The Impact of ICT Investment on Establishment Productivity

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Abstract
This paper finds substantial effects of ICT investments productivity for a large and representative German establishment panel data set. In contrast to the bulk of the literature also establishments without ICT capital are included and lagged effects of ICT investments are analysed. In addition, a broad range of establishment and employee characteristics are taken account of in order to avoid omitted variable bias. It is shown that taking into account unobserved heterogeneity of the establishments and endogeneity of ICT investments increases the estimated lagged productivity impact of ICT investments.

Key Words: ICT investments, microeconometric evaluation, establishment productivity, panel regression.

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Introduction

Although the first hype around the role of information and communication technologies (ICT) in improving the competitiveness and productivity of enterprises has given way to disillusionment, these technologies are still central to growth and competitiveness. While the first wave of empirical analyses of the productivity impact of ICT found little evidence that the use of computers has led to increases in output (which led to the so-called "productivity paradox"), more recent studies found productivity effects of ICT clearly above their investment costs. The absence of productivity effects in the earlier studies is attributed to small sample sizes and noisy data (Hitt and Brynjolfsson, 2002). A brief look at the literature teaches that although empirical studies in recent years use larger samples and more accurate information on the usage of ICT or investment costs in these technologies, mainly only the contemporaneous producticity effects are measured. In addition, several studies might suffer from estimation biases, because they do not take into account that firms with ICT investments might have been more productive than their competitors already before they invested in these technologies (unobserved heterogeneity) and that especially those firms invested in ICT that had the best relation between investment costs and benefits (endogeneity of ICT investments).

Lichtenberg (1995) finds evidence of excess contemporary returns to capital and labour deployed in information systems. He uses data of the US economy from two different sources with between 190 and 450 firms in the cross-section dimension. His results are based on Cobb-Douglas production functions with the input factors computer capital stock and non-computer capital stock, ICT labour and non-ICT labour. Lichtenberg does not measure the lagged productivity effects and takes no account of unobserved heterogeneity and endogeneity of ICT investment and ICT labour decisions, however.

Greenan and Mairesse (1996) argue that there is a positive relationship between a firm's productivity and the fraction of its employees who report using a PC at work. A problem is that they only observe a small subset of the employees of any given firm, and they also do not correct for endogeneity and unobserved establishment heterogeneity.

Bresnahan, Brynjolfsson and Hitt (2002) find on the basis of panel data of 331 US establishments from different sectors that ICT hardware capital has a significant positive impact on productivity. They also report positive interaction effects between ICT capital and skills (training activities) and work organization (teamwork and employee involvement) on value added. Problematic is that their study leaves lagged productivity effects, endogeneity of investments in ICT, and unobserved establishment heterogeneity out of account. In addition, human capital and workplace organization are measured in 1995/1996, while the production function with ICT capital is estimated for the period 1987–1994. In a comparable study, Brynjolfsson and Hitt (1995) control for unobserved heterogeneity by performing a within-transformation that removes the firm-specific intercept term. They show that "firm effects" may account for half of the productivity benefits imputed to ICT, while nonetheless the elasticity of ICT remains significantly positive. They conclude that US firms that use ICT are productive for other reasons. Brynjolfsson and Hitt (1996) use instrumental variable methods to filter out the endogeneous variation and error in ICT capital in a cross-section Cobb-Douglas production function including ICT labour and capital and non-ICT labour and capital. They use once-lagged values of the variables as instruments. The estimates are somewhat higher for computer capital than in the pooled OLS estimates. The authors therefore argue that ICT investments mainly take place after negative shocks.

Hempell (2002) also estimates the contemporary productivity impact of ICT capital, non-ICT capital and labour on the productivity of about 1200 German service sector firms in Cobb-Douglas and translog production functions. He corrects the endogeneity of the use of ICT and unobserved heterogeneity by using system GMM estimations. Controlling for unobserved heterogeneity reduces the coefficient of ICT capital and it is no longer significant. When endogeneity is also taken into account, the measured productivity effect increases again, however.

The main purpose of this paper is to shed more light on the lagged productivity effects of ICT investments. Brynjolfsson and Hitt (2000b) find that the inclusion of work practices, qualification levels, or other complements of ICT investments clearly reduces the measured productivity impact of ICT. Therefore, a broad range of establishment characteristics is included as control variables. This paper also assesses the effects of ICT after longer lags, because the short-run effects seem to be smaller than the long-run effects (Brynjolfsson and Hitt, 1998; Brynjolfsson and Hitt, 2000b). They argue that the short-term returns represent the direct effects of ICT investment, while the longer-term returns represent the effects of ICT when combined with related investments in organizational change. Therefore, the time structure clearly matters when looking at the productivity effects of ICT. In addition, the endogeneity of the decision of establishments to invest in ICT is analysed using external instrumental variables instead of the lagged values of the internal variables. Instrumental variable estimations can filter out the endogeneous variation and errors in the variables, which then allows a consistent estimation of the parameters (Brynjolfsson and Hitt, 1996). Finally, the structural differences between establishments are taken into account. Unmeasured and slowly changing organization practices, management quality, and labour relations significantly affect the returns to ICT investments, because, for example, those firms that were well organized before, heavily invested in ICT (Brynjolfsson and Hitt, 2000b; Black and Lynch, 2001; Wolf and Zwick, 2002).

