Discussion Paper No. 13-118

Mobile and More Productive? Firm-Level Evidence on the Productivity Effects of Mobile Internet Use at the Early Stage of Diffusion

Irene Bertschek and Thomas Niebel

ZEW

Zentrum für Europäische Wirtschaftsforschung GmbH

Centre for European Economic Research

Discussion Paper No. 13-118

Mobile and More Productive? Firm-Level Evidence on the Productivity Effects of Mobile Internet Use at the Early Stage of Diffusion

Irene Bertschek and Thomas Niebel

Mobile and More Productive? Firm-Level Evidence on the Productivity Effects of Mobile Internet Use at the Early Stage of Diffusion

Irene Bertschek* Thomas Niebel†

December 2013

Abstract

Mobile internet access allows for flexibility with respect to working time and working place. We analyse whether employees' use of mobile internet access improves firms' labour productivity. Our data set comprises 2460 German firms and refers to the year 2010, when mobile internet started its diffusion process to firms on a large scale. The econometric analysis shows that firms' labour productivity significantly increases with the share of employees with mobile internet access. However, an instrumental variable approach reveals that mobile internet use does not cause higher labour productivity.

Keywords: Mobile Internet, Labour Productivity, Firm-Level Data.

JEL Classification Numbers: D22, L20, O33.

*Corresponding author: ZEW Mannheim and University of Mannheim, *email*: bertschek@zew.de, Centre for European Economic Research (ZEW), ICT Research Department, P.O. Box 103443, 68034 Mannheim, Germany.

†ZEW Mannheim, niebel@zew.de. For further information on projects of the authors see www.zew.de/staff_ibe and www.zew.de/staff_tni as well as the ZEW annual report on www.zew.de/en. We thank James Binfield for research assistance.

1 Introduction

Computers and the internet are already well-established working tools. They have changed workplaces significantly, contributed to improving labour productivity and changed the demand for employee skills and qualifications. The technological prerequisites for mobile internet, which is diffusing rapidly through the economy, are advances in high-speed wireless connections and mobile devices such as laptops, tablets and smartphones. McKinsey Global Institute (2013) considers mobile internet as one of twelve disruptive technologies with a very high potential economic impact. OECD (2012, p.22) motivates the transformation from the information economy to the internet economy and points out that "Wireless Internet connections are the key source of recent Internet growth, increasing rapidly since 2001 and overtaking fixed broadband subscriptions in 2009." In Germany, the number of regular high speed mobile Internet users increased from 13.6 million in 2008 to 33.6 million in 2012. During the same period, mobile data volume increased even more rapidly, from 11.47 to 155.64 Petabytes (see Figure A.1).

The role of information and communication technologies (ICT) in determining labour productivity is well studied.[1] According to the survey by Cardona et al. (2013), the estimated production elasticity of ICT ranges on average between 0.05 and 0.06 and has increased over the period of observation.

Some studies analyse the contribution of the internet to productivity. At the macro level, Czernich et al. (2011) and Koutroumpis (2009) show that broadband internet has a positive and statistically significant impact on both productivity and growth in OECD countries.[2] At the micro level, the evidence is mixed. Based on a cross section of firms from New Zealand collected in 2006, Grimes et al. (2012) find that firms using broadband internet have a 7 to 10 percent higher labour productivity. By contrast, for the early phase of broadband diffusion in Germany, 2000 to 2002, Bertschek et al. (2013) find positive and significant effects of broadband on firms' innovation activity but not on their labour productivity. A positive relationship between innovation and employees' broadband access is also found by Polder et al. (2010) using Dutch firm-level data. As Colombo et al. (2013) point out and demonstrate for the case of small Italian firms, it is not necessarily the connection to the internet that matters but what firms do with the internet that might make them more productive.

To the best of our knowledge, there is no empirical work on the firm-level productivity effects of mobile internet so far. Why would we expect positive – or negative – productivity effects from mobile internet? One important result from the empirical analysis of ICT is that via reducing communication costs the decentralisation of organisation, such as the reduction of hierarchy levels and the implementation of autonomous working teams (see for example Bresnahan et al. (2002)), is supported. Mobile internet access can further improve information and communication and reduce involved costs, and employees are now able to access their employers' data anywhere, at any time. This supports decentralisation in terms of organisation and time. Moreover, it allows employees

[1] See for instance the literature reviews by Draca et al. (2007), Van Reenen et al. (2010), Bertschek (2012), and Cardona et al. (2013).

[2] See also the survey by Holt and Jamison (2009).

to better balance working time and private life. By contrast, coordination costs might increase if physical meetings become more difficult to arrange since everybody wants to be flexible. Moreover, monitoring might become more difficult if employees work geographically dispersed.

In our analysis, we take a firm-level perspective. Based on a survey of 2460 firms from the German manufacturing and services industry, we estimate classical production functions. We consider three measures of IT use at the workplace: the use of computers, the use of the internet and the use of mobile internet. While the positive correlations and contributions of computer use are well proven in the literature, the empirical evidence on internet access is so far mixed, and there is no empirical evidence on the use of mobile internet yet. Our econometric analysis shows that a one percentage point higher share of employees with mobile internet access is associated with a 0.3 percent higher labour productivity. This initial result, however, might be driven by the fact that more productive firms have more resources to invest in new technologies. When controlling for this potential source of endogeneity bias, we can no longer find any significant effect of mobile internet use on firm productivity. Thus, based on our sample of 2460 German firms for the year 2010, we cannot claim that mobile internet use at its early stage of diffusion has a causal impact on firms' labour productivity.

2 Data and Measures

Our analysis is based on the ZEW ICT survey which is a survey of manufacturing and business-related services firms that are located in Germany and have at least five employees.[3] In each of the five waves, collected in 2000, 2002, 2004, 2007 and 2010, about 4400 firms were interviewed by telephone about their characteristics and particularly about their ICT usage. The survey is designed as a panel but not all firms responded in all waves. For our analysis, we use the wave 2010. This wave is the first one containing information about mobile internet use. Taking account of item non-response and implausible values, we end up with a sample of 2460 firms.[4]

The central variables of our analysis are labour productivity as the performance measure and the use of computers, as well as access to the internet and to mobile internet, as measures of IT use at the workplace. Labour productivity is measured as sales per employee. The firms were asked about the percentage of employees working with computers most of the time and the percentage of employees having access to the internet. To capture mobile internet use, firms were asked about the percentage of employees with mobile internet access. More precisely, the three corresponding questions asked in the survey are:

[3]The data are available at the ZEW Research Data Centre http://kooperationen.zew.de/en/zew-fdz.

