says that e-commerce is associated with a 3.3 percentage points increase in the likelihood of global sourcing in manufacturing, while for services (column (6)) it is 6.6 percentage points. Given the different average global sourcing participation rates, taking

[26] The labour heterogeneity measures for computer work and Internet access refer only to work with personal computers. There is no information in the ICT survey 2010 about the degree of digitization of machines.

the results at face value, they would imply that e-commerce is associated with around a 5.5 percent change in global sourcing in manufacturing and a 32.8 percent change in services. Thus, the economic magnitudes of e-commerce on global sourcing are much larger in the service than in the manufacturing sector, at least in the year 2009 from which the data are.

In general, the results of a positive association between e-commerce and global sourcing are consistent with the view that transactions with suppliers and customers on electronic market places reduce communication and coordination costs as it has been found already in prior work (Abramovsky and Griffith 2006; Hyun 2010; Fort 2015). The result that also downstream-related business strategies like e-selling raise the sourcing likelihood could reflect that IT-enabled coordination costs reduction is particularly large if the firm has adopted supplier and customer IT together as it is demonstrated in Forman and McElheran (2015). The authors show that the use of externally-focused IT has led to a decrease in downstream vertical integration and that the effect is largest when both upstream- and downstream-oriented IT, i.e. IT-enabled coordination with suppliers and customers, are adopted together.[27]

A possible conjecture might be that the potential of Internet-based coordination and communication to reduce the associated costs with foreign business partners will only be realized if also firms in the country from which German firms import have the necessary technological level so that Internet-based communication across borders and distance is possible at all. The data do not include information about the firms' import countries to control for it. At the aggregate level, the top countries in terms of value German firms imported products from in 2009 were the Netherlands, China, France, the U.S., Italy and the UK (Meyer 2010). The top countries for service imports in the period from 2001 to 2010 were the U.S., the UK, the Netherlands, Switzerland, France and Austria (Biewen, Blank, and Lohner 2013). These statistics provide some evidence that the majority of import-related business activities by German firms in that period has been with countries with a comparable technology and Internet infrastructure level. Thus, it seems possible that the importing firms actually communicated over the Internet with their foreign business partners.

In the manufacturing sector, on average e-commerce activities do not increase the global sourcing probability robustly in contrast to the results from the service sector or from prior work based on manufacturing firms with evidence from the end-1990s or the early years of 2000 (e.g. Hyun 2010). One potential reason for this, which is also

[27]For a detailed discussion about the role of externally-focused IT on reducing supply chain frictions, see Forman and McElheran (2015).

reflected by the descriptive statistics that differentiate between global sourcing status, might be that in the survey reference year 2009, e-commerce uses have been already more broadly diffused among firms with similar firm characteristics in the manufacturing sector than in the service sector, regardless of the global sourcing status. For instance, in general manufacturing firms have higher input requirements than service firms as shown in the industry-level input-output tables. It might be that the non-importing firms source inputs only domestically and therefore, they use e-commerce solutions for these domestic activities. However, as the data do not include information about domestic sourcing, this hypothesis cannot be tested.

In both sectors, enterprise software intensity does not seem to be a distinguishing factor between importers and non-importers of similar characteristics. Given that the software systems considered in the analysis help organizing information from various business processes and do not exclusively provide support in managing externally-focused transactions with suppliers or customers like e-commerce, this result reflects that at least for these software systems, importing firms have not adopted them significantly more than non-importers. These systems have existed, at least in basic form, already at the end of the 1990s so that the diffusion process may have come to a saturation point in the survey year of 2010. Hence, there are no differences between importers and non-importers any longer, if they have ever been.[28]

Moreover, the results show that if firms export, they are also more likely to import in the manufacturing as well as the service sector. Similarly, in both sectors, more productive firms from industries with higher upstream industry diversity are more likely to source inputs from abroad. This finding is compatible with prior results for manufacturing firms that suggest self-selection of more productive firms into offshoring (e.g. Wagner 2011; Fort 2015) and it confirms predictions of heterogeneous firm models developed mainly for firms producing goods, i.e. manufacturing firms (e.g. Antrás and Helpman 2004). The positive relationship between productivity and global sourcing is also compatible with studies that find positive productivity effects from input importing (e.g. Halpern, Koren, and Szeidl 2015).