The paper is organized as follows. The second section presents the data basis. The next section explains the estimation strategy and the empirical evidence of the productivity effects of ICT investments. Here, endogeneity of the decision to adopt ICT and unobserved heterogeneity of the establishments are taken into account. The last section concludes.

The Data

This section provides a short description of the IAB establishment panel data set which is used for the following analysis.[1] The establishments participating in this survey are selected from the parent sample of all German establishments employing at least one employee with social security. Thus, self-employed and establishments that employ only people not covered by social security (mineworkers, farmers, artists, journalists, etc.) as well as public employers with solely federal employees do not belong to the original sample. The random draw on this sample covered information about almost 9.000 German establishments in 1997 and increased the size to almost 14,000 German establishments in the year 2000, of which 5,500 were located in East Germany.

The establishments covered by the survey are asked about turnover, number of employees, personnel problems, apprenticeship training, (ICT) investments, innovations, and public subsidies since 1993 (in East Germany since 1996). From time to time, additional topics, such as training and personnel measures, are added to the questionnaire. For the purpose of this analysis, only profit oriented establishments and establishments that have not been bought by other establishments or bought other establishments are included.[2] Unfortunately, it is only known if an establishment invested in ICT in 1996 or 1997, the corresponding size of the investment is unknown, however. Therefore, it is not possible to construct a measure for ICT capital analogously to other papers cited above. The cross-section estimations cover the years 1998 until 2000 in order to calculate the lagged productivity effects of ICT investments. The panel estimation includes data from the years 1997 – 2000.

Empirical Analysis of the Productivity Effects of ICT Investments

The productivity effects of ICT investments are determined by estimating Cobb-Douglas production functions (see also Black and Lynch, 2001). The dependent variable denotes the economic value added (turnover minus input costs), and the explanatory variables include capital, the number of employees, a dummy for ICT investments, and other control variables. In order to demonstrate the impact of endogeneity of the ICT investment decision and of unobserved heterogeneity on the estimation results, these possible estimation biases are taken account of one by one.

Productivity estimations in a cross-section analysis

Firstly, the productivity effects of ICT investments in cross-section Cobb-Douglas production functions are estimated:

(1) $$\ln Y_t = \alpha \ln K_t + \beta \ln L_t + \gamma ICT_{t-l} + \varphi T_t + \phi R_t + \delta X_t + \varepsilon_t,$$

where *Y* is value added, *K* is capital which is calculated by the perpetual inventory method from replacement investments (Black and Lynch, 2001; Hempell, 2002), *L* is the number of employees, *ICT* is a dummy for establishments with ICT investments, *T* denotes a dummy for establishments with continuous training investments, and *R* is an indicator for several re-organizations that increase the participation of employees. The three dummy-variables indicating if an establishment introduced re-organizations (introduction of team work, reduction of hierarchies, and introduction of autonomous workgroups) are closely correlated (see also Brynjolfsson and Hitt, 2000b; Bresnahan, Brynjolfsson and Hitt, 2002; Wolf and Zwick, 2002). This means that there may be multi-collinearity if they are estimated separately. Therefore, the observed three re-organizations are aggregated to one independent "re-organizations"-factor *R* by a factor analysis.[3] This approach captures the complementary nature of the three re-organizations better than using dummy-variables for individual measures, because it does not reduce the index value to zero if a single practice is absent in an establishment. Instead, the absence of one practice only reduces the value of the factor (Osterman, 1994; MacDuffie, 1995; Youndt et al., 1996).

Previous estimations of the productivity impact of ICT investments have been very parsimonious and did not include many additional variables besides capital, labour, and ICT investments (Brynjolfsson and Hitt, 1996). The coefficients of these input variables may considerably decrease when complementary establishment characteristics, such as industrial relations indicators, personnel management indicators, the quality of the workforce and the technical equipment, and variables for the competition situation are added (Zwick, 2002). In order to avoid omitted variable bias, a broad variety of establishment and employee characteristics are added in the vector of control variables *X*.

