Vol. 3, Issue 3, May-Jun 2013, pp.1095-1107

Enterprise Systems and Labor Productivity: Disentangling Combination Effects

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Abstract

This study analyzes the relationship between labor productivity and the three widely established enterprise software systems, i. e. Enterprise Resource Planning (ERP), Supply Chain Management (SM) and Customer Relationship Management (CRM), revealing performance gains incurred through the varying combinations of the systems with an exclusive focus on complementarities and interactions among them. Using German firm-level data, the results show that the highest productivity gains based on enterprise system usage are realized through the use of the three enterprise software systems in concert and not by relying on one or two of the systems alone. Concerning complementarity the results indicate that SCM and CRM function as complements if the firms already have an ERP System running or get the system in conjunction. The results stay robust to different model specifications and complementarity testing procedures.

Introduction

Enterprise systems, company-wide suites of business software devoted to particular process integration across the value chain, encompass a wide range of software products supporting day-to-day business operations and decision-making. The three main enterprise systems, Enterprise Resource Planning (ERP), Supply Chain Management (SCM) and Customer Relationship Management (CRM), serve many industries in numerous areas. They are designed to automate operations from supply management, inventory control, manufacturing scheduling or sales force automation and almost any other data-oriented management process. In 2006, the global market for ERP systems accounts for approximately $29 billion (Jacobsen et al. 2007). SAP, the largest global enterprise software vendor, estimates the addressable market for all enterprise software applications to be roughly $ 110 billion 2010.

Enterprise systems are often adopted to replace the usually poorly connected legacy software and are expected to reduce infrastructure support costs (Hendricks et al. 2007). These support costs originate from the need for costly programmed interfaces to connect legacy applications. Also, costs might occur in form of waiting time since legacy software is generally not efficiently programmed and therefore requires more time to execute orders compared to enterprise systems. In line with this legacy software can be expected to face more downtimes than enterprise systems based on its inefficient programming code. In addition, improvements in operational integration realized through enterprise software can affect the entire organization and therefore might positively affect firm performance. ERP systems provide benefits in the area of transaction automation, SCM systems lead to more sophisticated planning capabilities and CRM systems simplify customer relationship management.

Although many studies (e. g. Aral et al. 2006; Hendricks et al. 2007; Hitt et al. 2002) argue that adopted enterprise systems, in general, positively impact firm performance, performance benefits based on potential complementarity driven advantages resulting from the usage of different enterprise systems in combination are still not investigated. Overall, the majority of the existing analysis lays an exclusive focus on the adoption of a single system (e. g. Dehning et al. 2007; Hitt et al. 2002; Nicolaou 2004), thereby completely disregarding these complementarity based performance gains. This focus might turn out to produce biased results as enterprise systems nowadays are often adopted in concert and are expected to interact, complement or in rare cases even substitute each other to some extent. The goals of this study therefore are to disentangle the performance effects attributed to the combinations and interactions of enterprise systems using a unique database consisting of German firms from the manufacturing industry and from service sectors.

Based on a production function approach, the results provide empirical evidence about the productivity gains resulting from the use of enterprise system usage with respect particularly to the interacting nature of the systems. Contrary to former analysis, the highest productivity gain is achieved by using all three enterprise systems in concert. In addition, a complementary relationship between SCM and CRM is revealed once an ERP is also in use or acquired in conjunction. The results imply that analyzing the influence of the enterprise systems independently, whereby one disregards possible benefits stemming from the combination of systems, turns out to be insufficient for depicting the performance effects of enterprise software.

The study proceeds as follows. Section 1 gives an overview of the literature and derives hypotheses. Section 2 pictures the basic model and covers the issues concerning complementarity. The dataset is presented in section 3 whereas section 4 contains the estimation results. Section 1 concludes.

1 Background discussion and hypotheses

1.1 Benefits of enterprise systems in general

ERP systems replace complex interfaces between different systems with standardized cross-functional transaction automation. They use a source of data that integrates enterprise functions such as sales and distribution, materials management, production planning, financial accounting, cost control and human resource management (Aral et al. 2006). By using an ERP system, order cycle times can be reduced, which might lead to improved throughput, customer response times and delivery speeds (Cotteleer and Bendoly 2006; McAfee 2002). In addition, cash-to-cash cycle times and the time needed to reconcile financial data at the end of the quarter or year can be reduced through automated financial transactions (Mabert et al. 2000). With an ERP system, all enterprise data is collected once during the initial transaction, stored centrally and updated in real time. This ensures that all levels of planning are based on the same data, allowing the resulting plans to realistically reflect the prevailing operating conditions of the firm (Hendricks et al. 2007). All in all, standardized firm-wide transactions and centrally stored enterprise data greatly facilitate the governance of the firm (McAfee and Upton 1996; Scott and Vessey 2000). Providing managers with clear oversight of the relative performance of different parts of the company, ERP reports can be used to identify necessary improvements and to take advantage of market opportunities (Mehrjerdi 2010).

