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Mobile and more productive? Firm-level evidence on the productivity effects of mobile internet use

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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 contains 2143 German firms and refers to the year 2014, when high-speed mobile internet was still at a relatively early stage of diffusion within firms. The econometric analysis shows that firms' labour productivity significantly increases with the share of employees with mobile internet access. Our instrumental variables approach suggests that mobile internet use does cause higher labour productivity.

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1. Introduction

Computers and the internet are 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 52.6 million in 2014. During the same period, mobile data volume increased even more rapidly, from 11.5 to 394.8 Petabytes (see Fig. A.1).

While the role of information and communication technologies (ICT) in determining labour productivity is well studied,[1] there is, to the best of our knowledge, no empirical work on the firm-level productivity effects of mobile internet so far. Why would we expect productivity effects from mobile internet? One important result from the empirical analysis of ICT is that reduced communication costs support the decentralisation of organisation, such as the reduction of hierarchy levels and the implementation of autonomous working teams (see for example Bresnahan, Brynjolfsson, & Hitt, 2002). Mobile internet access can further improve information flows and communication and reduce involved costs. Employees are now able to access their firms' data and documents anywhere, at any time. This supports decentralisation in terms of organisation and

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

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time. 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. Thus, the net contribution of mobile internet is a priori not evident.

In our analysis, we take a firm-level perspective in order to analyse the role that employees' mobile internet access plays for firms' labour productivity. Based on a sample of 2143 firms from the German manufacturing and services industry, we estimate classical production functions. Mobile internet use as an input factor is measured by the percentage share of employees with mobile internet access in each firm. We control for ICT use at the workplace other than mobile internet access by including measures of the use of computers and access to fixed line internet. Since the estimates of the effect of mobile internet access might be prone to reverse causality, i.e. more productive firms have more resources to invest in new technologies, we apply an instrumental variables approach.

Our initial econometric analysis shows that a one percentage point higher share of employees with mobile internet access is associated with a 0.2% higher labour productivity. When controlling for potential endogeneity bias by instrumental variables estimation, we still find a significant effect of mobile internet use on firm productivity. Thus, based on our sample of 2143 German firms for the year 2014, we can claim that mobile internet access has a causal impact on firms' labour productivity.

Our paper contributes to the literature in various respects: (i) We provide first microeconometric firm-level evidence on the labour productivity effects of employees' mobile internet use. (ii) We control for computer use and fixed line internet access as further types of ICT use at the workplace. (iii) By applying an instrumental variables approach we take account of potential reverse causality between labour productivity and mobile internet use.

2. Related literature

To the best of our knowledge, there is no microeconometric study referring to the relationship between mobile internet use by employees and firms' labour productivity. There is, however, a quite extensive literature on the economic impact of mobile phones for small and micro enterprises in developing and emerging countries (e.g. Aker & Mbiti, 2010; Jensen, 2007; Muto & Yamano, 2009; Tadesse & Bahiigwa, 2015 and Paunov & Rollo, 2016). In general, this literature suggests that the use of mobile phones improves market outcomes. Furthermore, there exist various studies in information systems research and psychology about the implications of communication technologies and especially mobile internet use (i.e. constant connectivity) for individual employees. Middleton and Cukier (2006) provide a qualitative analysis on the mobile email usage patterns of individual employees. Their participants report positive aspects like allowing them to be efficient as well as negative aspects like the infringement on work-life boundaries. Diaz, Chiaburu, Zimmerman, and Boswell (2012) conclude that the use of communication technologies is associated with increased work satisfaction, but could also create work-life conflicts. The studies by Dery, Kolb, and MacCormick (2014); Mazmanian (2013); Mazmanian, Orlikowski, and Yates (2013) provide further descriptive evidence on the implications of constant connectivity and always on work practices for employees.