[4]We thereby dropped firms with sales per employee less than 10,000 Euro (3 observations) and more than 1 million Euro (74), with total investment larger than turnover (11), with less than 5 employees (177), with more than 5000 employees (35) and IT investment larger than total investment (5 observations). Since investment is taken in logs, zero investment is replaced by the minimum of investment per employee observed in the corresponding industry - firm size class. Missing investment information is replaced by the 50th percentile of the corresponding industry - firm size class.

- What is the percentage of employees working predominately with computers?
- What is the percentage of employees that have access to the internet?
- What is the percentage of employees that your company has equipped with mobile internet access for instance via smartphones such as Blackberry or iPhone or via UMTS-cards for laptops?

Table 2.1: Summary Statistics: Estimation Sample

	N	Mean	Median	SD	Min	Max
Labour Productivity	2460	0.16	0.11	0.15	0.012	1
Sales	2460	28.5	3.80	103.6	0.060	2000
Employees	2460	138.3	30	376.7	5	5000
Investment/Employee	2460	0.0081	0.0037	0.018	0.0000015	0.34
% Highly Qualified Employees	2460	0.20	0.10	0.25	0	1
Respond. Uses Smartphone	2460	0.64	1	0.48	0	1
% of Emp. Using Mob. Internet	2460	0.14	0.050	0.20	0	1
% of Emp. Using Internet	2460	0.57	0.50	0.37	0	1
% of Emp. Predom. Using PC	2460	0.47	0.38	0.34	0	1
Export Dummy	2460	0.51	1	0.50	0	1
East Germany Dummy	2460	0.31	0	0.46	0	1
High % of IT Staff Dummy	2460	0.49	0	0.50	0	1
% of Employees IT Staff	2460	0.097	0.017	0.21	0	1
% of Employees < Age 30	2460	0.23	0.20	0.18	0	1

Source: ZEW ICT survey 2010.

Table 2.1 shows some descriptive statistics of the sample. The firms have on average 138 employees, and 28.5 million euro sales. 51 percent of the firms are engaged in export activities and the share of highly qualified employees is 20 percent. On average, 47 percent of the employees work predominantly with computers, 57 percent have internet access and 14 percent have mobile internet access. The figures for mobile internet use demonstrate that in 2010, mobile internet in firms was still at the beginning of the diffusion process (see also Figure A.2 on the UMTS roll-out in Germany and Figure A.3 in the Appendix). Differentiating between firms with and without mobile internet use reveals that firms equipping their employees with mobile internet (68 percent of the firms in the sample) have a higher labour productivity, are considerably larger and, as a consequence, have higher sales and invest more. Furthermore, they are more IT intensive and have a higher share of highly qualified employees (see Table A.1 in the Appendix).

Our data set also contains information on the interviewee's private attitude towards the use of smartphones. More precisely, the question asked to the interviewee is: Can you imagine using a smartphone in your leisure time or do you already use a smartphone in your leisure time? Of all respondents, 64 percent reported that they could imagine using a smartphone or actually use a smartphone in their leisure time. This value largely differs across industries. The highest fraction of

positive responses, 80 percent, is observed in ICT services. This is also the industry with the largest share of employees with mobile internet access (42 percent, see Figure A.4 in the Appendix).

3 Estimation Strategy

A firm's production process is modelled by a Cobb-Douglas production function with various input factors:

$$Y_i = f(A_i; L_i; K_i; PC_i; WWW_i; MW_i; X_i) \tag{1}$$

Output Y_i is a function of labour L_i, capital K_i and total factor productivity A_i. The production function is augmented by the share of workers predominately using computers (PC_i), having internet access (WWW_i), and having mobile internet access (MW_i). A vector of various control variables X_i captures a firm's share of highly qualified employees, its export activity, its share of young employees, its regional location (East or West Germany) and its sector affiliation.

Our main interest is in the relationship between labour productivity defined as sales per employee (Y_i/L_i) and mobile internet MW_i. Taking logs of the production function results in:

$$\begin{aligned} \ln\left(\frac{Y_i}{L_i}\right) = \ln A_i + (\alpha_L - 1)\ln L_i + \alpha_K \ln K_i + \beta_{MW} MW_i + \\ \beta_{WWW} WWW_i + \beta_{PC} PC_i + \boldsymbol{\gamma}_{\mathbf{X}}\mathbf{X_i} + \mu_i \end{aligned} \tag{2}$$

where α_L, α_K represent the production elasticities of labour and capital, respectively, and $\beta_{(\bullet)}$ are the production elasticities with respect to IT use. Productivity and IT use might be simultaneously determined since firms choose their inputs depending on the output they plan to produce and vice versa. We argue that one can distinguish between the different types of IT use with respect to their potential endogeneity. Computers (mainframes) had started to diffuse in the 1960s, particularly in the financial sector. Personal computers diffused to firms mainly in the 80s and 90s, whereas the internet diffused to firms in the 90s and early 2000s. As diffusion rates show (from 33.8 percent in 2000 to 55.6 percent in 2007 and 59.6 percent in 2010 - see Figure A.6), the fraction of workplaces equipped with computers and internet access has been quite stable during the last few years or has only increased at a very slow rate. A firm's production process determines the appropriate degree of IT use within the firm. A certain percentage of employees might be equipped with computers whereas others might have jobs or tasks that are not related to the use of IT. Thus, it seems plausible to assume that in the year 2010, the diffusion of computers and internet access had reached a point of saturation and further diffusion will only take place at a slow rate. Therefore, we conclude that computer use and internet access are quasi-fixed input factors.

Mobile internet, by contrast, has just begun its diffusion process. Only 14 percent of employees in our sample are equipped with mobile internet access. We assume that the use of mobile internet is restricted to employees that have used computers and the internet before, and that the share of employees using computers or the internet is not affected by mobile internet access. What mobile internet adds to the use of computers and the internet is that it enables users to become more independent with respect to their working place and working time. We would like to analyse whether this potential for worker mobility makes firms more productive.

The empirical analysis consists of three steps. In the first step, we estimate various model specifications by simple OLS. In the second step, in order to take account of potential simultaneity between labour productivity and mobile internet use, we apply an instrumental variable approach and use the respondent's private use of smartphones and the firms' IT staff as instruments. The first instrument is the respondent's private smartphone use. The second instrument, high share of IT staff, is a dummy variable that takes the value one if the IT staff in the firm as a share of employees is larger than the industry median.