IT-based SCM systems coordinate and integrate the flow of information, materials and finances along the value chain and enhance operational and business planning (Dehning et al. 2007). With the real-time planning capabilities offered by SCM systems, firms can react quickly to supply and demand changes and are able to serve customers in a timely and comprehensive fashion (Cachon and Fisher 2000; Hendricks et al. 2007). In addition, SCM systems can directly improve inventory management by reducing inventory levels, holding costs, spoilage and lead times. This results in increased profitability by reducing costs, avoiding lost sales and improving customer satisfaction (Cachon and Fisher 2000). SCM systems may also have indirect effects on firm performance due to lower coordination, sales, general and administrative costs as well as improved decision-making or forecasting (Dehning et al. 2007).

CRM is a synthesis of customer focused management and many existing principles from relationship marketing (Jancic and Zabkar 2002; Morgan and Hunt 1994; Sheth et al. 2000). The key focus of CRM systems is to facilitate the creation of long-term relationships with customers by providing the appropriate infrastructure, e. g., enabling effective sales force automation, centralized customer data warehousing and data mining paired with decision support and reporting tools (Engelstätter 2012). Offering a complete view of customer needs and wants, a CRM system is also expected to lead to superior customer loyalty, reduced cost of sales and services and improved bottom-line profits (Chen 2001). In addition, a CRM system reduces duplication in data entry and maintenance by providing a centralized firm-wide database of customer information. This database replaces systems maintained by individual sales people, institutionalizes customer relationships, prevents the loss of organizational customer knowledge when sales staff leaves the firm and can reduce costs by streamlining repetitive transactions and sales processes (Cohen et al. 2006; Hendricks et al. 2007).

1.2 Complementarity between enterprise software applications

As the three main enterprise systems show many linkages among each other, this section will cover the possible combinations of enterprise systems and their special interactions separately. For instance, the integrated data, processes and interfaces provided by an ERP system, facilitate the effective implementation of supply chain activities. This planning of internal production activities through the ERP system can be directly influenced or automated by information inputs from supply chain partners via use of an SCM system (Aral et al. 2006). The two-way information exchange between ERP and SCM systems enables companies to optimize processes across the product lifecycle. Based on the rapid data transfer between these two enterprise systems information about resource usage and product life cycles can be accessed by correspondent employees in real time as needed. Based on this information room for process improvements and product enhancements is easy to identify (Engelstätter2012). Especially the usage of best-of-breed SCM applications with ERP, as opposed to relying on the innate SCM functionality of some ERP systems, provides firms with specialized SCM features which could even forecast expected supply and demand. Accordingly, firms that use the advanced features of SCM systems in conjunction with ERP systems are expected to realize complementary benefits and a higher firm performance as it is argued in Wieder et al. (2006).

The centralized customer data provided by CRM systems can be used as source for ERP systems and is particularly valuable to the management of multiple product lines are managed (Hendricks et al. 2007). The flow of information between the two systems will, generally, ease the firms' data management effort as the shared information avoids redundant data keeping. In addition, the CRM system can utilize the data mining capabilities of ERP systems and data warehousing to reveal profiles of key customers, customer profitability and purchasing patterns (Conlon 1999). Companies might also gain additional insights into customer orders, contracts and buying behaviour if they use ERP applications in conjunction with CRM systems, possibly allowing them to establish more focused sales and marketing strategies based on in-depth analysis of customer behaviour, interests and context. Hence, deploying ERP systems in conjunction with CRM systems should, based on complementary benefits, increase a firms' performance.

A firm can utilize the insights into customer behaviour and demand patterns provided by a CRM system to streamline manufacturing and distribution, if the CRM system is connected with the firm's SCM applications. Especially information on customer segmentation can provide advice for the structuring of the purchase of raw materials, scheduling manufacturing, managing inventory and running of the supply chain in general, possibly resulting in reduced costs. A streamlined supply chain based on connected CRM and SCM systems is key for reaching out to the right customer at the right time and should benefit the company additionally through improved resource allocation potentially reducing inventory stocks. In this context, Mithas et al. (2005) reveal that firms are more likely to benefit from CRM systems if they have a greater supply chain integration, e. g. based on an SCM system already installed. Therefore, using SCM and CRM systems in conjunction can be expected to increase firm performance based on a complementarity relationship.