Apart from that, there is a broad literature on productivity effects of ICT in general as well as for fixed-line broadband internet. According to the survey by Cardona, Kretschmer, and Strobel (2013), the estimated production elasticity of ICT ranges on average between 0.05 and 0.06 and has increased over the period of observation. Several studies analyse the contribution of fixed-line internet to productivity. At the macro level, Koutroumpis (2009), Czernich, Falck, Kretschmer, and Woessmann (2011), Gruber, Hätönen, and Koutroumpis (2014) and Kongaut and Bohlin (2014) show that broadband internet has a positive and statistically significant impact on both productivity and growth in EU and OECD countries.[2] Thompson and Garbacz (2011) find a positive impact of fixed-line and mobile broadband on GDP per household in a sample containing high and low income countries. However, they do only find a significant impact for mobile broadband but not for fixed-line broadband internet in the subsample of high income countries. Using a novel data set at the meso-level, Hagsten (in press) finds a positive and significant relationship between labour productivity and the share of broadband-enabled employees in firms with the strength of relationships varying considerably across countries and industries. At the micro level, the evidence is rather mixed. Based on a cross section of firms from New Zealand collected in 2006, Grimes, Ren, and Stevens (2012) find that firms using fixed-line broadband internet have a 7–10% higher labour productivity. By contrast, for the early phase of broadband diffusion in Germany, 2000–2002, Bertschek, Cerquera, and Klein (2013) find positive and significant effects of fixed-line broadband on firms' innovation activity but not on their labour productivity. Comparable insignificant results are found by De Stefano, Kneller, and Timmis (2014) for British firms and by Haller, and Lyons (2015) for Irish firms. Akerman, Gaarder, and Mogstad (2015) again find, based on Norwegian data that a 10 percentage point increase in fixed-line broadband availability raises output by 0.4%. A positive relationship between innovation and employees' broadband access is also found by Polder, Leeuwen, Mohnen, and Raymond (2010) using Dutch firm-level data. As Colombo, Croce, and Grilli (2013) 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. Maliranta and Rouvinen (2006) show, based on a sample of Finish firms surveyed in 2001, that portability and wireless connectivity of computers boost labour productivity. They measure wireless connectivity by wireless local area networks (WLAN) access whereas in our study, we capture the possibility to access the internet via cellular networks providing much greater mobility and flexibility to the user.

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

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A few macroeconometric studies analyse the role of mobile phones or mobile telecommunication services that are not necessarily related to the internet and that do not specifically refer to employees' mobile internet access. Based on a cross-country data set Vu (2011) studies the impact of ICT in terms of personal computers, mobile phones and internet users on economic growth. He finds positive and significant effects for all three types of technology. The analysis by Ward and Zheng (2016) reveals positive effects of mobile telephone services on growth in China. This effect is larger for the first period from 1991 to 2000 than for the second from 2001 to 2010, thus the effect declines with the economic development of Chinese provinces.

3. Estimation strategy

In order to analyse the impact of mobile internet access on labour productivity we apply a production function framework as a standard approach to empirically analyse the relationship between productivity and technology. A firm's production process is modelled as a Cobb-Douglas production function with various input factors:

$$Y_i = A_i L_i^{\alpha_L} K_i^{\alpha_K} e^{\beta_{MOB} MOB_i} e^{\beta_{WWW} WWW_i} e^{\beta_{PC} PC_i} e^{\gamma_X X_i} \tag{1}$$

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 predominantly using computers (PC_i), having internet access (WWW_i), and having mobile internet access (MOB_i). Mobile internet access is measured as the share of employees that the company has equipped with mobile devices like smartphones, tablets and notebooks providing internet access via cellular networks. A vector of various control variables X_i captures a firm's share of highly qualified employees, export activity, share of young employees, regional location (East or West Germany), remote email access, and its sector affiliation (17 industries).

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

$$\ln\left(\frac{Y_i}{L_i}\right) = \ln A_i + (\alpha_L - 1)\ln L_i + \alpha_K \ln K_i + \beta_{MOB} MOB_i + \beta_{WWW} WWW_i + \beta_{PC} PC_i + \boldsymbol{\gamma_X X_i} + u_i \tag{2}$$

where α_L, α_K represent the output elasticities of labour and capital, respectively, and $\beta_{(\bullet)}$ refer to the output elasticities with respect to employees' ICT use.

Our main hypothesis is that the coefficient of mobile internet use β_{MOB} is larger than zero. Mobile internet access is expected to further decrease communication costs and thereby allows employees to autonomously decide on their most efficient working place and working time. By contrast, the alternative hypothesis is that reduced communication costs and improved decentralisation are outweighed by employees being permanently connected and thus becoming less productive. In addition, increased monitoring and coordination costs, for instance for organising a project meeting, might have negative impacts on labour productivity. Strictly speaking, our measure of mobile internet is a measure of mobile internet access. It measures the share of employees with mobile internet devices and not their actual use of these devices. It seems to be plausible, however, that employees who are equipped with mobile devices by their employers will also use these devices to access the internet. Therefore, we apply the terms mobile internet access and mobile internet use as synonyms.