The interviewee's private smartphone use seems to be a valid instrument. Electronic devices such as smartphones or tablets as well as applications such as social media started their diffusion process among individuals before diffusing to firms. Thus, the private use of a smartphone might be a good predictor for a firm using mobile internet. However, the entire firm's labour productivity will not depend on the private smartphone use of one single person working in this firm. A high share of IT staff in a firm also appears to be a valid instrument. Having in-house IT staff in a firm can be a precondition for investing in new technologies such as mobile internet and mobile devices since the IT staff can take care of their maintenance. By contrast, whether or not a firm has an above median share of IT staff does not directly explain a firm's labour productivity. In the estimations, we control for factors such as firm size and the share of young employees. Larger firms and those with a higher share of employees younger than 30 years old might have a higher probability of using mobile devices and applications. At the same time, these variables might be positively or negatively related to labour productivity. All estimations include industry dummies (see Table A.2 for the distribution of firms across industries).

4 Results

Table 4.1 presents results from simple OLS estimations. All three IT inputs[5] — share of employees working with computers, having access to the internet and being equipped with mobile internet access — have positive and highly significant estimated coefficients, thus revealing a positive correlation with labour productivity. The estimated coefficients remain highly significant even when all three IT variables are included in the estimation (specification 7). In the next step, we apply an instrumental

[5]The raw coefficients of the ICT inputs without additional firm characteristics are shown in Table A.8 in the Appendix.

variable estimation.[6] We instrument the firms' shares of mobile internet users with a dummy variable indicating whether the respondent uses a smartphone for private purposes and a dummy variable indicating whether a firm's IT staff as a share of employment is above the industry median. First and second stage results are shown in Tables 4.2 and 4.3. The F-test statistic on the instrumental variables has large values between 37 and 51 (see Table 4.3). The Hansen J-test rejects the hypothesis of overidentification. These results suggest that the respondent's private use of a smartphone and a firm having a high share of IT staff are relevant for explaining a firm's share of employees equipped with mobile internet access. Moreover, the share of employees with mobile internet access positively correlates with investment, the share of highly qualified employees and the share of employees younger than 30. The estimated coefficient of mobile internet use becomes insignificant in all specifications of the second stage estimation as soon as the share of internet users or the share of computer users are considered (specifications (2) to (4)), implying that although there is a positive correlation between labour productivity and mobile internet use, there is no causal effect of mobile internet use on labour productivity. According to previous studies, labour productivity increases with export activity and decreases with the share of younger employees. The results remain qualitatively the same if we use only one of the two instrumental variables in the IV estimations (see Tables A.4 and A.5 as well as A.6 and A.7 in the Appendix).

[6]The analysis was carried out in Stata using the IVREG2 command provided by Baum et al. (2002).

Table 4.1: Dependent Variable: Log Labour Productivity - OLS Regression

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
% of Emp. Using Mob. Internet	0.356***			0.245***		0.283***	0.243***
	(0.086)			(0.087)		(0.084)	(0.086)
% of Emp. Using Internet		0.376***		0.345***	0.194***		0.164***
		(0.052)		(0.053)	(0.057)		(0.058)
% of Emp. Predom. Using PC			0.571***		0.460***	0.550***	0.459***
			(0.066)		(0.074)	(0.066)	(0.074)
Employees (in logs)	-0.016	-0.008	-0.016	-0.005	-0.010	-0.012	-0.007
	(0.015)	(0.015)	(0.015)	(0.015)	(0.015)	(0.015)	(0.015)
Investment (in logs)	0.100***	0.099***	0.102***	0.097***	0.100***	0.100***	0.098***
	(0.010)	(0.010)	(0.010)	(0.010)	(0.010)	(0.010)	(0.010)
% Highly Qualified Employees	0.350***	0.240***	0.153*	0.197**	0.107	0.095	0.064
	(0.084)	(0.085)	(0.090)	(0.084)	(0.089)	(0.090)	(0.089)
Export Dummy	0.170***	0.154***	0.145***	0.158***	0.143***	0.149***	0.147***
	(0.032)	(0.031)	(0.032)	(0.031)	(0.031)	(0.031)	(0.031)
East Germany Dummy	-0.215***	-0.197***	-0.190***	-0.190***	-0.181***	-0.180***	-0.174***
	(0.030)	(0.030)	(0.029)	(0.030)	(0.030)	(0.030)	(0.030)
% of Employees < Age 30	-0.218***	-0.208**	-0.232***	-0.226***	-0.233***	-0.253***	-0.251***
	(0.084)	(0.082)	(0.081)	(0.083)	(0.081)	(0.082)	(0.082)
Constant	-2.046***	-2.166***	-2.124***	-2.182***	-2.184***	-2.154***	-2.200***
	(0.085)	(0.084)	(0.082)	(0.085)	(0.083)	(0.083)	(0.083)
Industry Dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2460	2460	2460	2460	2460	2460	2460
Adjusted R^2	0.279	0.291	0.301	0.293	0.305	0.305	0.307

Robust standard errors in parentheses, * p<0.10, ** p<0.05, *** p<0.01.
Source: ZEW ICT survey 2010.

Table 4.2: Dependent Variable: Percentage of Employees Using Mobile Internet - 2SLS Regression - First Stage of Table 4.3

	(1)	(2)	(3)	(4)
High % of IT Staff Dummy	0.030***	0.022***	0.026***	0.022***
	(0.007)	(0.007)	(0.007)	(0.007)
Respond. Uses Smartphone	0.061***	0.053***	0.058***	0.054***
	(0.007)	(0.007)	(0.007)	(0.007)
% of Emp. Using Internet		0.109***		0.113***
		(0.012)		(0.016)
% of Emp. Predom. Using PC			0.053***	-0.010
			(0.019)	(0.022)
Employees (in logs)	-0.019***	-0.014***	-0.018***	-0.014***
	(0.004)	(0.004)	(0.004)	(0.004)
Investment (in logs)	0.007***	0.006**	0.007***	0.006**
	(0.002)	(0.002)	(0.002)	(0.002)
% Highly Qualified Employees	0.224***	0.170***	0.199***	0.173***
	(0.029)	(0.030)	(0.032)	(0.031)
Export Dummy	-0.018**	-0.020**	-0.019**	-0.020**
	(0.009)	(0.009)	(0.009)	(0.009)
East Germany Dummy	-0.035***	-0.027***	-0.032***	-0.027***
	(0.007)	(0.007)	(0.008)	(0.007)
% of Employees < Age 30	0.077***	0.072***	0.073***	0.072***
	(0.022)	(0.021)	(0.022)	(0.021)
Constant	0.075***	0.036*	0.067***	0.036*
	(0.020)	(0.020)	(0.020)	(0.020)
Industry Dummies	Yes	Yes	Yes	Yes
Adjusted R^2	0.294	0.316	0.298	0.316
Observations	2460	2460	2460	2460

Robust standard errors in parentheses, * p<0.10, ** p<0.05, *** p<0.01.
Source: ZEW ICT survey 2010.