According to (Charkari and Abdolvand 2004), the isolated use of SCM or CRM systems separately might result in missed opportunities and poor performance. To put it short, ERP systems generally determine the business processes, the two other applications optimize these business processes in a specific area, especially by linking the front office of the enterprise, e. g., sales, marketing, customer services, with the back office, e. g., operations, logistics, financials, human resources. As an example showing the linkages between the three applications, let a company be supposed to deliver an order to ten clients the next day. The SCM solution now calculates that the company can only deliver to five customers in the given time span, the ERP can then pull the data from the CRM system to determine which orders should be fulfilled (Horwitt 2009). In conclusion, it can be expected that firms using all three main enterprise systems will probably realize larger productivity increases compared to those companies which rely on less enterprise software applications or no enterprise systems at all.

2 Research methodology

2.1 The basic model

Following e. g. Aral et al. (2006) or Hitt et al. (2002), a production function specification is used to estimate the effects of enterprise system usage on firm performance. Throughout this paper I use the performance measure labor productivity Y_i/L_i, i.e. sales over employees. The inputs are capital (K_i), labor (L_i) and other firm characteristics. These additional characteristics, e. g., enterprise software adoption (ES_i), capture differences in performance and can simply be added to the production function in its log-log form (Hitt et al. 2002). The coefficients of these added terms can then accordingly be interpreted as percentage differences in productivity. In case of software adoption, the coefficient captures the enterprise software's effect on firm-level productivity other things being equal (Shin, 2006). Besides software adoption I control for East German heritage, industry sector and for ICT capital captured in X_i. The according production function in its log-log form results in:

(1) $\ln(Y_i/L_i) = c + \alpha \ln(K_i) + \beta \ln(L_i) + \gamma ES_i + \delta X_i + \varepsilon_i$

2.2 Modeling complementarity

Taking the potential complementarity between the enterprise software systems into account, this section outlines the definitions and conditions regarding complementarity and substitutability for the cases of discrete practices. Throughout this paper, each practice represents the use of a different enterprise system. Complementarity is defined as in Baumol et al. (1988) and Athey and Stern (1998):

Practices x_i and x_j are considered complementary in the function f if and only if $\partial^2 f / \partial x_i \partial x_j$ is always larger or equal to zero, and larger than zero for at least one value of (x_1 ,...,x_n).

Following (Carree et al. 2007), an objective function f is considered as a starting point. The value of f is determined by the practices x_p= (p

=1,…,n) with n=3 in the present case of enterprise software system usage. A cross-term specification of the objective function f allows testing for complementarity or substitutability. This implies the following expression for n equal to 3:

$$(2) \quad f(x_1,x_2,x_3) = \theta_0 + \theta_1 x_1 + \theta_2 x_2 + \theta_{12} x_1 x_2 + \theta_3 x_3 + \theta_{13} x_1 x_3 + \theta_{23} x_2 x_3 + \theta_{123} x_1 x_2 x_3$$

In the present case of observed enterprise system usage, the practices are measured dichotomously, i.e. variables take the value one if the practice is used and zero otherwise. In that case, function (2) can be conveniently rewritten in terms of possible combinations of practices (Mohnen and Röller 2005). The collection of possible combinations considering three practices is defined in the usual binary order as D = {(0,0,0),(1,0,0),(0,1,0),(0,0,1),(1,1,0),(1,0,1),(0,1,1),(1,1,1)}, with the indicator function for three practices $I_{D=(r,s,t)}$ being equal to one whenever the combination is (r,s,t) and zero otherwise. The function f can accordingly be rewritten as:

$$(3) \quad f(x_1, x_2, x_3) = \sum_{r=0}^{1} \sum_{s=0}^{1} \sum_{t=0}^{1} \lambda_{rst} I_{(x_1,x_2,x_3)=(r,s,t)}$$

The conditions of pairwise complementarity between practice 1 and 2 then correspond to $\theta_{12} = \lambda_{110} + \lambda_{000} - \lambda_{100} - \lambda_{010} \geq 0$ and $\theta_{12} + \theta_{123} = \lambda_{111} + \lambda_{001} - \lambda_{101} - \lambda_{011} \geq 0$, with at least one inequality holding strictly. Similar inequalities apply for the pairs (1,3) and (2,3). For substitutability, the inequalities are reversed.

2.3 Testing for complementarity

The most established and convenient method to check for complementarity, even for discrete practices, is the standard interaction term approach as proposed in Athey and Stern (2002). Alternatively, one can use a Wald type test based on a minimum distance estimator derived in Mohnen and Röller (2005) to verify a complementarity relationship. For this purpose, two independent tests are conducted which test separately for complementarity and substitutability. Carree et al. (2007) advanced this method and derived a test which decides between complementarity and substitutability in one run. Their multiple restrictions test uses a Likelihood-ratio test procedure which specifically tests for the two inequalities derived above but faces a computational demanding test-statistic. As the test-statistic follows a mixed chi-square distribution under the null hypothesis of no complementarity or no substitutability, exact p-values need to be computed using specific weights (Shapiro 1985). A first appliance of this test in empirical analysis can be found in Belderbos et al. (2006). As the likelihood-ratio test approach is most recent and has not been tested in several different settings and simulation I stick to the well established interaction terms as a baseline in the empirical analysis employing the likelihood-ratio test merely as robustness check.

