THE IMPACT OF ICT INVESTMENT ON ESTABLISHMENT PRODUCTIVITY

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This paper finds substantial effects of ICT investments on 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.

Introduction

Although the first hype surrounding 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 have 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, in the main only the contemporaneous productivity effects are measured. In addition, several studies may suffer from estimation biases, because they do not take into account that firms with ICT investments might already have been more productive than their competitors before investing in these technologies (unobserved heterogeneity), and also that firms with the best relation between investment costs and benefits (endogeneity of ICT investments) were most likely to invest in ICT.

Lichtenberg (1995) finds evidence of excess contemporary returns to capital and labour deployed in information systems. He uses US economy data 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. One 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 organisation (teamwork and employee involvement) on value added. It is problematic 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

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organisation are measured in 1995/1996, while the production function with ICT capital is estimated for the period 1987–94. 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, although 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 is no longer significant. However, when endogeneity is also taken into account, the measured productivity effect increases again.

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 organisational 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 organisation practices, management quality, and labour relations significantly affect the returns to ICT investments, because, for example, firms that were well organised already were particularly likely to invest heavily 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 basic data. The third 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 fourth 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, neither the self-employed, nor establishments employing only people not covered by social security (mineworkers, farmers, artists, journalists, etc.), nor public employers with solely federal employees, belong to the original sample. The random draw on this sample covered information on almost 9000 German establishments in 1997 and increased to almost 14,000 German establishments in the year 2000, of which 5500 were located in East Germany.

The establishments covered by the survey were 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, were added to the questionnaire. For the purpose of this analysis, only profit-oriented establishments and establishments that have neither been bought, or have themselves bought, other establishments are included.[2] Unfortunately, it is only known whether or not an establishment invested in ICT in 1996 or 1997; the corresponding size of the investment is unknown. 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 1998–2000 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:

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

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 reorganisations that increase the participation of employees. The three dummy variables indicating whether an establishment introduced reorganisations (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 reorganisations are aggregated to one independent 'reorganisations' factor R by a factor analysis.[3] This approach captures the complementary nature of the three reorganisations 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 technical equipment, and competitiveness variables are added (Zwick, 2002). In order to avoid omitted variable bias, a broad variety of establishment and employee characteristics is 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. ICT investments cannot be expected to 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 is to be expected that a high share of qualified employees, training investment, as well as modern technical equipment, increase the productivity of the establishment (Black and Lynch, 2001; Zwick, 2002). Reorganisations 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 sixteen dummy-variables, and four 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 of the appendix to this paper.

The second and third columns of tables A3, A4, and A5 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, reorganisations, 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 organisational measures that either increase the participation of employees, or decentralise 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 reorganisations.[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 reorganisations, are positive and significant. The sample used by 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, whether ICT investments, reorganisations, 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, we cannot exclude the fact that reorganisations and training investments, 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 the 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 fail to provide suitable additional variables to meet the requirements for qualification 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 it depicts 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:

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

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 $\hat{ICT}$, 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). Some coefficients or reorganisations and training are smaller and/or have lower significance levels, while the other control variables are virtually unchanged in model 2 in comparison with model 1. Comparable results are also obtained by Brynjolfsson and Hitt (1996; 1998) and Hempel (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] In addition, it may imply several things. First, it may imply that establishments with a productivity problem are particularly likely to invest in ICT in order to improve their situations.[9] Another interpretation is that the higher coefficients in instrumental variables regressions could be attributed to errors in measurement, which tend to create a downward bias (Griliches and Hausman, 1986). The dummy variable for ICT investments in particular entails a large measurement error, because it values the purchase of a new telephone as equivalent to the purchase of expensive new mainframes or software. In addition, establishments may not all classify the purchase of a new telephone as an investment in ICT. A final reason may be that the returns to ICT investments are heterogeneous between establishments (Card, 1999). One may argue that establishments that increase formal internal training after investment and expect increases in qualification demand are particularly likely to 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 upward bias of the instrumental variables in comparison to the OLS regression. Therefore it remains unclear whether establishments invest in ICT when they are confronted with a productivity gap or in good economic situations.

The results of the instrumental equation explaining the decision of the establishments to invest in ICT or not can be found in table A7 in the appendix. According to theoretical considerations, expected higher demand for training and qualifications and an increased emphasis on formal internal training courses have a positive impact on the probability that an establishment invests in ICT. Other papers also 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 organisational 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). Enterprises need well-educated employees in order to implement new ICT effectively and the complementary new organisational 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), that larger establishments invest both earlier and more heavily in ICT, because they can better spread risks from future development of ICT, economies of scale, and so on.