[28]For instance, importing firms may have adopted the systems earlier because they needed them or could rather afford them. However, with the data, this hypothesis cannot be further explored.

4.5 Conclusion

Facilitating coordination across distance and changing work processes, modern ICT and the diffusion of the Internet are seen as important drivers behind the global increase in trade in intermediate goods and also in services. This chapter provides new findings for the relevance of ICT for global sourcing activities of inputs for manufacturing firms as well as first evidence for service firms. The results show differences in the role of ICT for global sourcing between manufacturing and service firms. In the manufacturing sector, a higher share of employees with Internet access increases the global sourcing probability in industries with lower upstream supply chain complexity. In the service sector, the probability of sourcing inputs from abroad is increasing in the firm's e-commerce intensity with a larger marginal effect than in the manufacturing sector. The strong association between e-commerce and global sourcing in services is also found for sourcing activities across firm boundaries and the effect is largest for firms in industries with higher upstream supply chain complexity. Under that circumstance, e-commerce weakly increases the global sourcing probability in the manufacturing sector, too. These results provide evidence that e-commerce lowers coordination costs of managing business relationships across distance. Overall, the results suggest that it is not necessarily ICT intensity per se that increases the global sourcing probability but it depends on the type of ICT and also on sector-specific differences in work processes and in diffusion processes of ICT between the manufacturing and service sector. However, for both sectors, the results underline the role of Internet-based activities for global sourcing activities.

Furthermore, in both sectors, more productive firms are more likely to source inputs from abroad, especially in industries that source inputs from many different industries. This result confirms the importance of productivity for importing decisions highlighted in heterogeneous firm models of international trade (e.g. Antrás and Helpman 2004; Antrás, Fort, and Tintelnot 2014) and the productivity advantage of internationally active firms (e.g. Bernard et al. 2012; Wagner 2011). Since empirical evidence about service firms in international trade is still scarce and heterogeneous firm models are mainly developed for goods-producing firms, the empirical results in this chapter provide supportive evidence for the view that models for goods-producing firms are a good starting point for the analysis of service trade (Breinlich and Criscuolo 2011).

Certain limitations of the analysis point to potential opportunities for future research. Due to data limitations, the empirical analysis could not distinguish which types of goods or services and from which countries the firms imported. Given ongoing discussions about trade liberalization reforms for goods and services and the efforts to establish a single digital market in Europe,[29] analysing which kinds of inputs are often sourced globally and in how far the technological intensity and other firm characteristics play a role, may be important to assess which types of inputs might be sourced in the future even more, thereby possibly substituting domestically produced inputs. Moreover, the different global sourcing behaviour according to technology intensity and productivity levels may have implications for the firms' performance outcomes, such as productivity or innovation. Since existing research shows that ICT and also input importing may be productivity-enhancing as well as enablers for innovation, future trade liberalization reforms and reductions in online trade barriers might enlarge the performance gap between globally active and non-active firms. Investigating further the interactions between ICT, importing and productivity can help to understand better why internationally active firms are on average more productive, even in the service sector, which is usually less trade intensive than the manufacturing sector.