3 The data

This study is based on a dataset resulting from two computer-aided telephone surveys conducted in 2004 and 2007 by the Centre for European Economic Research (ZEW). These surveys laid a specific focus on the use and diffusion of ICT in German firms. The interviewee was, in general, the chief executive officer of the companies who could also pass on questions to a corresponding employee such as, e. g., the head of the ICT department. Each wave of this ICT-dataset originally contained information of about 4,000 firms with five or more employees which were representatively chosen from important service and manufacturing sectors in Germany. The data basis for the sample originates from the credit rating agency Creditreform. This agency offers the largest data base on firms available in Germany. Creditreform collects some basic information like address, sector and firm size on all enterprises that ever applied for a bank credit. The selection from the population of German firms was stratified according to three size classes, to industries (seven branches of the manufacturing industry and seven selected service sectors) and to two regions (East/West Germany). As many firms as necessary were asked until all strata were filled.

Besides detailed information on the use of ICT, the dataset contains additional information about total sales, the firms' workforce, the total investments and various other variables. The questionnaire also covered the usage level of the three main enterprise software applications ERP, SCM and CRM. The level of usage could be none, minor or broad. Minor usage could be referring to software which is only employed by a small number of employees, departments or subsidies whereas broad usage might describe software packages in use by the entire firm (Engelstätter 2012). However, the questionnaire did not make any distinctions between these categories and provides no additional explanations for minor and broad usage. Without additional information, an interpretation of a productivity effect due to minor software use in comparison to no or broad usage cannot be illustrated appropriately. Accordingly, I constructed a dummy variable for the use of each software application, which takes the value one if a firm uses the software at least to a minor degree or broadly and zero otherwise.

The survey in 2007 covers total sales and the number of employees for 2006 only. However, the answers on enterprise system usage in that survey relate to the year 2007. Since the survey is organized as a panel dataset, I use the software usage level reported in 2004 to construct the dummy variables necessary. This two-year difference between software use and firm performance forms a well-defined temporal sequence which should be adequate to measure the productivity effects of enterprise systems, given that multiple analyses concluded that enterprise software needs about two years to generate some kind of performance effect (e. g. Matolcsy et al. 2005; Nicolaou 2004; Nicolaou et al. 2003).

Due to panel mortality and item-nonresponse, matching the data for the two periods results in nearly 1,000 observations. By dropping the banking sector, I obtained 927 observations for my final data set. As there is no data available to measure the firms' physical capital stock, I follow e. g. Bertschek et al. (2006) and Hall et al. (2009) by using the gross investment figures as an empirical proxy for the capital stock. A potential problem with this method arises as some firms report zero investments in 2004, although the occurrence of zero investments is explained by Bond and Van Reenen (2007) and is therefore not surprising at all. However, with an econometric specification of the production function in logarithmic values for the factor inputs, these firms must be excluded from the final sample. To do away with this problem and to avoid losing further observations, I follow the approach used in Ohnemus (2007) and determine the value of investment for the firms reporting zero investments as the 10 percent quantile of their respective industry and size class.

Table 1 shows the descriptive statistics for the variables of the production function estimation in this study. Table 1 also includes two additional variables, namely export activity and the existence of a works council which will be used for additional analysis in the next section. Sales, labor and the labor productivity ratio refer to the year 2006, all other inputs, like e. g. capital, refer to the year 2004. In addition, Table 1also provides the descriptive statistics for the industry affiliations of the firms in the final sample.

Table 1: Summary statistics

Variable	Mean	Std. Dev.	DV[4]
Output (sales)	46,667.2	169,785.8	
labor productivity[1]	192.2	229.7	
capital[2]	2282.6	9843.0	
labor[3]	245.7	916.5	
ln (output)	8.879	1.914	
ln (labor productivity)	4.891	0.811	
ln (capital)	5.366	2.230	
ln (labor)	3.987	1.644	
share of computer workers	0.467	0.328	
East Germany	0.273		yes
export share	0.557		yes
works council	0.368		yes
consumer goods	0.093		yes
chemical industry	0.052		yes
other raw materials	0.081		yes
metal and machine construction	0.118		yes
electrical engineering	0.076		yes
precision instruments	0.066		yes
automobile	0.073		yes
complete manufacturing sector	0.559		yes
whole sale trade	0.054		yes
retail trade	0.051		yes
transport and postal services	0.065		yes
electronic data transfer	0.097		yes

technical services	0.102	yes
other business-related services	0.073	yes
Number of observations	927	

Notes: [1] Sales per employee (in 2006) in €1,000. [2] Capital is proxied by gross investment in €1,000. [3] Labor is measured in amount of total employees. [4] Dummy variable
Source: ZEW ICT survey 2004, 2007 and own calculations.