The index *t* stands for the cross-section year 1997 – 2000, while *l* indicates the lag between ICT investment and productivity. It cannot be expected that ICT investments have an instantaneous effect on establishment productivity, and therefore their productivity impact is lagged. In addition, by lagging the ICT variable the endogeneity of this measure in the productivity regression can be mitigated (Caroli and Van Reenen, 2001). In the cross-section regression for the year 2000, the lag index is three, for example. The parameters α, β, γ, φ, ϕ, and δ are the regression coefficients to be estimated, and ε is the normally distributed error term with expected value zero and variance σ^2.

It can be expected that a high share of qualified employees, training investments as well as a modern technical equipment increase the productivity of the establishment (Black and Lynch, 2001; Zwick, 2002). Re-organizations that increase the participation of the employees or delegate decision making to teams also increase establishment productivity (Wolf and Zwick, 2002). In addition, exporters and firms with work councils and collective bargaining usually exhibit a significantly higher productivity (Addison et al., 2000). East German establishments may still have lower productivity. Differences between the business sectors are captured by 16 dummy-variables, and 4 dummies for different legal forms are added. A definition of the control variables as well as their average values can be found in table A1 in the appendix.

The second and third column of the tables A3, A4, and A5 in the appendix show the cross-section regression results of model 1 for 1998 – 2000. The establishments in our sample produce with a capital intensity of around 0.15.[4] In the light of the evidence presented in the introduction, the incidence of ICT investments in 1996 or 1997 has a surprisingly small impact on productivity in the years after. Only in 2000 is the impact marginally significant. The control variables all have the expected effects on the productivity of the enterprises – besides collective bargaining all control variables have a positive significant impact on establishment productivity. The productivity gap between East and West Germany is still persistent, individual establishments and partnerships are on average less productive than limited liability companies and publicly listed establishments, and the productivity differentials between the economic sectors are jointly significant.

The complementarities between ICT investments, re-organizations, and training are widely ignored in the empirical literature (Cappelli and Neumark, 2000; Hitt and Brynjolfsson, 2002). In additional regressions, therefore interaction terms between investments in ICT and organizational measures that increase the participation of employees or de-centralize decisions and investments in continuous training were added (Bresnahan, Brynjolfsson and Hitt, 2002). In contrast to the theoretical considerations – though in accordance with comparable estimations (McNabb and Whitfield, 1999; Wolf and Zwick, 2002) – there are only very weak interaction effects between ICT investments, training, and re-organizations.[5] In contrast, Bresnahan, Brynjolfsson and Hitt (2002) demonstrate that the pair wise interaction terms between ICT stock and worker skill as well as between ICT stock and re-organizations are positive and significant. The sample of Bresnahan, Brynjolfsson and Hitt (2002) only includes establishments with ICT stock, however. This paper takes the "one-style-fits-all view" that looks at productivity effects irrespective of the sector or the presence of ICT stock (Huselid, 1995). It is unclear, however, if ICT investments, re-organizations, and training efforts in the establishments are intended to support each other. Only the joint incidence of these measures in some establishments can be observed. Therefore, it cannot be excluded that re-organizations and training investments that have been specifically designed to improve the adoption of ICT have a positive impact on productivity.

Endogeneity of ICT investment

The explorative regressions in the last section can give only first indications on possible productivity effects of ICT investments, because possibly important unobserved establishment characteristics and endogeneity of the investment decisions are not taken into account. In this section, we show on the basis of instrumental variable regressions that the results presented in the previous estimations are biased because the choice of ICT investments is endogeneous (model 2).

Most data sets do not provide suitable additional variables that meet the requirements for qualifying them as identifying variables in an instrument regression (Brynjolffson and Hitt, 2000a). In the case of panel data, lagged values or differences of the explaining variable in question are often used as instruments (see for example Brynjolfsson and Hitt, 1996 or Hempell, 2002). This strategy is problematic, however, when the instruments are only weakly correlated with the endogeneous variables and if the explanatory variables, such as ICT investments, are only weakly correlated over time (Dearden, Reed and Van Reenen, 2000). Therefore, it is preferable to use external instruments that intuitively explain the selection process in the establishment and exhibit the necessary statistical properties (Griliches and Mairesse, 1998). The IAB establishment panel contains information on expected personnel problems which may serve as identifying regressors. Two suitable exclusion restrictions can be identified: an expected increase in demand for qualification and training[6] and an expected increase in the incidence of formal training courses.[7] Each of these variables is correlated with the decision of the establishment to invest in ICT because they depict the increase in qualification demand that may be induced by the ICT investments. On the other hand, the identifying variables turn out to be uncorrelated with establishment productivity.