Productivity and ICT 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 ICT 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% in 2000 to 55.6% in 2007 and 58.4% in 2014 - see Fig. A.2), the fraction of workplaces equipped with computers and internet access has been quite stable during the last few years. The firm's production process determines the appropriate degree of ICT use within the firm. A certain percentage of employees might be equipped with computers whereas others might have jobs or tasks that are not directly related to the use of ICT. Thus, it is reasonable to assume that in the year 2014, the diffusion of computers and internet access has 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 and rule out reverse causality for these two variables. In 2014, mobile internet in firms, by contrast, was still at an early stage of diffusion. Only 26% of employees in our sample are equipped with mobile devices being able to connect to the internet. 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 mobile and independent with respect to their working place and working time.

The empirical analysis consists of two steps. In the first step, we estimate various model specifications by simple OLS. In the second step, we apply an instrumental variables approach to take account of potential reverse causality between labour productivity and mobile internet use. In the first stage estimation, two variables are used as instruments for mobile internet access: the average mobile internet use at the industry level and the number of years the interviewee owns a smartphone.

The number of years the respondent uses a (private) smartphone is in our view a valid instrument. Electronic mobile devices such as smartphones or tablets as well as applications such as social media started their diffusion process among individuals before diffusing to firms. As the interviewee is usually from the firm's senior management or the IT department,

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he or she decides or is at least involved in the firms' decision on the investment in mobile internet devices. Thus, the number of years the respondent uses a smartphone might be a good predictor for the extent to which the firm is using mobile internet devices. However, the entire firm's labour productivity will not depend on the number of years a single person working in this firm owns a smartphone.

The average share of mobile internet use is measured at the level of 51 industries. This aggregate measure of mobile internet use also appears to be a valid instrument. It is a good predictor for the share of employees having mobile internet access within firms since it reflects the stage of diffusion of mobile internet use by employees across industries. By contrast, it does not directly determine a single 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. Moreover, we include a dummy variable measuring whether or not employees have remote access to their email accounts. This is a kind of application that employees could access with their mobile devices via mobile internet but also via fixed-line internet. All estimations include dummies for 17 industries (these 17 industries refer to a higher aggregation level than the 51 industries the instrumental variable refers to) and controls for export activity and location (East/West Germany).

4. 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 six waves, collected in 2000, 2002, 2004, 2007, 2010 and 2014, about 4400 firms were interviewed about their characteristics and particularly about their ICT usage. The data were collected via computer-aided telephone interviews (CATI) based on a sample stratified with respect to industry and firm size. In small and medium-sized enterprises, the respondent is usually the chief executive officer whereas in larger firms he or she is either from the board of management or head of the IT (72% are either CEOs or from the board of management and 7% are the heads of the IT department). Our main variable of interest, the share of employees equipped with mobile internet devices, is in line with other data sources.[4] The survey is designed as a panel but not all firms responded in all waves. For our analysis, we use the 2014 wave. This wave is the second one containing information about mobile internet use. Taking account of item non-response and implausible values, we end up with a sample of 2143 firms.[5] As suggested by Table A.3, the observations not included in the estimation sample are missing at random.

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 ICT 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:

- What is the percentage of employees working predominantly with computers?
- What is the percentage of employees who have access to the internet?
- What is the percentage of employees that your company has equipped with mobile devices like smartphones, tablets and notebooks that provide internet access via cellular networks?

The first question reflects the usage of computers by the employees, whereas the other two measure the access to the internet. The percentage of employees working with computers as a measure of ICT intensity is also used in other studies as for instance Bloom, Sadun, and Van Reenen (2012). Table 4.1 shows descriptive statistics of the sample. On average, a firm has 125 employees and 25.6 million euro in sales. 48% of the firms are engaged in export activities and the average share of highly qualified employees is 21%. On average, 48% of the employees work predominantly with computers, 60% have internet access and 27% have mobile internet access via UMTS or LTE. The figures for mobile internet use demonstrate that in 2014, mobile internet in firms was still at a relatively early stage of diffusion, although its diffusion has almost doubled compared to 2010 (see Fig. A.3 in the Appendix). Differentiating between firms with and without mobile internet use reveals that firms that equip their employees with mobile internet devices (86% of the firms in the sample) have a higher labour productivity, are considerably larger, have higher sales and invest more. Furthermore, they are more ICT intensive and have

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

[4] Official data from Eurostat on the ICT usage by European companies show an average share of employees equipped with mobile internet devices of 19% for German companies. This slightly lower value compared to the value in our full sample (25.5%) is probably driven by the fact that the Eurostat data does not include the financial sector and only includes companies with ten or more employees. It turns out that in our data set, smaller firms of a size between 5 and 9 employees as well as larger firms have higher shares of employees equipped with mobile devices (33% and 23%, respectively) than medium-sized firms (18%) supporting the consistency of our data compared to the data from Eurostat.