In 2006, mean sales amount to € 46,667,200 and the average firm size results in 246 employees. For 2004, the mean investment is € 2,382,600. The mean share of workers mainly using a personal computer for their work, as proxy for the ICT capital of the firm, is around 47 percent in the used sample. This ICT capital measure should be included in the estimation to reduce omitted variable bias, as working with a computer can be expected to positively impact productivity (Greenan and Mairesse, 1996; Astrostic and Nyugen, 2005). Nearly 27 percent of the firms are located in East Germany. Export activity is reported by 56 percent of the firms and 47 percent of the sample firms have established a works council. Regarding the industry affiliation of the firms, the largest share of 12 percent does business in metal and machine construction, whereas only a small number is associated with the wholesale or retail trade industry (5 percent each).

Table 2 provides the summary statistics for the dummy variables of enterprise system usage and shows additional statistics of the firms using these systems. In addition, it lays a specific focus on the group of firms using either no enterprise systems at all or the full suite of enterprise systems.

It is striking that around one quarter of firms (28 percent) in the sample use all three enterprise systems in concert or no enterprise software at all (24 percent). The use of ERP is widespread (64 percent), around 44 percent apply SCM software and about 51 percent of the firms have adopted CRM software. Providing initial descriptive evidence by comparing the average labor productivity for each group with the overall sample mean reported in Table 2, it stands out that the firms' labor productivity exceeds the average productivity of € 192.200 once they adopt some kind of enterprise software. Especially firms using all three systems in concert achieve the highest average labor productivity, reaching € 234.200. Unsurprisingly, companies using no enterprise systems at all seem to fall behind in terms of labor productivity (€ 167.000). In addition, it seems to be the case that large firms choose to use all three systems together. These firms engage the services of an average of 566 employees, as shown in Table 2 However, as the available sample suggests smaller firms also seem to have confidence in the full suite of enterprise software applications as about 43 percent of the firms which use all three enterprise systems have 100 or less employees (not reported).

Table 2: Means and shares for the enterprise systems

	No system	All systems	ERP	SCM	CRM
Share of entire population	0.236	0.278	0.636	0.442	0.513
Labor Productivity Mean	167.0	234.2	205.6	217.1	204.8
	(269.0)	(245.8)	(215.8)	(219.8)	(229.4)
Size Mean	43.1	566.3	359.5	441.3	357.8
	(70.1)	(1605.1)	(1132.1)	(1319.7)	(1229.6)
share of manufacturing sector	0.457	0.667	0.625	0.676	0.538

Notes: Standard errors in parentheses.
Source: ZEW ICT survey 2004, 2007 and own calculations.

4 Empirical results

4.1 Returns to enterprise systems in general

Table 3 reports the basic estimation results, using the regression formulation described in equation (1). The firm-level labor productivity is regressed on production input variables and an indicator of each enterprise software application with additional controlling for industry and the geographical region of East Germany. As the current analysis focuses particularly on the impacts of enterprise systems on firm performance, I will discuss other factors influencing labor productivity only briefly. Overall, the input factors labor, capital and the share of computers per worker turn out to be highly significant at the one percent level in every single one of the following specifications, indicating a high impact of all three factors on labor productivity.

In order to provide a suitable baseline, I firstly introduce the three enterprise systems one by one in the production function estimation. Overall, I find that firms using ERP or SCM show greater performance in terms of labor productivity than firms without these systems. Both point estimates are statistically significant at the one percent level. For instance, the estimate of 0.152 in Column (1) of Table 3 indicates that ERP users demonstrate a greater labor productivity, averaging 15.2 percent above those firms which do not use ERP. Both coefficients show a similar order of magnitude, with SCM having the highest impact. The coefficient of CRM, on the other hand, turns out to be only weakly significant at the ten percent level as shown in Column (3).

Table 3: Returns of enterprise systems evaluated individually

Dependent Variable: Labor Productivity	**(1)**	**(2)**	**(3)**
ln (labor)	-0.111***	-0.111***	-0.102***
	(0.026)	(0.026)	(0.026)
ln (capital)	0.125***	0.124***	0.127***
	(0.019)	(0.019)	(0.019)
share of computer	0.584***	0.593***	0.593***
workers	(0.106)	(0.106)	(0.108)
ERP	0.152***	-	-
	(0.055)		
SCM	-	0.164***	-
		(0.051)	
CRM	-	-	0.082*
			(0.049)
Constant	5.697***	5.703***	5.727***
	(0.166)	(0.166)	(0.167)
Control variables	Industry, East	Industry, East	Industry, East
R^2	0.234	0.235	0.230
Number of Observations	927		

Notes: *** p<0.01; ** p<0.05; * p<0.1; robust standard errors in parentheses.
Source: ZEW ICT survey 2004, 2007 and own calculations.