The instrument equation for the ICT investment dummy can be described as follows:

$$(2) \qquad ICT = \alpha_1 I_1 + \alpha_2 I_2 + \delta X + \varepsilon,$$

where I_1 and I_2 are the identifying variables and X is the vector of control variables from equation (1). Equation (2) is now estimated simultaneously with the production function (1) using a maximum likelihood procedure that takes account of the dummy-variable characteristic of ICT. This implies that the endogenous investments in ICT that are correlated with the error term in equation (1) are replaced by ICT, the instrumented ICT investments in equation (2). The estimated values for *ICT* are correlated with the original values but independent from ε in equation (1) and therefore exogenous.

A comparison between model 1 and model 2 shows that ICT investments gain considerably in their measured productivity impact and significance when the endogeneity problem is cured (see tables A3-A5 in the appendix). Some coefficients of re-organizations and training are smaller and/or have lower significance levels, while the other control variables are virtually unchanged in model 2 in comparison to model 1. Comparable results are also obtained by Brynjolfsson and Hitt (1996), Brynjolfsson and Hitt (1998), and Hempell (2002).The increase in the ICT coefficient demonstrates that even after taking lags for ICT investments and thereby controlling for simultaneity bias, the choice of ICT investments is still not exogeneous in our productivity estimation.[8] It additionally may imply several things. First, it may imply that especially those establishments decide to invest in ICT that have a productivity problem and want to improve this situation by ICT investment.[9] Another interpretation is that the higher coefficients in instrumental variables regressions could be attributed to errors in measurement, which tends to create a downward bias, Griliches and Hausman (1986). Especially the dummy variable for ICT investments entails a large measurement error, because it values the purchase of a new telephone equivalently to the purchase of expensive new mainframes or software. In addition, establishments may not all classify the purchase of a new telephone is an investment in ICT. A final reason for the finding may be that the returns to ICT investments are heterogeneous between establishments, Card (1999). One may argue that especially those establishments that increase formal internal training after investment and expect increases in qualification demand can reap the full productivity return. This fact is not captured by the imprecise training dummy and its interaction term with the ICT dummy. Therefore the instruments used may reveal a complementarity between ICT investments and subsequent formal training and qualification demand increases. We do not know the size of the biases induced by measurement errors and heterogeneous ICT returns that both imply an up-ward bias of the instrumental variables in comparison to the OLS regression. Therefore its remains unclear, if establishments invest in ICT when they are confronted with a productivity gap or in good economic situations.

The results of the instrumental equation that explain the decision of the establishments to invest in ICT or not can be found in table A7 in the appendix. According to the theoretical considerations, expected higher demand for training and qualifications and an increase of the importance of formal internal training courses have a positive impact on the probability that an establishment invests in ICT. Also other papers show that international competitive pressure has a positive impact on the propensity of establishments to invest in ICT, because strong international competition drives establishments to innovation and rapid technology adoption (Hollenstein, 2002). It is also found that the adoption of ICT is positively influenced by the adoption or presence of organizational forms that increase the participation of employees (Brynjolfsson and Hitt, 2000a; Bresnahan, Brynjolfsson and Hitt, 2002). In addition, the qualification level of the employees and training investments have a positive impact on the inclination of the establishment to invest in ICT (O'Mahony, 2002; Bresnahan, Brynjolfsson and Hitt, 2002; Zwick, 2003). The enterprises need well educated employees in order to effectively implement new ICT and the complementary new organizational forms that require greater levels of cognitive skill, flexibility, and autonomy. Work councils also have a positive impact on ICT investments. Larger establishments do not seem to invest more frequently in ICT. This is in contrast to the argument by Hollenstein (2002) who expects that larger establishments invest earlier and more in ICT, because they can better spread risks from future development of ICT, economies of scale, etc.

Unobserved Heterogeneity

Finally, the impact of time-invariant unobserved heterogeneity on the estimation results is studied. If unobserved time-invariant characteristics of the establishment, such as management quality, intangible assets, or industrial relations, are correlated with both, the incidence of ICT investments and productivity, cross-section estimates will be inconsistent. Doms, Dunne and Troske (1997), for example, find that plants using more advanced manufacturing technologies had higher productivity, but this was commonly the case even before the technologies were introduced. On the basis of panel data, the coefficients of the production function and the impact of unobserved characteristics can be estimated consistently with a fixed effects estimation. This method, however, tends to go too far in discarding potentially valuable cross-sectional information, because the impact of observed (almost) time-invariant factors, such as the industry sector, high employee participation as well as other quasi-fixed variables in the production function, cannot be identified, or measurement errors may explain a large part of their variance (Ichniowski, Shaw and Prennushi, 1997; Griliches and Mairesse, 1998; Dearden, Reed and Van Reenen, 2000). This feature proves to be a crucial hindrance in our case, because we only know if an establishment invests in ICT or not in the years 1996 and 1997, and this variable does not change over time. Therefore ICT investments are also treated as quasi-fixed variable, in other words, it is assumed that firms that invested either in 1996 or 1997 also invested in ICT before and afterwards.