[29]For more information about the European Commission's aim and strategies to develop a digital single market in the European Union, see, e.g., http://ec.europa.eu/digital-agenda/en/digital-single-market

4.6 Appendix

4.6.1 Additional tables

Table 4.11: Industry distribution in full sample and the complete data set from 2010

Industry	N	% of sample	N	% of data set
Consumer goods	324	15.16	504	14.38
Chemical and pharmaceutical industry	104	4.87	171	4.88
Other raw materials	179	8.38	279	7.96
Metal industry	168	7.86	261	7.45
Electrical engineering	194	9.08	314	8.96
Machine construction	182	8.52	279	7.96
Vehicle construction	92	4.31	168	4.79
Transportation	133	6.22	239	6.82
Media services	101	4.73	175	4.99
IT and other information services	169	7.91	259	7.39
Financial and insurance activities	97	4.54	211	6.02
Real estate activities	81	3.79	123	3.51
Business consultancy and advertising	76	3.56	135	3.85
Technical services	142	6.64	233	6.65
Other business services	95	4.45	153	4.37
Number of observations	2137	100	3504	100

Data source: ZEW ICT survey 2010.

Table 4.12: Descriptive statistics of general firm characteristics

	Mean	SD	Median	Min.	Max.
	Manufacturing sector (N=1243)				
Number of employees	185.26	941.01	40	5	25000
Sales in millions of euros	43.17	258.04	4.5	0.08	7000
Labour productivity in millions of euros	0.17	0.21	0.12	0.02	2.85
% Exporters	0.69	0.46	1	0	1
% with foreign affiliate	0.17	0.37	0	0	1
% Highly skilled employees	0.15	0.17	0.10	0	1
% of firms with product innovation	0.63	0.48	1	0	1
% of firms with process innovation	0.62	0.49	1	0	1
% of firms with works council	0.34	0.47	0	0	1
Workplace organization indicator	2.34	1.30	2	0	5
	Service sector (N=894)				
Number of employees	242.35	1349.50	25	5	30000
Sales in millions of euros	59.15	617.47	2.55	0.09	15000
Labour productivity in millions of euros	0.16	0.24	0.10	0.02	2.86
% Exporters	0.29	0.45	0	0	1
% with foreign affiliate	0.10	0.31	0	0	1
% Highly skilled employees	0.32	0.31	0.20	0	1
% of firms with product innovation	0.49	0.50	0	0	1
% of firms with process innovation	0.63	0.48	1	0	1
% of firms with works council	0.28	0.45	0	0	1
Workplace organization indicator	2.40	1.28	2	0	5

Data source: ZEW ICT survey 2010.

Table 4.13: Average firm characteristics by global sourcing status

	global sourcing firms		non-global sourcing firms	
Variables	Mean	SD	Mean	SD
	Manufacturing sector (N=1243)			
Number of employees	252.18	1188.33	87.13	313.63
Sales in millions of euros	59.63	321.91	19.03	106.70
Labour productivity in millions of euros	0.20	0.22	0.14	0.18
% Exporters	0.84	0.37	0.47	0.50
% with foreign affiliate	0.23	0.42	0.07	0.26
% Highly skilled employees	0.16	0.17	0.12	0.17
% of firms with product innovation	0.70	0.46	0.52	0.50
% of firms with process innovation	0.67	0.47	0.54	0.50
% of firms with works council	0.42	0.49	0.22	0.41
Workplace organization indicator	2.58	1.28	1.99	1.26
	Service sector (N=894)			
Number of employees	289.38	1043.33	230.49	1416.67
Sales in millions of euros	53.95	234.56	60.47	680.95
Labour productivity in millions of euros	0.19	0.33	0.15	0.21
% Exporters	0.59	0.49	0.21	0.41
% with foreign affiliate	0.22	0.42	0.07	0.26
% Highly skilled employees	0.36	0.32	0.31	0.30
% of firms with product innovation	0.69	0.46	0.44	0.50
% of firms with process innovation	0.69	0.46	0.61	0.49
% of firms with works council	0.34	0.48	0.26	0.44
Workplace organization indicator	2.78	1.22	2.31	1.28

Data source: ZEW ICT survey 2010.