As all three systems are expected to contribute to performance enhancement, omitting one of them could upwardly bias all the returns of the observed one (Aral et al. 2006). In order to check for this potentially omitted variable bias and to give a first insight of the interacting nature of enterprise systems, Table 4 reports the regression results taking all possible combinations of enterprise systems into account. If the assumption of omitted variable bias is true, one would expect a decrease in significance and in the size of the coefficients once all enterprise systems are integrated together in the regression. Overall, ERP and SCM stay significant if one additionally controls for CRM. Abstracting from SCM leads to a higher significance of ERP, as shown in Column (2) of Table 4. The coefficient of CRM stays insignificant in all regressions. Moreover, every coefficient decreases in magnitude once the adoption of another enterprise system is controlled for. This result confirms the assumption of omitted variable bias implying that once the enterprise systems are considered simultaneously in the regressions the performance impact of one enterprise system is to some extent explained by the other one with SCM explaining the major part in the available dataset. The bias might even turn out to be larger if the systems are used in combination as potential performance gains resulting from a complementary relationship among these interacting systems are not explicitly revealed. The possible complementarity relation between the systems is addressed in the next section.

Table 4: Returns to enterprise systems

Dependent Variable: Labor Productivity	**(1)**	**(2)**	**(3)**	**(4)**
ln (labor)	-0.119***	-0.112***	-0.111***	-0.119***
	(0.026)	(0.026)	(0.026)	(0.026)
ln (capital)	0.120***	0.123***	0.123***	0.120***
	(0.019)	(0.019)	(0.019)	(0.019)
share of computer	0.584***	0.570***	0.584***	0.566***

workers	(0.105)	(0.107)	(0.107)	(0.106)
ERP	0.120** (0.055)	0.138** (0.057)	-	0.118** (0.057)
SCM	0.139*** (0.051)	-	0.152*** (0.054)	0.135** (0.053)
CRM	-	0.049 (0.050)	0.034 (0.052)	0.012 (0.053)
Constant	5.669*** (0.166)	5.688*** (0.167)	5.697*** (0.167)	5.667*** (0.167)
Control variables	Industry, East	Industry, East	Industry, East	Industry, East
R^2	0.239	0.234	0.236	0.239
Number of Observations	927			

Notes: *** p<0.01; ** p<0.05; * p<0.1; robust standard errors in parentheses.
Source: ZEW ICT survey 2004, 2007 and own calculations.

The large impact of SCM is not surprising at all, bearing in mind the potential benefits a SCM system has to offer and the positive impacts of SCM on firm performance, as reported by many studies focusing on SCM usage, e g. Dehning et al. (2007) or Hendricks et al. (2007). For CRM usage, however, there is nearly no evidence of positive impacts. The performance effect of ERP, on the other hand, might already be generated much earlier. Thus, it does not show high significance anymore, as most firms install their ERP system first and adopt SCM and CRM applications a few years later. Unfortunately, the data does not provide any information about the date of purchase or implementation of the enterprise systems. However, without an ERP system already installed, the firms would need to feed their SCM and CRM systems from legacy systems, often in form of spreadsheets spread out over different departments and subsidiaries of the firm. Without a reliable information basis in form of an ERP system the information from all areas of the company cannot be accessed quickly, which could result in bottle necks and idle times.

4.2 Complementarity and interaction between the enterprise systems

To test for complementarity Table 5 reports the interaction terms controlling for the adoption of any two systems together in Column (1) to (3). Indicating no complementarity between any two enterprise software applications at a first glance no interaction term turns out to be significant in the regressions containing two different enterprise systems. Even the performance impact of the enterprise systems individually drops down to zero with the exception of ERP which shows a small impact in Column (2). However, the specifications in Column (1) to (3) only control for two systems at a time neglecting potential influence of the third system. Accordingly, the specification used in Column (4) controls for all possible interactions between the three software systems. In this specification, the influence of ERP turns out to be significant, indicating an increase in labor productivity for firms using this kind of system. Striking, however, is the significance, even only at the ten percent level, of the interaction term which captures the use of all three software systems together. According to this term, firms using ERP and additionally employing SCM and CRM systems demonstrate a considerable increase in labor productivity. Complementarity between the three different systems seems not to be directly realized through the adoption of only two systems, but SCM and CRM complement each other once ERP is already in use or implemented in conjunction. The result confirms the complementary benefits outlined in section 1 that utilizing SCM and CRM without an ERP system running might not be as useful as otherwise. Linking front and back office an ERP system provides the necessary infrastructure to feed the needed data to the SCM and CRM system. The performance effects generated through the use of an ERP system are increased even further once the firms adopt the other two systems. Therefore, adopting the full suite of enterprise systems turns out to be most useful for firms if they can rely on the needed data infrastructure provided by an ERP system in first place.