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)

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***

Source: IAB Establishment Panel, waves 1997–2001, own calculations.
Notes: Significance levels are: **<5 per cent, *<1 per cent.

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 whether or not an establishment invests in ICT in 1996 and 1997, and this variable does not change over time. Therefore ICT investments are also treated as quasi-fixed variables; in other words, it is assumed that firms that invested either in 1996 or 1997 also invested in ICT before or after those years.

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:

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

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. Again the low coefficient of the input capital is striking, although it has a similar size to that in the comparable estimation in Black and Lynch (2001). 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 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 reorganisation factor, and all variables in X in values for 1997:

$$\upsilon = \gamma ICT + \varphi T + \phi R + \delta X + \varepsilon. \tag{4}$$

The estimation results of equation (4) are shown in table A6. 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 models 1 and 3, while reorganisations and training have a higher productivity impact on the fixed effect. This may indicate also that 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 the next step the ICT investments in estimation (4) are instrumented using equation (2) – see the results of model 4 in table A7.

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 1998–2000. This contrasts with 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 product-ivity. 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 summarised in table 1.

Conclusions

This paper shows that investments in ICT substantially increase the average productivity of German establishments. Establishments with ICT investments in 1996 or 1997 had average productivity almost one log unit higher in 1997–2000. 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 structural fixed productivity 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 both establishments without ICT capital and 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 three or four years after the investment. Taking into account the endogeneity of the decision to invest in ICT, and unobserved time-invariant heterogeneity of establishments, increases the calculated productivity impact of ICT.

With a dummy variable indicating whether 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, ie there are establishments that invest at least once in two years in ICT and other establishments that 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 reorganisations that increase the participation of the employees. No far reaching conclusions should therefore 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.

NOTES

1 An in-depth description of this data set can be found in Kölling (2000).
2 The establishments are sorted 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 reorganisation measures to one independent factor with an eigen value of 1.82 (Osterman, 1994). The resulting factor 'reorganisations' explains 61 per cent of the total variance. The factor loadings are shown in table A2.
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 towards 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 six 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 interpret 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.

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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

Source: IAB establishment panel, waves 1997–2001, own calculations.
Notes: Averages are derived from cross-section samples and weighted according to establishment weights.

Table A2. Rotated component matrix of factor analysis

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

Source: IAB establishment panel, wave 1999, own calculations.
Note: The factors have been rotated by promax.

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
Reorganisations	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	

Source: IAB Establishment Panel, waves 1997–1999, own calculations. Notes: Significance Levels: ***<1 per cent, **<5 per cent, all values are for 1998, except indicated otherwise. 16 sector dummies are included, standard errors are heteroscedasticity robust.

Table A4. Productivity effects of ICT investment in 1996/7 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
Reorganisations	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	

Source: IAB Establishment Panel, waves 1997– 2000, own calculations. Notes: Significance Levels: ***<1 per cent, **<5 per cent, all values are for 1999, except indicated otherwise. 16 sector dummies are included, standard errors are heteroscedasticity robust.

Table A5. Productivity effects of ICT investment in 1996/7 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
Reorganisations	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	

Source: IAB Establishment Panel, waves 1997–2001, own calculations.
Notes: Significance Levels: ***<1 per cent, **<5 per cent, all values are for 2000, except indicated otherwise. 16 sector dummies are included, standard errors are heteroscedasticity robust.

Table A6. Productivity effects of ICT investment in 1996/7 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
Reorganisations	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	

Source: IAB Establishment Panel, waves 1997 - 2001, own calculations.
Notes: Significance Levels: ***<1 per cent, **<5 per cent, all values are for 1997, except work council which is only available for 1998. Also 16 sector dummy-variables are added, standard errors are heteroscedasticity robust.

Table A7. Instrumental variable regression, endogeneous variable: ICT investments, 1996/7

Variables	Coefficient	z-values
Reorganisations	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

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

Notes: Significance levels: ***<1 per cent, **<5 per cent. 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 heteroscedasticity robust.

Table A8. Fixed effect production function 1997–2000, endogeneous variable: value added

Variables	Coefficient	z-values
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 = 0.00	

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

Notes: Significance levels: ***<1 per cent, **<5 per cent.