Table 4.14: Global sourcing probability and ICT - For different sets of manufacturing SMEs

	Manufacturing sector					
	(1)	(2)	(3)	(4)	(5)	(6)
	All SMEs	Across firm boundaries	Exporters	Internet ordering	Higher upstream industry diversity	Lower upstream industry diversity
E-commerce indicator	0.021	0.020	0.007	0.013	0.077**	0.001
	(0.017)	(0.018)	(0.021)	(0.023)	(0.031)	(0.019)
Software indicator	-0.005	-0.001	-0.012	0.001	-0.017	0.004
	(0.013)	(0.014)	(0.016)	(0.015)	(0.024)	(0.015)
% Empl. working with PC	0.040	0.080	0.025	0.061	0.168	0.006
	(0.080)	(0.085)	(0.104)	(0.090)	(0.151)	(0.094)
% Empl. with Internet access	0.145***	0.152***	0.150**	0.083	-0.058	0.208***
	(0.055)	(0.057)	(0.074)	(0.062)	(0.102)	(0.063)
log(employment)	0.018	0.021	0.032	0.021	0.030	0.009
	(0.017)	(0.019)	(0.021)	(0.020)	(0.032)	(0.020)
log(labour productivity)	0.060***	0.065***	0.027	0.038	0.093**	0.046*
	(0.021)	(0.023)	(0.027)	(0.026)	(0.038)	(0.025)
Export activity	0.267***	0.268***		0.277***	0.305***	0.255***
	(0.028)	(0.030)		(0.032)	(0.055)	(0.033)
Foreign location	0.092*		0.104**	0.091*	0.129	0.079
	(0.048)		(0.049)	(0.054)	(0.081)	(0.058)
% Highly skilled empl.	-0.053	-0.105	-0.133	0.061	-0.008	-0.048
	(0.098)	(0.106)	(0.124)	(0.113)	(0.166)	(0.116)
Product innovation	0.057*	0.058*	0.048	0.031	0.029	0.064*
	(0.029)	(0.031)	(0.037)	(0.034)	(0.054)	(0.034)
Process innovation	0.039	0.040	0.062*	0.042	0.082	0.011
	(0.028)	(0.030)	(0.035)	(0.032)	(0.051)	(0.033)
Works council	0.015	0.007	-0.010	0.027	-0.036	0.041
	(0.038)	(0.043)	(0.043)	(0.044)	(0.068)	(0.045)
Workplace organization	0.033***	0.039***	0.033**	0.039***	0.021	0.043***
	(0.012)	(0.013)	(0.015)	(0.014)	(0.022)	(0.015)
Sector and location dummies	yes	yes	yes	yes	yes	yes
Number of observations	1096	963	725	839	330	766
Pseudo-R^2	0.1736	0.1657	0.0526	0.1741	0.1786	0.1895

Significance levels: * : 10% ** : 5% *** : 1%. Robust standard errors in parentheses. Sector dummy variables include a full set of two-digit industry dummy variables, location defines a dummy variable if the firm is located in a new member state, i.e. in former East Germany. Moreover, all regressions control for multi-plant affiliation.

Table 4.15: Global sourcing probability and ICT - For different sets of service SMEs