As specification (1) of section 2 is rather parsimonious in terms of variables which affect labor productivity besides enterprise systems and traditional inputs, the results might to some extent be driven by unobserved heterogeneity with respect to firm characteristics. Therefore, a reduction of the heterogeneity bias by introducing more variables affecting productivity seems reasonable, especially as the evidence is based on weak significance. For this kind of robustness check I introduce two additional dummy variables in the estimation, the first one taking the value one if the firm reports any exporting activity and zero elsewise. Compared to firms that are only active in their home market, firms engaged in export activities are more exposed to international market pressure. Those firms are generally used to making quick adjustments in response to changes in the market environment. They rely on a highly flexible workforce as worldwide demand may change more rapidly and drastically than domestic demand. Therefore, export activity is argued to positively impact labor productivity (Baldwin and Gu 2004; Bernard and Jensen 2004). The second dummy variable introduced takes the value one if the firm has established a works council. With an established works council, employees are expected to show a higher degree of identification with their enterprise and the corresponding decisions made, encouraging them to feel more committed to the company and consequently do a better job. In addition, employee participation in decision-making might balance production more effectively to eliminate bottle-necks or interruptions of the production process. Hence, the establishment of a works council should also lead to higher labor productivity (Zwick 2003). Column (5) of Table 5 reports the result once works council and export activity is controlled for. As expected, both estimates show a significant positive impact on labor productivity. Concerning complementarity between the enterprise systems, the two newly introduced variables do not affect the relationship much. Both relevant coefficients, ERP and the interaction term of all three systems, decrease in size but still show a significant impact on labor productivity.

Table 5: Returns to enterprise systems – interaction between the systems

Dependent Variable: Labor Productivity	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**
ln (labor)	-0.120*** (0.026)	-0.112*** (0.026)	-0.110*** (0.026)	-0.121*** (0.026)	-0.146*** (0.028)
ln (capital)	0.120*** (0.019)	0.123*** (0.019)	0.122*** (0.019)	0.120*** (0.019)	0.110*** (0.019)
share of computer workers	0.568*** (0.105)	0.571*** (0.107)	0.582*** (0.107)	0.572*** (0.107)	0.572*** (0.106)
export activity	-	-	-	-	0.148*** (0.057)
works council	-	-	-	-	0.171** (0.069)
ERP	0.107 (0.068)	0.135* (0.072)	-	0.185** (0.084)	0.154* (0.085)
SCM	0.103 (0.085)	-	0.072 (0.076)	0.171 (0.116)	0.139 (0.118)
CRM	-	0.044 (0.089)	-0.023 (0.070)	0.046 (0.121)	0.045 (0.123)
ERP & SCM	0.049 (0.104)	-	-	-0.196 (0.151)	-0.186 (0.151)
ERP & CRM	-	0.007 (0.106)	-	-0.179 (0.149)	-0.189 (0.150)
SCM & CRM	-	-	0.138 (0.100)	-0.134 (0.180)	-0.110 (0.183)
All three systems	-	-	-	0.419* (0.219)	0.408* (0.220)
Constant	5.678*** (0.169)	5.690*** (0.168)	5.711*** (0.167)	5.664*** (0.169)	5.574*** (0.171)
Control variables	Industry, East	Industry, East	Industry, East	Industry, East	Industry, East
R^2	0.239	0.234	0.237	0.244	0.255
Number of Observations	927				

Notes: *** p<0.01; ** p<0.05; * p<0.1; robust standard errors in parentheses.
Source: ZEW ICT survey 2004, 2007 and own calculations.

4.3 Alternative procedure to test for complementarity

As a robustness check I conduct the likelihood-ratio test from Lokshin et al. (2007). Table 6 reports the computed log-likelihood values of the unconstrained and constrained models, the likelihood-ratio statistics and p-values. I rely on the method developed by Shapiro (1985) to generate the needed weights. Overall, the likelihood-ratio statistics turn out to be small in the first two cases and the test rejects the hypothesis of pairwise complementarity for the combinations of ERP and either SCM or CRM. However, in the third case, the test reports a highly significant complementarity relationship between SCM and CRM. The complementarity relationship is unconditional on ERP adoption indicating that complementary benefits are realized even if an ERP system is not installed. Overall, this result is slightly different to the results obtained based on the interaction term specification. However, this recent testing method still lacks empirical evidence. Accordingly, one has to treat the results with appropriate care. As this robustness check is not sufficient I also conducted the likelihood-ratio testing procedure of for two practices, namely SCM and CRM, but only if ERP is also in use. The appropriate one-sided t-test reports a complementarity relationship significant at the one percent level and thus strengthens the results of Table 5.