Table 4.3: Dependent Variable: Log Labour Productivity - 2SLS Regression - Second Stage

	(1)	(2)	(3)	(4)
% of Emp. Using Mob. Internet	0.976**	0.536	0.321	0.191
	(0.418)	(0.502)	(0.440)	(0.491)
% of Emp. Using Internet		0.308***		0.170*
		(0.085)		(0.088)
% of Emp. Predom. Using PC			0.547***	0.459***
			(0.073)	(0.073)
Employees (in logs)	-0.005	-0.001	-0.011	-0.008
	(0.017)	(0.016)	(0.017)	(0.016)
Investment (in logs)	0.094***	0.095***	0.099***	0.099***
	(0.011)	(0.010)	(0.010)	(0.010)
% Highly Qualified Employees	0.200	0.145	0.087	0.073
	(0.131)	(0.121)	(0.126)	(0.123)
Export Dummy	0.177***	0.163***	0.149***	0.146***
	(0.032)	(0.032)	(0.032)	(0.032)
East Germany Dummy	-0.190***	-0.181***	-0.178***	-0.175***
	(0.035)	(0.033)	(0.033)	(0.033)
% of Employees < Age 30	-0.267***	-0.248***	-0.256***	-0.247***
	(0.093)	(0.092)	(0.090)	(0.090)
Constant	-2.122***	-2.202***	-2.158***	-2.197***
	(0.099)	(0.091)	(0.095)	(0.089)
Industry Dummies	Yes	Yes	Yes	Yes
Adjusted R^2	0.260	0.289	0.305	0.307
Kleibergen-Paap LM P-value	0.000	0.000	0.000	0.000
Angrist-Pischke F-test	50.801	37.191	42.949	36.894
Hansen J Overid P-value	0.894	0.796	0.595	0.517
Observations	2460	2460	2460	2460

Robust standard errors in parentheses, * p<0.10, ** p<0.05, *** p<0.01.
Source: ZEW ICT survey 2010.

5 Conclusion

According to our empirical results mobile internet use is positively and significantly related with firms' labour productivity. However, the instrumental variable estimations reveal that it does not *cause* a higher labour productivity. There are several ways of interpreting our results and various avenues for future research: First, the results might be driven by the early stage of diffusion analysed. We know from previous studies that investment in ICT takes some time to be deployed. Since the share of mobile internet users today is much higher than it was in 2010 and firms now have more experience in using it, results with more recent data might be in favour of a causal effect of mobile internet on labour productivity. Second, we also know from previous studies that investment in ICT should be accompanied by complementary investment in organisation and human capital in order to be fully utilised (see for example Bresnahan et al. (2002) or Bloom et al. (2012)). Thus, further analysis should take account of workplace models that are flexible with respect to working time and working place.

Although our results are not very exciting, they can spark interesting discussions and motivate future research. Since 2010 the diffusion of mobile internet has rapidly progressed, facilitating flexible and decentralised working methods such as home office, co-working, working while traveling, etc. To learn more about how mobile internet can improve labour productivity, it is important to know which resources employees have access to when working remotely. Do they have access only to their e-mail accounts or can they access data bases and software? Are employees able and allowed to regularly work at home or must they work in their office? Improving work-life balance and creating the possibility to combine work and family are important assets for firms aiming to acquire and retain highly qualified employees, in particular in times of demographic change. At the same time, there are controversial discussions about the health risks of worker flexibility and of being always and everywhere online and the problems associated with monitoring mobile workers. For evaluating the potentials of mobile internet, we need new concepts for measuring mobility not only with respect to the technical dimension but also with respect to organisation and working time. Such a multi-dimensional concept renders a causal analysis non-trivial, thus posing several challenges for future research.

References

Baum, C. F., Schaffer, M. E. and Stillman, S. (2002), 'IVREG2: Stata Module for Extended Instrumental Variables/2SLS and GMM Estimation', Statistical Software Components, Boston College Department of Economics. Available at http://ideas.repec.org/c/boc/bocode/s425401.html.

Bertschek, I. (2012), ICT, Internet and Worker Productivity, *in* S. N. Durlauf and L. E. Blume, eds, 'The New Palgrave Dictionary of Economics', Palgrave Macmillan. Online Edition.

Bertschek, I., Cerquera, D. and Klein, G. J. (2013), 'More Bits-More Bucks? Measuring the Impact of Broadband Internet on Firm Performance', *Information Economics and Policy* **25**(3), 190–203.

Bloom, N., Sadun, R. and Van Reenen, J. (2012), 'Americans Do IT Better: US Multinationals and the Productivity Miracle', *American Economic Review* **102**(1), 167–201.

Bresnahan, T. F., Brynjolfsson, E. and Hitt, L. M. (2002), 'Information Technology, Workplace Organization, and the Demand for Skilled Labor: Firm-Level Evidence', *The Quarterly Journal of Economics* **117**(1), 339–376.

Bundesnetzagentur (2013), 'Tätigkeitsbericht Telekommunikation 2012/2013'. Available at http://www.bundesnetzagentur.de/SharedDocs/Downloads/DE/Allgemeines/Bundesnetzagentur/Publikationen/Berichte/2013/131216_TaetigkeitsberichtTelekommunikation2012-2013.pdf?__blob=publicationFile&v=8.

Cardona, M., Kretschmer, T. and Strobel, T. (2013), 'ICT and Productivity: Conclusions from the Empirical Literature', *Information Economics and Policy* **25**(3), 109–125.

Colombo, M. G., Croce, A. and Grilli, L. (2013), 'ICT Services and Small Businesses' Productivity Gains: An Analysis of the Adoption of Broadband Internet Technology', *Information Economics and Policy* **25**(3), 171–189.

Czernich, N., Falck, O., Kretschmer, T. and Woessmann, L. (2011), 'Broadband Infrastructure and Economic Growth', *The Economic Journal* **121**(552), 505–532.

Draca, M., Sadun, R. and Van Reenen, J. (2007), Productivity and ICT: A Review of the Evidence, *in* R. Mansell, ed., 'The Oxford Handbook of Information and Communication Technologies', Oxford University Press, pp. 100–147.

Grimes, A., Ren, C. and Stevens, P. (2012), 'The Need for Speed: Impacts of Internet Connectivity on Firm Productivity', *Journal of Productivity Analysis* **37**(2), 187–201.

Holt, L. and Jamison, M. (2009), 'Broadband and Contributions to Economic Growth: Lessons from the US Experience', *Telecommunications Policy* **33**(10), 575–581.

Koutroumpis, P. (2009), 'The Economic Impact of Broadband on Growth: A Simultaneous Approach', *Telecommunications Policy* **33**(9), 471–485.

McKinsey Global Institute (2013), Disruptive Technologies: Advances that will Transform Life, Business, and the Global Economy, Technical report. Available at http://www.mckinsey.com/insights/business_technology/disruptive_technologies.