Therefore, a two step estimation procedure similar to that used by Black and Lynch (2001) and O'Mahony and Vecchi (2002) is proposed here. In this model, the parameters of the time-variant input factors are determined by a simple fixed effects Cobb-Douglas production function on the basis of panel data from 1997 to 2000, while the effects of the (almost) time-invariant determinants are regressed on the fixed effects from the panel analysis in the second step. Therefore, the fixed effects estimation in the first step can be written as:

(3) $$\ln Y_t = \alpha \ln K_t + \beta \ln L_t + \upsilon + \varepsilon_t \quad \text{with} \quad t = 1997 - 2000,$$

where υ is the unobserved time-invariant establishment-specific fixed effect and ε_t the idiosyncratic component of the error term. The estimation results of the first estimation step can be found in table A8 in the appendix. Striking is again the low coefficient of the input capital, which has a similar size to that in the comparable estimation in Black and Lynch (2001), however. If input and output are chosen simultaneously or if there are measurement errors for the input factors (especially for capital), the within-estimator will be inconsistent and we may observe too low capital intensities in the production function (Griliches and Mairesse, 1998).[10]

On the basis of these first step regression results, we calculate the fixed effect υ for every establishment. The fixed effect can be interpreted as the average establishment-specific difference to productivity predicted on the basis of the variable inputs or, in other words, total factor productivity. This time-invariant variable therefore indicates whether establishment productivity was below or above the average of the other firms during the observation period. It serves as the dependent variable for the second estimation step. The vector of explanatory variables in the second step contains all (almost) time-invariant establishment characteristics from model 1, which are ICT investments, training investments, the re-organization factor, and all variables in *X* in values for 1997:

$$(4) \qquad \upsilon = \gamma ICT + \varphi T + \phi R + \delta X + \varepsilon.$$

The estimation results of equation (4) are shown in table A6 in the appendix. ICT investments have a significant positive impact on the establishment-specific fixed effects (model 3). In comparison to the results of the first model, taking account of unobserved heterogeneity increases the significance of the impact of ICT investments on firm productivity. The significance and relative impact of the other variables on productivity are roughly the same in the models 1 and 3, while re-organizations and training have a higher productivity impact on the fixed effect. This may indicate that also the lagged impact of these variables on productivity is higher than their contemporaneous effect.

Final statements on the effects of high performance workplace organisations can only be made, however, if we control for both, unobserved fixed effects and endogeneity. Therefore, in a next step the ICT investments in estimation (4) are instrumented using equation (2) – see the results of model 4 in table A7 in the appendix. Analogous to the cross-section regressions, controlling for endogeneity increases the measured productivity effect of ICT investments and their significance. The coefficients of the other explanatory variables are more or less the same. This result proves that taking account of selection effects can be decisive for the evaluation of the productivity effects of ICT investments. The impact of ICT investments on average productivity in 1997-2000 is clearly larger than for the cross section equations 1998 until 2000. This is in contrast to other studies controlling unobserved heterogeneity (Brynjolfsson and Hitt, 1995; Hempell, 2002). This result suggests that enterprises which invest in ICT have unobserved time-invariant characteristics that decrease their productivity. Firms with structural productivity problems therefore try to improve their situation by investing in ICT. If one ignores the impact of these unobserved fixed effects, the measured productivity effect of ICT investments is too low.

The changes in the estimated coefficients of ICT investments on value added after correcting endogeneity of ICT investments and unobserved heterogeneity and for different time lags are summarized in table 1:

Table 1: Productivity effects of ICT investments

	without selection control	with selection control	without selection control	with selection control	without selection control	with selection control	without selection control	with selection control
	1998		1999		2000		average 1997-2000	
ICT investments in 1996/7	0.05	0.51**	0.03	0.53***	0.05*	0.79***	0.02***	0.98***

Notes: Significance levels are: **<5%, *<1%.

Source: IAB Establishment Panel, Waves 1997 - 2001, own calculations.

Conclusions

This paper shows that investments in ICT substantially increase the average productivity of German establishments . This result is in line with other empirical papers that find high contemporary productivity impacts of ICT capital or ICT employees (Lichtenberg, 1995, Bresnahan, Brynjolfsson and Hitt, 2002, Hempell, 2002). One has to take into account, however, that now the effects on the structural fixed productivity effects are measured and therefore the simultaneity problem between ICT investments and productivity is avoided. In addition, other empirical papers usually calculate the incremental productivity impact of ICT capital, i.e. include only establishments with ICT investments in the past. This paper calculates the lagged impact of the decision to invest in ICT or not, however, and therefore includes establishments without ICT capital and also very small establishments.