[5] We dropped firms with sales per employee less than 10,000 Euro (4 observations) and more than 1 million Euro (43), with total investment larger than turnover (9), with less than 5 employees (163), with more than 5000 employees (19) and ICT investment larger than total investment (1 observation). Since investment is taken in logs, zero investment is replaced by the 10th percentile of investment per employee observed in the corresponding industry multiplied by the number of employees. Missing investment information is replaced by the 50th percentile of the corresponding industry.

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Table 4.1.
Summary statistics: Estimation Sample.

	N	Mean	Median	SD	Min	Max
Sales in Mill. Euro	2143	25.6	3.50	115.9	0.10	2500
Employees	2143	125.0	31	360.9	5	5000
Labour productivity (Sales per Emp.)	2143	0.16	0.11	0.14	0.010	1
Investment in Mill. Euro	2143	1.26	0.15	5.72	0.00050	130
% of Emp. Predom. Using PC	2143	0.48	0.38	0.35	0	1
% of Emp. Using Internet	2143	0.60	0.60	0.37	0	1
% of Emp. Using Mob. Internet	2143	0.27	0.16	0.29	0	1
Smartphone since t years	2143	6.03	5	3.65	1	21
Remote Email Access	2143	0.74	1	0.44	0	1
% Highly Qualified Employees	2143	0.21	0.10	0.25	0	1
% of Employees <Age 30	2143	0.24	0.21	0.17	0	1
East Germany Dummy	2143	0.23	0	0.42	0	1
Export Dummy	2143	0.48	0	0.50	0	1
Labour Productivity (in logs)	2143	−2.16	−2.17	0.76	-4.61	0
Employees (in logs)	2143	3.63	3.43	1.39	1.61	8.52
Investment (in logs)	2143	−1.78	−1.90	1.92	−7.60	4.87
Smartphone since t Years (logs)	2143	1.61	1.61	0.65	0	3.04
Av.% Mob. Inter.	2143	0.25	0.22	0.14	0.10	0.63

a higher share of highly qualified employees (see Table A.2 in the Appendix). For the distribution of firms across industries, see Table A.3.

The first instrumental variable used in the IV estimations refers to the (log) number of years the interviewee owns a smartphone. The average number of years, the interviewee owns a smartphone is 6.03 years, with the highest share in the media services industry (see Fig. A.4 in the Appendix). Our second instrumental variable is the average share of mobile internet use in 51 industries, with a mean of 25%.

5. Results

Table 5.1 presents results from simple OLS estimations. All three ICT inputs — share of employees working with computers, having access to the internet and being equipped with mobile internet access — have positive and highly significant coefficients, thus revealing a positive correlation with labour productivity. The coefficients for the share of employees with mobile internet access and the share of employees working with computers remain highly significant even when all three ICT variables are included in the estimation (specification 6). A one percentage point higher share of employees with mobile internet access is associated with an approximately 0.2% higher labour productivity. The input factors labour (proxied by the

Table 5.1.
Dependent Variable: Log Labour Productivity - OLS Regression.

	(1)	(2)	(3)	(4)	(5)	(6)
% of Emp. Using Mob. Internet		0.226[a]			0.180[a]	0.165[a]
		(0.057)			(0.055)	(0.057)
% of Emp. Predom. Using PC			0.526[a]		0.507[a]	0.460[a]
			(0.069)		(0.069)	(0.077)
% of Emp. Using Internet				0.310[a]		0.079
				(0.053)		(0.060)
Employees (in logs)	−0.082[a]	−0.085[a]	−0.082[a]	−0.081[a]	−0.070[a]	−0.068[a]
	(0.016)	(0.016)	(0.016)	(0.016)	(0.016)	(0.017)
Investment (in logs)	0.163[a]	0.143[a]	0.141[a]	0.142[a]	0.137[a]	0.137[a]
	(0.012)	(0.012)	(0.012)	(0.012)	(0.012)	(0.012)
Constant	−1.677[a]	−1.823[a]	−1.893[a]	−1.884[a]	−1.949[a]	−1.966[a]
	(0.084)	(0.086)	(0.086)	(0.088)	(0.088)	(0.089)
Industry Dummies	Yes	Yes	Yes	Yes	Yes	Yes
Additional Controls	No	Yes	Yes	Yes	Yes	Yes
Observations	2143	2143	2143	2143	2143	2143
Adjusted R^2	0.270	0.334	0.353	0.341	0.356	0.356

Robust standard errors in parentheses. Additional Controls: Exports, East Germany, Remote Email, % Highly Qualified and % of Employees < Age 30.
[a] $p < 0.01$.