Neumann, C. (2012), *Fundamentale Mobilfunkinnovationen in Deutschland - Eine wettbewerbsökonomische Analyse*, Springer Gabler.

OECD (2012), *OECD Internet Economy Outlook 2012*, OECD Publishing.

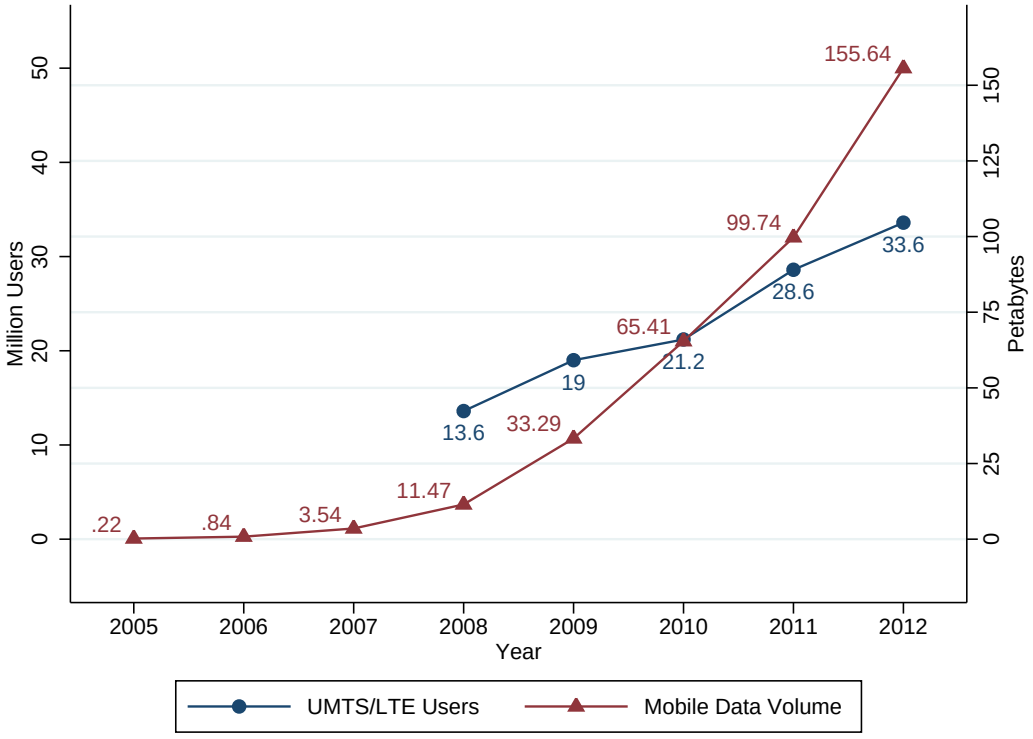
Polder, M., Leeuwen, G. v., Mohnen, P. and Raymond, W. (2010), Product, Process and Organizational Innovation: Drivers, Complementarity and Productivity Effects, UNU-MERIT Working Paper Series 2010-035, United Nations University, Maastricht Economic and Social Research and Training Centre on Innovation and Technology.

Van Reenen, J., Bloom, N., Draca, M., Kretschmer, T. and Sadun, R. (2010), *The Economic Impact of ICT*, Centre for Economic Performance, London School of Economics. Available at http://cep.lse.ac.uk/textonly/_new/research/productivity/Management/PDF/breugel_cStudyTheImpactofICTLSE.pdf.

A Appendix

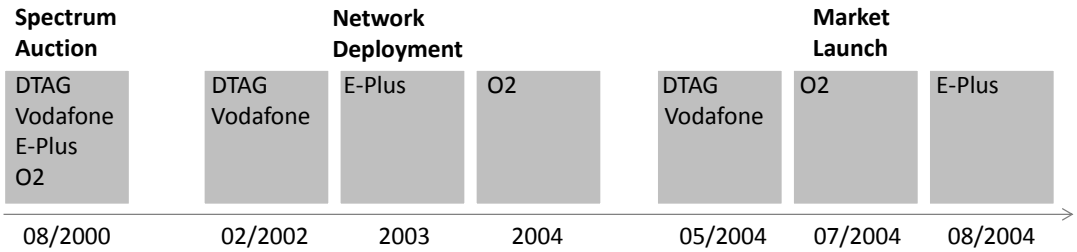
A.1 Additional Graphs

Figure A.1: Mobile Data Volumes and UMTS/LTE Users in Germany 2005-2012



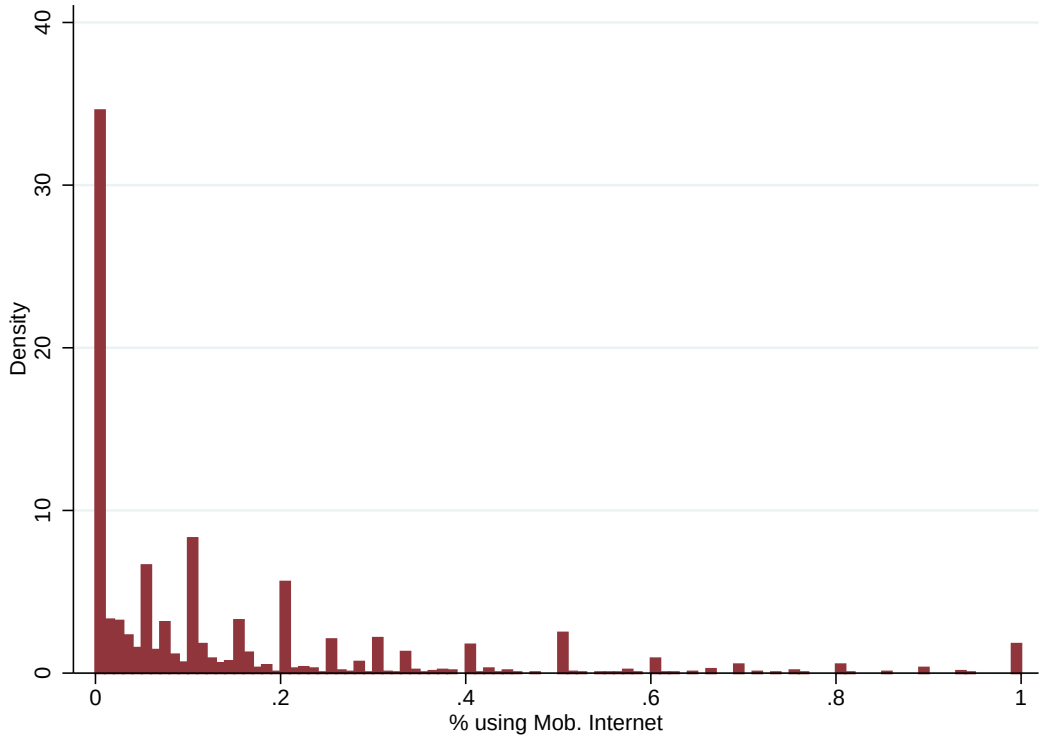
Source: Bundesnetzagentur (2013), pages 44 and 45.