In cross section regressions, it is also found that the productivity impact of ICT investments at least does not decrease during the 3 or 4 years after the investment. Taking into account the endogeneity of the decision to invest in ICT and unobserved time.invariant heterogeneity of establishments both increases the calculated productivity impact of ICT.

With a dummy variable indicating if an establishment invested in ICT in 1996 or 1997, this paper uses a rough measure of ICT investments. In order to better understand the impact of ICT on establishment productivity, it would be preferable at least to know the size of the ICT investment or the exact investment date. In this paper, we therefore have to assume that ICT investments are quasi-fixed, i.e. there are establishments that invest at least once in 2 years in ICT and other establishments that do never invest in ICT. The imprecise data might also be a reason for very weak interaction effects between the ICT investment dummy and potentially complementary training investments and the introduction of re-organizations that increase the participation of the employees. Therefore no far reaching conclusions should be drawn from these results. A final caveat concerns the usage of external instruments in order to exogenize ICT investments in the production function. Although this approach is preferable to using the lagged values as internal instruments, the results seem to depend on the set of instruments used. More research therefore seems waranted here.

Appendix

Table A1: Descriptive statistics of variables used

Variables	1997	1998	1999	2000	Comments
Value Added	12.90	12.85	12.99	13.07	Turnover minus inputs, in DM, in logs
Capital	12.44	12.45	12.38	12.44	Constructed from expansion investments by perpetual inventory method, in DM, in logs
Labour	1.95	1.95	1.97	1.96	Number of employees, in logs
Share qualified employees	0.51	0.48	0.53	0.53	Share of employees with professional degree on all employees
Exporter	0.11	0.10	0.18	0.25	Establishment exports, yes=1, no=0
State-of-the-art technical equipment	0.70	0.72	0.74	0.76	Technical state of equipment is modern or state-of-the-art, yes=1, no=0
Work council	n.a.	0.20	0.22	0.26	Establishment has work council, yes=1, no=0
Collective bargaining	0.54	0.67	0.67	0.70	Establishment is subject to or orients itself on sector or establishment-specific collective wages, yes=1, no=0
Individual establishment	0.58	0.60	0.59	0.56	Establishment is an individual firm, yes=1, no=0
Partnership	0.09	0.09	0.09	0.11	Establishment is a partnership, yes=1, no=0
Publicly listed establishment	0.01	0.01	0.01	0.02	Establishment is publicly listed, yes=1, no=0
Limited company (reference)	0.32	0.30	0.31	0.31	Establishment is a public limited company, yes=1, no=0
Training	0.37	n.a.	0.40	0.41	Establishment offered training in first half of the year, yes=1, no=0
ICT investment	0.48				Establishment invested in ICT in 1996 or 1997, yes=1, no=0
Expected skill shortage	0.19				Establishment expects skill shortages in next 2 years, yes=1, no=0
Expected large demand for training and qualification	0.07				Establishment expects large demand for training and qualification in next 2 years, yes=1, no=0
Expected increase in formal internal courses	0.11				Establishment expects increases in internal formal courses in next 2 years, yes=1, no=0
East German establishment	0.20	0.20	0.22	0.24	Establishment has head quarter in East Germany, yes=1, no=0

Notes: Averages are derived from cross-section samples and weighted according to establishment weights.

Source: IAB establishment panel, waves 1997-2001, own calculations.

Table A2: Rotated[a] component matrix of factor analysis

Factor	Variables	Factor loadings
Organizational changes	Shift responsibilities	0.82
	Teamwork	0.80
	Independent work groups	0.72

Notes: [a] The factors have been rotated by promax.

Source: IAB establishment panel, wave 1999, own calculations.

Table A3: Productivity effects of ICT investment in 1997 on productivity 1998, endogeneous variable: value added 1998

	Model 1 (OLS regression)		Model 2 (maximum likelihood treatment effects model)	
	Coefficients	z-values	Coefficients	z-values
ICT investment 1997	0.05	1.39	0.51**	2.51
Capital	0.16***	11.37	0.15***	9.47
Labour	0.82***	36.27	0.80***	30.81
Re-organization	0.01	0.55	-0.00	-0.13
Training	0.07**	2.07	0.03	0.55
Share qualified employees	0.42***	6.00	0.41***	4.86
Exporter	0.18***	3.65	0.15***	2.56
State-of-the-art technical equipment	0.07*	1.80	0.07*	1.66
Work council	0.14***	2.67	0.12**	1.88
Collective bargaining	0.06	1.46	0.08*	1.93
Individual establishment	-0.26***	-5.52	-0.26***	-4.58
Partnership	-0.01	-0.18	-0.01	-0.19
Publicly listed establishment	0.15**	1.81	0.16	1.60
East German establishment	-0.35***	-9.68	-0.32***	-7.98
Constant	9.26***	47.34	9.20***	40.35
	N=2287		N=1833	
	R^2=0.88		Wald Test of independent equations, Prob > χ^2 = 0.03	

Notes: Significance Levels: ***<1%, **<5%, all values are for 1998, except indicated otherwise. 16 sector dummies are included, standard errors are heterosedasticity robust.