	Service sector					
	(1)	(2)	(3)	(4)	(5)	(6)
	ICT & controls	Across firm boundaries	Exporters	Only firms with Internet ordering	Higher upstream industry diversity	Lower upstream industry diversity
E-commerce indicator	0.055***	0.051***	0.132***	0.045**	0.066***	0.049**
	(0.015)	(0.015)	(0.038)	(0.022)	(0.022)	(0.020)
Software indicator	0.006	0.009	0.015	0.009	0.010	-0.001
	(0.012)	(0.012)	(0.034)	(0.015)	(0.017)	(0.019)
% Empl. working with PC	-0.048	-0.054	0.137	-0.022	-0.155**	0.072
	(0.057)	(0.057)	(0.147)	(0.068)	(0.078)	(0.080)
% Empl. with Internet access	0.043	0.029	0.065	0.045	0.083	0.010
	(0.062)	(0.062)	(0.162)	(0.075)	(0.104)	(0.076)
log(employment)	-0.005	-0.006	-0.070	-0.015	-0.022	0.022
	(0.017)	(0.017)	(0.044)	(0.020)	(0.026)	(0.023)
log(labour productivity)	0.053***	0.050***	0.204***	0.040*	0.092***	0.022
	(0.019)	(0.019)	(0.057)	(0.023)	(0.028)	(0.022)
Export activity	0.175***	0.159***		0.203***	0.159***	0.202***
	(0.025)	(0.026)		(0.030)	(0.033)	(0.039)
Foreign location	0.083*		0.185**	0.121**	0.109*	0.032
	(0.043)		(0.085)	(0.052)	(0.056)	(0.073)
% Highly skilled empl.	-0.035	-0.010	-0.243*	-0.060	-0.022	0.006
	(0.055)	(0.056)	(0.124)	(0.066)	(0.070)	(0.100)
Product innovation	0.068**	0.077**	0.107	0.077**	0.084*	0.045
	(0.030)	(0.030)	(0.076)	(0.035)	(0.046)	(0.038)
Process innovation	-0.011	-0.025	-0.011	-0.006	0.008	-0.038
	(0.029)	(0.029)	(0.075)	(0.034)	(0.039)	(0.041)
Works council	0.009	0.005	-0.093	0.028	0.007	-0.010
	(0.038)	(0.041)	(0.095)	(0.046)	(0.063)	(0.046)
Workplace organization	0.001	0.002	0.013	-0.000	-0.004	0.006
	(0.012)	(0.012)	(0.031)	(0.014)	(0.017)	(0.017)
Sector and location dummies	yes	yes	yes	yes	yes	yes
Number of observations	784	724	217	630	425	359
Pseudo-R^2	0.1958	0.1715	0.1662	0.1814	0.1985	0.2240

Significance levels: $*$: 10% $**$: 5% $***$: 1%. Robust standard errors in parentheses. Sector dummy variables include a full set of two-digit industry dummy variables, location defines a dummy variable if the firm is located in a new member state, i.e. in former East Germany. Moreover, all regressions control for multi-plant affiliation.

Table 4.16: Industry classification

Industry	Explanation	WZ 2008
Consumer goods		
	manufacture of food products, beverages and tobacco	10-12
	manufacture of textiles, textile products, leather and leather products, shoes	13-15
	manufacture of wood and wood products	16
	manufacturing of pulp, paper and paper products	17
	manufacturing of furniture, other commodities	31-32
Chemical and pharmaceutical industry		
	manufacture of chemicals and chemical products	20
	manufacture of pharmaceutical products	21
Other raw materials		
	manufacture of rubber and plastic products	22
	manufacture of glass, glass products, ceramic; stones and noble earths	23
Metal industry		
	metal production and processing	24
	manufacture of fabricated metal products (except machinery and equipment)	25
Electrical engineering		
	manufacture of data processing equipment, electronic and optic products	26
	manufacture of electrical machinery and apparatus	27
Machine construction		
	manufacture of machinery	28
	reparation and installation of machinery and equipments	33
Vehicle construction		
	manufacturing of motor vehicle and further vehicle parts	29
	manufacturing of other transport equipment	30
Transportation		
	land transport, transport via pipeline	49
	water transport	50
	air transport	51
	warehousing and further transport services	52
	post and courier activities	53
	supporting and auxiliary transport activities; activities of travel agencies	79
Media services		
	manufacture of publishing and printing	18
	publishing	58
	manufacture, rental and distribution of movies and television programmes; cinemas and distribution of music; broadcasting	59-60
IT and other information services		
	telecommunications	61
	information technology services	62-63
Financial and insurance activities		
	financial intermediation	64
	insurance activities	65
	services related to financial and insurance activities	66
Real estate activities		
	property and housing	68
	renting of movable products	77
Business consultancy and advertising		
	legal advice, accounting and auditing activities; tax consultancy; business and management consultancy	69-70
	advertising and market research	73
Technical services		
	architectural and engineering activities and related technical consultancy; technical testing and analysis	71
	research and development	72
Other business-related services		
	other self-employed, scientific and technical activities	74
	labour recruitment and provision of personnel	78
	investigation and security services; industrial cleaning; miscellaneous business activities n.e.c.	80-82