Figure A.2: UMTS Roll-Out in Germany



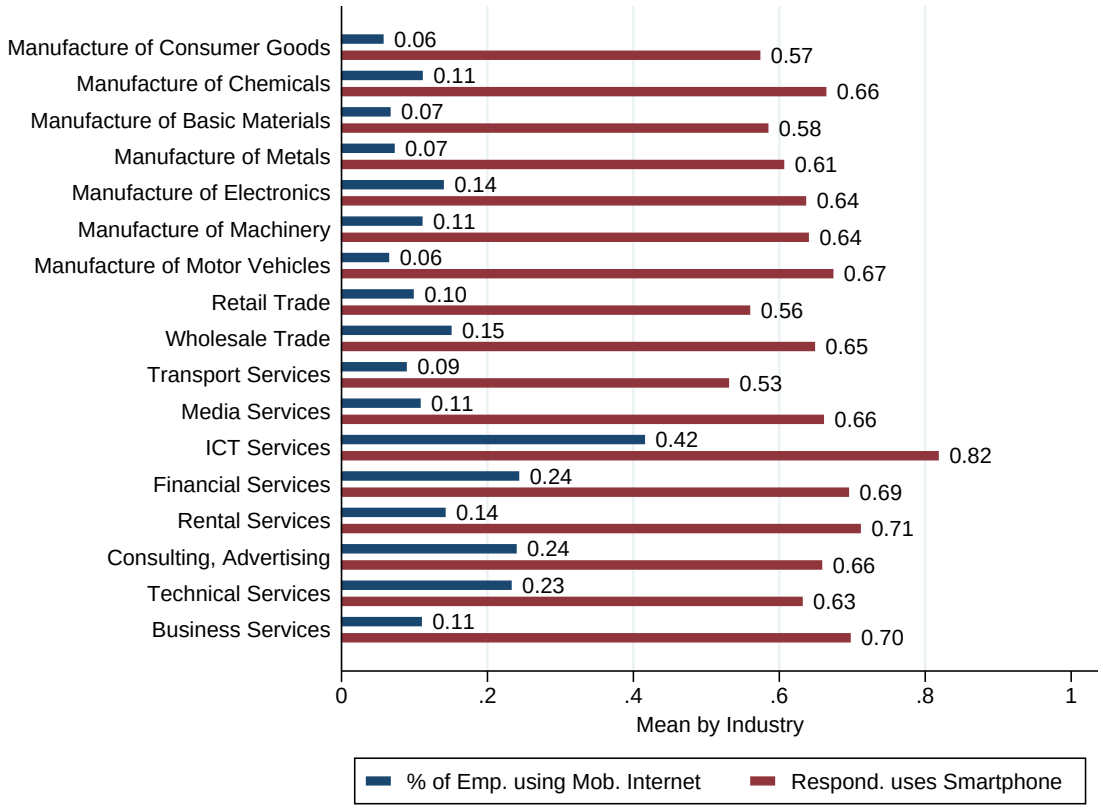
Source: Neumann (2012), page 10.

Figure A.3: Share of Employees Using Mobile Internet: Estimation Sample



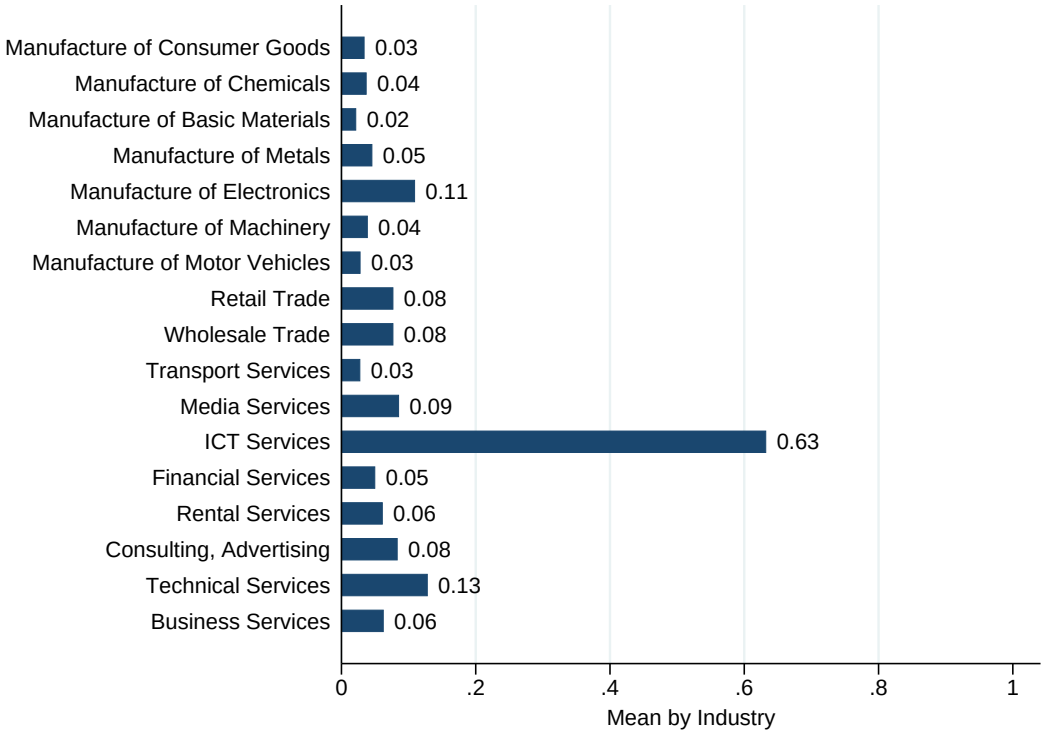
Source: ZEW ICT survey 2010.