Table 6: Multiple restrictions test for complementarity

Complementarity Relation	Unconstrained	Inequality Constrained ≥ 0	Inequality Constrained ≤ 0	Equality Constrained	LR-Statistic	P-Value
ERP – SCM	-658.475	*-659.319*	-659.804	-660.653	2.668	0.117
ERP – CRM	-658.475	-659.694	*-659.499*	-660.709	2.420	0.134
SCM – CRM	-658.475	*-658.768*	-662.311	-662.604	7.672	0.010

Note: In the LR tests the null corresponds to the value in italics and the alternative corresponds to the equality constraint. In order to conclude in favor of complementarity or substitability the Log-Likelihood value with the inequality constraints should be significantly larger than the Log-Likelihood value with the equality constraint.
Source: ZEW ICT survey 2004, 2007 and own calculations.

5 Conclusion

With the first wave of implementations dating back to the early 1990s, enterprise systems are nowadays widely spread and broadly accepted among industries and firms of all sizes. Their exact influence on firm performance, however, remains to be discovered and revealed as it is still unknown whether the interactions between various enterprise systems affect performance in a different way than the reliance on a single application.

The paper approaches this question from a different and novel angle as it focuses explicitly on disentangling the productivity impacts caused by the combinations of different enterprise systems. The results provide empirical evidence of the impacts of the three major enterprise systems on labor productivity and display possible complementarities among the systems. It is shown that SCM and CRM function as complements, especially if an ERP system is already in place and provides the necessary IT-infrastructure for both enterprise software applications. The complementarity relationship turns out to be robust even if a non-parsimonious labor productivity specification is used for inference. Hence, the productivity gains caused by enterprise system implementation are not only generated by the usage of one single system, but rather augmented and increased by adopting the three major enterprise systems together. In consequence, previous estimations of the productivity impacts due to enterprise software usage might be biased as long as any interaction effects of the systems are not taken into account and pictured adequately.

This analysis faces a few caveats which are primarily related to data restriction. First, a potential short-coming of this analysis might be the fact that I could only check for the effects of adopting different enterprise software systems without controlling for other obstacles interfering with enterprise system usage. This may be a drawback since not only the adoption of other enterprise systems might influence the productivity gains of one system. Special IT-training or the quality of updates and maintenance, to name only a few examples, may also affect the performance effects of enterprise software. The dataset also doesn't contain information on the usage of Enterprise Application Integration (EAI) software. This software enhances the communication between the different enterprise systems and enables them to check for redundant information thereby increasing the performance of the systems. Without information about EAI the estimated impacts of enterprise systems might be downwardly biased as with EAI software running the impacts of enterprise software on labor productivity can be expected to be larger. However, due to data constraints I have to pass the exploration of the productivity effects generated by EAI software usage on to future research with newly obtained data. Besides EAI software, it may also be the case that some companies might have less legacy systems compared to other firms, allowing them to implement next generation enterprise software faster and consequently realizing performance benefits earlier. Future availability of new data may provide evidence even for these cases. Lastly, a potential endogeneity bias cannot be excluded completely. Although based on a well-defined temporal sequence incorporating a two year lag between software usage and performance measured it is not clear if the firms possess the software to increase performance or because they are already performing well acquiring the software as an additional asset. However, the works council captures such strategic firm decisions to some extent as it has the option to confirm or deny certain decisions. Accordingly, as the estimations control for the establishment of a works council the mentioned bias due to unobserved strategic decisions of firms can be expected to be negligibly small in size.

6 Appendix Chapter 1

Table 6: Distribution of the combinations of enterprise systems

	Frequency	Percent
no enterprise system	219	23.62
Only ERP	121	13.05
Only SCM	23	2.48
Only CRM	54	5.83
Only ERP and SCM	88	9.49
Only ERP and CRM	123	13.27
Only CRM and SCM	41	4.42
All three systems	258	27.83
number of observations	927	100

Source: ZEW ICT survey 2004.

Survey-Question for enterprise system usage:

Which application or system do you use in your daily business routine? Please state if the application or system is used to minor degree, broadly or not at all.

software for planning and controlling, e. g. SAP/R3 (ERP system from SAP)

customer relationship management (CRM)

supply chain management (SCM)

Table 8: Distribution of enterprise systems usage (in percent)

	ERP	SCM	CRM
no usage	36.35	55.77	47.65
minor usage	16.83	25.46	32.79
broad usage	46.82	18.77	18.55
number of observations	927	927	927

Source: ZEW ICT survey 2004.

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