Source: IAB Establishment Panel, Waves 1997 - 1999, own calculations. All standard errors are heteroscedasticity robust.

Table A4: Productivity effects of ICT investment in 1996/1997 on productivity 1999, endogeneous variable: value added 1999

	Model 1 (OLS regression)		Model 2 (maximum likelihood treatment effects model)	
	Coefficients	z-values	Coefficients	z-values
ICT investment 1997	0.03	0.97	0.53***	2.95
Capital	0.13***	11.67	0.14***	9.46
Labour	0.82***	42.10	0.80***	31.03
Re-organization	0.00	0.16	-0.01	-0.35
Training	0.03	0.83	0.03	0.66
Share qualified employees	0.40***	5.76	0.35***	3.71
Exporter	0.18***	4.16	0.12**	2.03
State-of–the-art technical equipment	0.10***	3.07	0.17***	3.88
Work council	0.23***	5.02	0.21***	3.39
Collective bargaining	0.07*	1.76	0.08	1.51
Individual establishment	-0.27***	-5.96	-0.27***	-4.12
Partnership	-0.07	-1.53	-0.11	-1.59
Publicly listed establishment	0.12	1.38	0.13	1.20
East German establishment	-0.35***	-10.55	-0.32***	-7.48
Constant	9.73***	66.62	9.49***	47.59
	N=2506		N=1511	
	R^2=0.87		Wald Test of independent equations, Prob > χ^2 = 0.00	

Notes: Significance Levels: ***<1%, **<5%, all values are for 1999, except indicated otherwise. 16 sector dummies are included, standard errors are heterosedasticity robust.

Source: IAB Establishment Panel, Waves 1997 - 2000, own calculations. All standard errors are heteroscedasticity robust.

Table A5: Productivity effects of ICT investment in 1996/1997 on productivity 2000, endogeneous variable: value added 2000

	Model 1 (OLS regression)		Model 2 (maximum likelihood treatment effects model)	
	Coefficients	z-values	Coefficients	z-values
ICT investment 1997	0.05*	1.68	0.79**	3.90
Capital	0.15***	15.52	0.14***	9.55
Labour	0.81***	48.76	0.77***	26.98
Re-organization	0.01	0.63	0.01	0.52
Training	0.08***	2.90	0.06	1.14
Share qualified employees	0.52***	9.92	0.39***	4.17
Exporter	0.25***	7.67	0.17***	2.67
State-of-the-art technical equipment	0.05*	1.69	0.01	0.27
Work council	0.25***	7.29	0.18***	2.96
Collective bargaining	-0.01	-0.30	0.04	0.68
Individual establishment	-0.31***	-8.54	-0.33***	-4.99
Partnership	-0.07*	-1.79	-0.16**	-2.06
Publicly listed establishment	0.12*	1.65	0.14	1.19
East German establishment	-0.35***	-12.95	-0.34***	-7.52
Constant	9.74***	85.96	9.72***	52.95
	N=4314		N=1603	
	R^2=0.85		Wald Test of independent equations, Prob > χ^2 = 0.00	

Notes: Significance Levels: ***<1%, **<5%, all values are for 2000, except indicated otherwise. 16 sector dummies are included, standard errors are heterosedasticity robust.

Source: IAB Establishment Panel, Waves 1997 - 2001, own calculations. All standard errors are heteroscedasticity robust.

Table A6: Productivity effects of ICT investment in 1996/1997 on average productivity 1997-2000, endogeneous variable: average fixed effect 1997-2000

	Model 3 (OLS regression)		Model 4 (maximum likelihood treatment effects model)	
	Coefficients	z-values	Coefficients	z-values
ICT investment	0.02**	1.98	0.98***	9.36
Re-organizations	0.14***	4.40	-0.02	1.48
Training	0.19***	5.31	0.12***	2.94
Share qualified employees	0.58***	9.58	0.60***	8.92
Exporter	0.26***	5.67	0.18***	3.55
State-of-the-art technical equipment	0.18***	6.64	0.13***	3.72
Work council	0.48***	10.14	0.44***	8.32
Collective bargaining	0.15***	4.32	0.15***	4.32
Individual establishment	-0.52***	-11.99	-0.51***	-11.69
Partnership	-0.13***	-2.59	-0.12***	-2.30
Publicly listed establishment	0.15**	2.00	0.14**	1.79
Establishment size 20-199	0.79***	18.12	0.94***	20.54
Establishment size 200-499	1.50***	22.11	1.62***	21.49
Establishment size 500-999	1.81***	20.21	2.00***	21.78
Establishment size 1000+	2.43***	25.59	2.59***	24.90
East German establishment	-0.36***	-11.10	-0.36***	-11.09
Constant	-1.19***	-11.57	-1.17***	-11.26
	N=3168		N=3168	
	R^2=0.73		Wald Test of independent equations, Prob > χ^2 = 0.00	