Figure A.4: Industry Means of Mobile Internet Use: Estimation Sample



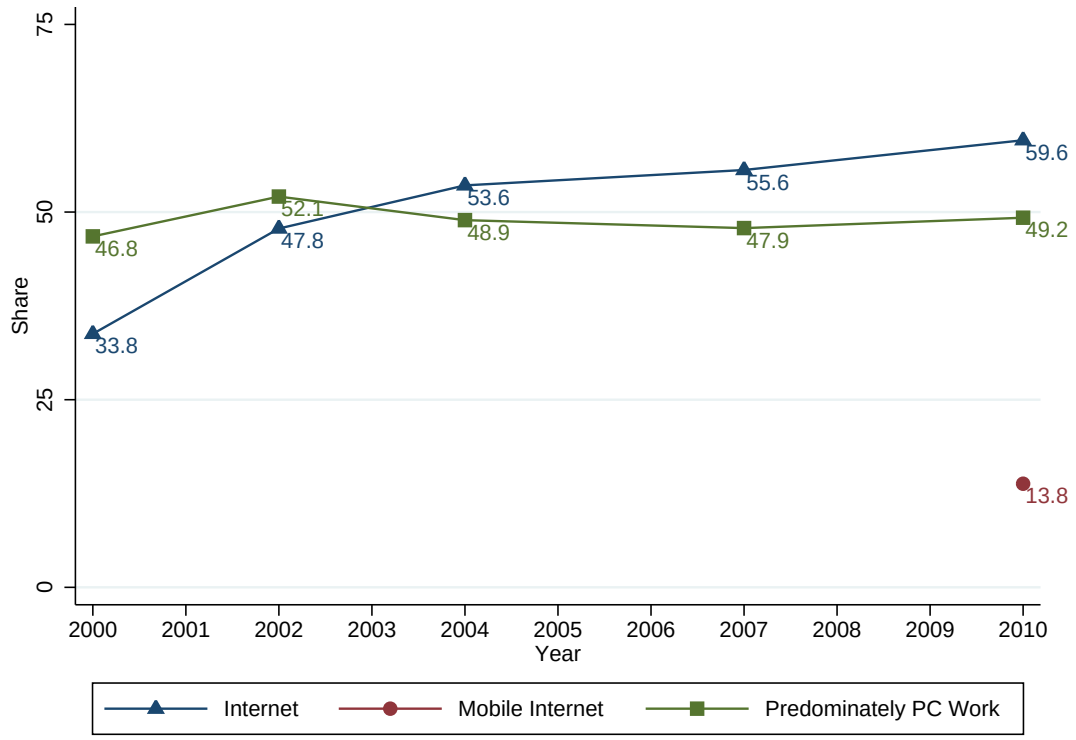
Source: ZEW ICT survey 2010.

Figure A.5: Industry Means of IT Staff: Estimation Sample



Source: ZEW ICT survey 2010.

Figure A.6: Share of Employees Using (Mobile) Internet/Predominately Work with Computers: Full Sample



Source: ZEW ICT survey 2000, 2002, 2004, 2007 and 2010.

A.2 Additional Tables

Table A.1: Summary Statistics by Mobile Internet Use: Estimation Sample

	Without Mobile		**With Mobile**		**Total**	
	N	Mean	N	Mean	N	Mean
Labour Productivity	788	0.13	1672	0.17	2460	0.16
Sales	788	4.62	1672	39.76	2460	28.50
Employees	788	33.99	1672	187.53	2460	138.34
Investment/Employee	788	0.01	1672	0.01	2460	0.01
% Highly Qualified Employees	788	0.12	1672	0.24	2460	0.20
Respond. Uses Smartphone	788	0.41	1672	0.74	2460	0.64
% of Emp. Using Mob. Internet	788	0.00	1672	0.20	2460	0.14
% of Emp. Using Internet	788	0.44	1672	0.64	2460	0.57
% of Emp. Predom. Using PC	788	0.35	1672	0.53	2460	0.47
Export Dummy	788	0.38	1672	0.57	2460	0.51
East Germany Dummy	788	0.39	1672	0.28	2460	0.31
High % of IT Staff Dummy	788	0.36	1672	0.56	2460	0.49
% of Employees IT Staff	788	0.06	1672	0.12	2460	0.10
% of Employees $<$ Age 30	788	0.21	1672	0.24	2460	0.23

Source: ZEW ICT survey 2010.

Table A.2: Distribution of Industries: Estimation Sample

	N	Percentage
Manufacture of Consumer Goods	335	13.62
Manufacture of Chemicals	110	4.47
Manufacture of Basic Materials	190	7.72
Manufacture of Metals	170	6.91
Manufacture of Electronics	195	7.93
Manufacture of Machinery	197	8.01
Manufacture of Motor Vehicles	101	4.11
Retail Trade	152	6.18
Wholesale Trade	108	4.39
Transport Services	132	5.37
Media Services	106	4.31
ICT Services	170	6.91
Financial Services	95	3.86
Rental Services	83	3.37
Consulting, Advertising	76	3.09
Technical Services	141	5.73
Business Services	99	4.02
Total	2460	100.00

Source: ZEW ICT 2010.

Table A.3: Share of Employees Using Mobile Internet by Personal Smartphone Use of Respondent: Estimation Sample

	No Personal Smartphone			**Personal Smartphone**		
	Mean	Median	SD	Mean	Median	SD
% Mob. Internet	0.079	0	0.16	0.17	0.10	0.22
Observations	896			1564		

Source: ZEW ICT 2010.

Table A.4: Dependent Variable: Percentage of Employees Using Mobile Internet - 2SLS Regression - First Stage of Table A.5

	(1)	(2)	(3)	(4)
Respond. Uses Smartphone	0.063***	0.054***	0.059***	0.055***
	(0.007)	(0.007)	(0.007)	(0.007)
% of Emp. Using Internet		0.114***		0.116***
		(0.012)		(0.016)
% of Emp. Predom. Using PC			0.061***	-0.005
			(0.019)	(0.022)
Employees (in logs)	-0.019***	-0.014***	-0.018***	-0.014***
	(0.004)	(0.004)	(0.004)	(0.004)
Investment (in logs)	0.007***	0.006***	0.007***	0.006***
	(0.002)	(0.002)	(0.002)	(0.002)
% Highly Qualified Employees	0.234***	0.176***	0.205***	0.177***
	(0.029)	(0.030)	(0.032)	(0.031)
Export Dummy	-0.016*	-0.019**	-0.018**	-0.019**
	(0.009)	(0.009)	(0.009)	(0.009)
East Germany Dummy	-0.037***	-0.027***	-0.033***	-0.027***
	(0.007)	(0.007)	(0.008)	(0.007)
% of Employees < Age 30	0.077***	0.072***	0.073***	0.072***
	(0.022)	(0.021)	(0.022)	(0.021)
Constant	0.089***	0.044**	0.078***	0.044**
	(0.020)	(0.019)	(0.020)	(0.019)
Industry Dummies	Yes	Yes	Yes	Yes
Adjusted R^2	0.290	0.313	0.294	0.313
Observations	2460	2460	2460	2460

Robust standard errors in parentheses, * p<0.10, ** p<0.05, *** p<0.01.
Source: ZEW ICT survey 2010.