Source: ZEW 2010. WZ 2008 is the abbreviation for the German classification of industries; it corresponds to the NACE industry classification.

4.6.2 Upstream industry diversity measure based on input-output tables

In order to compute upstream industry diversity at the industry level, I use information from the German input-output (IO) tables from 2009, published in 2013 (article number: 2180200097005). The German IO tables include three relevant tables for the inputs, measured in costs, from one industry by another: 1. Inputs from domestic production and imports, 2. Imported inputs only, 3. Domestic inputs only. In total, there are 73 industries at the two-digit level (Classification of the industries 2008 (WZ 2008)) to potentially source from but none of the industries sources from all potential industries. I use the variation in the number of industries a certain industry sources inputs from in order to compute a measure for input industry diversity. For the main measure used in this chapter, I consider the variation in the number of industries for domestic input sourcing as well as for import sourcing

$$\text{upstream industry diversity}_j = \frac{\text{no. ind. domestic inputs}_j + \text{no. ind. foreign inputs}_j}{2 * \text{total no. possible input industries}}$$

This formula is identical to the one in Subsection 4.4.2. Since the industry classification used in this chapter is broader than the classification at the two-digit industry level in the IO tables, I compute the upstream industry diversity ratio for each two-digit industry in the IO tables and then I take the average of those values aggregated to the industry composition used in this chapter (see Table 4.16). Table 4.17 shows the upstream industry diversity ratios for each broad industry in the ICT survey and the categorization into higher and lower upstream industry diversity based on the median value. Higher values indicate that an industry sources inputs from more different industries, domestically and from abroad.

Table 4.17: Upstream industry diversity by industry based on input-output tables

Industry	Upstream industry diversity ratio	Classification
Manufacturing sector		
Consumer goods	0.65	low
Chemical and pharmaceutical industry	0.71	high
Other raw materials	0.62	low
Metal industry	0.66	low
Electrical engineering	0.66	low
Machine construction	0.71	high
Vehicle construction	0.69	high
Median	0.66	
Standard deviation	0.031	
Service Sector		
Transportation	0.44	low
Media services	0.53	low
IT and other information services	0.54	high
Financial and insurance activities	0.50	low
Real estate activities	0.49	low
Business consultancy and advertising	0.57	high
Technical services	0.55	high
Other business services	0.58	high
Median	0.53	
Standard deviation	0.047	

Data source: ZEW ICT survey 2010.

The values for upstream industry diversity reflect that all manufacturing industries source from more other industries than all service industries. Moreover, according to the standard deviation the heterogeneity is larger in service than in manufacturing industries. This comparison between the manufacturing and service sector is plausible given that supply chains are on average less complex in service industries than in manufacturing, at least to the extent with how many different industries service industries trade upstream.

The same categorization of industries into higher and lower upstream industry diversity is obtained when in the numerator of the formula for upstream industry diversity either the number of industries with positive domestic inputs or the corresponding number of import industries or the number of industries, either domestic or foreign, are considered. The denominator is then only one time the number of possible industries, i.e. 73. The IO tables show that the central difference in the number of industries with positive inputs between domestic industries and foreign industries is that the number of domestic input industries is larger than the number of foreign input industries for manufacturing as well as for service industries. Consequently, the upstream industry diversity ratios are larger for domestic inputs than for imported inputs (not reported).

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