Notes: Significance Levels: ***<1%, **<5%, all values are for 1997, except work council which is only available for 1998. Also 16 sector dummy-variables are added, standard errors are heterosedasticity robust.

Source: IAB Establishment Panel, Waves 1997 - 2001, own calculations. All standard errors are heteroscedasticity robust.

Table A7: Instrumental variable regression, endogeneous variable: ICT investments 1996/1997

Variables	Coefficient	z-Value
Re-organizations	0.15***	8.41
Training	0.16***	2.82
Share qualified employees	0.24***	2.66
Exporter	0.28***	3.84
State-of-the-art technical equipment	0.15***	3.16
Work council	0.28***	3.62
Individual establishment	-0.43***	-6.17
Partnership	-0.04	-0.51
Publicly listed establishment	0.08	0.64
Establishment size 20-199	0.04	0.62
Establishment size 200-499	0.20	1.64
Establishment size 500-999	-0.04	-0.27
Establishment size 1000+	0.30	1.63
Expected large demand for training and qualification	0.04***	0.52
Expected increase in formal internal courses	0.16**	2.54
Constant	-0.58***	-3.89

Notes: Significance levels: ***<1%, **<5%. All variables take the values of year 1997 (except work councils that are only available for 1998), also 16 sector dummy–variables are added, standard errors are heterosedasticity robust.

Source: IAB establishment panel, waves 1997 and 1998, own calculations.

Table A8: Fixed Effect Production Function 1997-2000, Endogeneous Variable: Value Added

Variables	Coefficient	z-Value
Capital	0.02**	2.54
Labour	0.44***	12.38
Year 1998	-0.00	-0.04
Year 1999	0.02	1.55
Year 2000	0.07***	4.55
Constant	12.82***	85.58
Number of observations = 11322	R^2 = 0.83	
Number of groups = 6293	F(5,5024) = 37.91	
	Prob > F = 0.0000	

Notes: Significance levels: ***<1%, **<5%.

Source: IAB establishment panel, wave 1999, own calculations.

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1 An in-depth description of this data set can be found in Kölling (2000).

2 We sorted the establishments into the following sectors: Agriculture and forestry, mining and basic materials, food, consumer goods, production goods, investment goods, construction, trade, traffic and communication, credit and insurance, hotels and restaurants, education, health and social affairs, electronic data processing and research and development as well as business consulting, other business services, and other personal services.

3 A main component factor analysis is applied to reduce the three re-organization measures to one independent factor with an eigen value of 1.82 (Osterman, 1994). The resulting factor "re-organizations" explains 61% of the total variance. The factor loadings are shown in Table A2 in the Appendix.

4 The low capital coefficient may be a consequence of the approximation of capital by replacement investments. The measurement errors incurred by this method lead to the well-known bias of the capital coefficients toward zero (Griliches and Mairesse, 1998).

5 The regression results are very similar and therefore not included here.

6 The dummy variable has the value one when the establishment expects an increase in the demand for qualification and training. It is based on the question, "Which personnel problems do you expect in the following two years?"

7 The dummy variable has the value one when the establishment expects an increase in the intensity of formal external courses. It is based on the question, "Will these training forms gain in importance in your establishment in the future?" There are 6 other training categories mentioned; compare Zwick (2002) for details.

8 Please note that because variables for 1997 are used in the instrumental equations, the number of observations of the instrumented productivity estimations decreases in comparison to the uninstrumented productivity estimations. Some differences in the results may be explained by the decrease in sample size and the fact that only those firms are included that "survived" from 1997 to 2000.

9 Several authors interprete the differences between the OLS and instrumental variables results as expressions of negative or positive selection. An increase in IV estimates with respect to OLS, for example, indicates that firms introduce these measures especially when they have temporary unobserved characteristics that reduce their productivity (Caroli and Van Reenen, 2001, Wolf and Zwick, 2002).

10 Some papers demonstrate that these problems can be avoided by using estimators based on differences or lags, such as (system) GMM or the two-stage least-squares first-differenced estimator (Anderson and Hsiao, 1981); see Black and Lynch (2001) or Hempell (2002). This approach is not possible with the data at hand, however, because the number of observations would decline dramatically.