Table A.5: Dependent Variable: Log Labour Productivity - 2SLS Regression - Second Stage

	(1)	(2)	(3)	(4)
% of Emp. Using Mob. Internet	0.949**	0.588	0.426	0.319
	(0.460)	(0.534)	(0.473)	(0.520)
% of Emp. Using Internet		0.302***		0.154*
		(0.088)		(0.091)
% of Emp. Predom. Using PC			0.539***	0.458***
			(0.074)	(0.073)
Employees (in logs)	-0.005	-0.001	-0.009	-0.006
	(0.017)	(0.016)	(0.017)	(0.016)
Investment (in logs)	0.095***	0.095***	0.098***	0.098***
	(0.011)	(0.011)	(0.011)	(0.010)
% Highly Qualified Employees	0.206	0.136	0.066	0.051
	(0.137)	(0.124)	(0.131)	(0.126)
Export Dummy	0.177***	0.163***	0.151***	0.148***
	(0.032)	(0.032)	(0.032)	(0.032)
East Germany Dummy	-0.191***	-0.180***	-0.175***	-0.171***
	(0.036)	(0.034)	(0.034)	(0.033)
% of Employees < Age 30	-0.265***	-0.251***	-0.264***	-0.257***
	(0.094)	(0.093)	(0.091)	(0.091)
Constant	-2.118***	-2.205***	-2.169***	-2.206***
	(0.101)	(0.091)	(0.097)	(0.090)
Industry Dummies	Yes	Yes	Yes	Yes
Adjusted R^2	0.262	0.288	0.304	0.307
Kleibergen-Paap LM P-value	0.000	0.000	0.000	0.000
Angrist-Pischke F-test	79.973	62.043	69.743	61.688
Observations	2460	2460	2460	2460

Robust standard errors in parentheses, * p<0.10, ** p<0.05, *** p<0.01.
Source: ZEW ICT survey 2010.

Table A.6: Dependent Variable: Percentage of Employees Using Mobile Internet - 2SLS Regression - First Stage of Table A.7

	(1)	(2)	(3)	(4)
High % of IT Staff Dummy	0.034***	0.024***	0.029***	0.024***
	(0.007)	(0.007)	(0.007)	(0.007)
% of Emp. Using Internet		0.120***		0.121***
		(0.013)		(0.016)
% of Emp. Predom. Using PC			0.066***	-0.002
			(0.019)	(0.023)
Employees (in logs)	-0.017***	-0.013***	-0.017***	-0.013***
	(0.004)	(0.004)	(0.004)	(0.004)
Investment (in logs)	0.008***	0.007***	0.008***	0.007***
	(0.002)	(0.002)	(0.002)	(0.002)
% Highly Qualified Employees	0.230***	0.171***	0.199***	0.171***
	(0.029)	(0.030)	(0.032)	(0.032)
Export Dummy	-0.013	-0.016*	-0.015*	-0.016*
	(0.009)	(0.009)	(0.009)	(0.009)
East Germany Dummy	-0.039***	-0.029***	-0.035***	-0.029***
	(0.007)	(0.007)	(0.008)	(0.007)
% of Employees < Age 30	0.080***	0.074***	0.075***	0.074***
	(0.022)	(0.021)	(0.022)	(0.021)
Constant	0.104***	0.057***	0.093***	0.057***
	(0.021)	(0.020)	(0.020)	(0.020)
Industry Dummies	Yes	Yes	Yes	Yes
Adjusted R^2	0.275	0.302	0.281	0.301
Observations	2460	2460	2460	2460

Robust standard errors in parentheses, * p<0.10, ** p<0.05, *** p<0.01.
Source: ZEW ICT survey 2010.

Table A.7: Dependent Variable: Log Labour Productivity - 2SLS Regression - Second Stage

	(1)	(2)	(3)	(4)
% of Emp. Using Mob. Internet	1.068	0.280	-0.106	-0.443
	(0.821)	(1.123)	(0.940)	(1.138)
% of Emp. Using Internet		0.340**		0.249
		(0.151)		(0.153)
% of Emp. Predom. Using PC			0.579***	0.461***
			(0.099)	(0.075)
Employees (in logs)	-0.003	-0.005	-0.018	-0.016
	(0.021)	(0.021)	(0.022)	(0.022)
Investment (in logs)	0.094***	0.097***	0.103***	0.103***
	(0.012)	(0.013)	(0.013)	(0.013)
% Highly Qualified Employees	0.177	0.191	0.174	0.185
	(0.218)	(0.219)	(0.215)	(0.223)
Export Dummy	0.178***	0.159***	0.143***	0.136***
	(0.034)	(0.036)	(0.034)	(0.036)
East Germany Dummy	-0.186***	-0.189***	-0.194***	-0.194***
	(0.046)	(0.046)	(0.045)	(0.046)
% of Employees < Age 30	-0.274**	-0.229*	-0.224**	-0.201*
	(0.108)	(0.117)	(0.108)	(0.118)
Constant	-2.133***	-2.184***	-2.112***	-2.154***
	(0.132)	(0.114)	(0.130)	(0.115)
Industry Dummies	Yes	Yes	Yes	Yes
Adjusted R^2	0.254	0.293	0.297	0.285
Kleibergen-Paap LM P-value	0.000	0.001	0.000	0.001
Angrist-Pischke F-test	22.079	11.765	16.084	11.650
Observations	2460	2460	2460	2460

Robust standard errors in parentheses, * p<0.10, ** p<0.05, *** p<0.01.
Source: ZEW ICT survey 2010.

Table A.8: Dependent Variable: Log Labour Productivity - OLS Regression

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
% of Emp. Using Mob. Internet	0.459***			0.287***		0.300***	0.257***
	(0.086)			(0.088)		(0.085)	(0.087)
% of Emp. Using Internet		0.427***		0.379***	0.184***		0.146**
		(0.052)		(0.053)	(0.059)		(0.060)
% of Emp. Predom. Using PC			0.650***		0.530***	0.609***	0.520***
			(0.060)		(0.071)	(0.061)	(0.071)
East Germany Dummy	-0.257***	-0.242***	-0.234***	-0.237***	-0.229***	-0.227***	-0.224***
	(0.031)	(0.031)	(0.031)	(0.031)	(0.030)	(0.031)	(0.031)
Constant	-2.255***	-2.368***	-2.381***	-2.372***	-2.414***	-2.391***	-2.416***
	(0.045)	(0.047)	(0.045)	(0.047)	(0.046)	(0.045)	(0.046)
Industry Dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2460	2460	2460	2460	2460	2460	2460
Adjusted R^2	0.187	0.202	0.219	0.206	0.222	0.223	0.225

Robust standard errors in parentheses, * p<0.10, ** p<0.05, *** p<0.01.
Source: ZEW ICT survey 2010.