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Table 5.2.
Dependent Variable: Log Labour Productivity - 2SLS Regression - Second Stage.

	(1)	(2)	(3)
% of Emp. Using Mob. Internet	0.748	0.929[a]	0.891[a]
	(0.555)	(0.336)	(0.292)
% of Emp. Predom. Using PC	0.472[a]	0.476[a]	0.475[a]
	(0.081)	(0.082)	(0.082)
% of Emp. Using Internet	−0.040	−0.077	−0.069
	(0.132)	(0.094)	(0.088)
Employees (in logs)	−0.035	−0.025	−0.027
	(0.035)	(0.026)	(0.024)
Investment (in logs)	0.127[a]	0.124[a]	0.125[a]
	(0.015)	(0.014)	(0.013)
Constant	-2.114[a]	-2.160[a]	−2.150[a]
	(0.166)	(0.128)	(0.120)
Industry Dummies	Yes	Yes	Yes
Additional Controls	Yes	Yes	Yes
Instrument	Years Smartphone	51 Industry Averages	Both
Adjusted R^2	0.323	0.299	0.305
Kleibergen-Paap LM P-value	0.000	0.000	0.000
Angrist-Pischke *F*-test	20.745	59.302	37.844
Endogeneity Test P-value	0.277	0.015	0.008
Hansen *J*-test P-value			0.780
Observations	2143	2143	2143

Robust standard errors in parentheses. Additional Controls: Exports, East Germany, Remote Email, % Highly Qualified and % of Employees < Age 30.
[a] $p < 0.01$.

number of employees) and capital (proxied by gross investment) are highly significant and show with −0.1 and 0.15, respectively, the expected signs and coefficients.[6]

In the next step, we perform an instrumental variables estimation.[7] We instrument the firms' shares of mobile internet users with the average mobile internet use in 51 industries and the number of years the interviewee owns a smartphone. First stage results are shown in Table A.1. The first column uses just the number of years the interviewee owns a smartphone as an instrument and the second column only takes into account the average share of employees with mobile internet access at the industry level. Column (3), our preferred specification, uses the combination of both instruments.

The Angrist-Pischke *F*-test, which in our case of a single endogenous regressor equals the standard *F*-test for weak identification, has rather large values between 21 and 59 (see Table 5.2). The Kleibergen-Paap LM-test is a heteroscedasticity-robust test for underidentification. In all our specifications, the null hypothesis is rejected, meaning that the model is identified. Furthermore, the Hansen *J*-test does not reject the null hypothesis of no correlation between residuals and instruments in specification (3). These results suggest that our instruments are relevant for explaining a firm's share of employees equipped with mobile internet access.

The estimated coefficient of mobile internet use of the second stage estimations of specifications (2) to (3) are still significant, implying that mobile internet use has a causal positive effect on labour productivity.[8] The coefficient of our preferred specification (3) of Table 5.2 is, however, noticeably larger than the OLS results in Table 5.1. Again, the coefficients of the input factors labour and capital show the expected signs with labour now being insignificant.

6. Conclusions and future research

According to our empirical results, mobile internet use is positively and significantly related with firms' labour productivity. Our instrumental variables estimates suggest that this relationship is indeed causal. The positive aspects of mobile internet, like the improved information flows and the support for a more flexible organisation of work, seem to outweigh the increased difficulty of monitoring the employees or of employees getting distracted because of permanent connectivity. The gains from using mobile internet devices might even increase in the future, as network effects within firms, arising

[6] The coefficient of labour is expected to be negative since it reflects the size of the production elasticity minus one; see Eq. (2).
[7] The analysis was carried out in Stata using the IVREG2 command provided by Baum, Schaffer and Stillman (2010).
[8] In an earlier version of this paper, based on data from 2010, we could not find any significant causal effect. There are three different explanations for the diverging results: (1) weak instruments in the old version, (2) network effects in firms, as there are now much more employees equipped with mobile internet devices and (3) the fact that the capabilities of the mobile devices, networks (3G UMTS vs. 4G LTE) and software increased enormously between 2010 and 2014.

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when more and more employees use such devices and access common information bases, might be reinforced.

There are various avenues for future research. First, in order 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 email accounts or also to data bases and enterprise software? 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).

The recent paper by Bloom, Liang, Roberts and Ying (2015) finds positive impacts from introducing working from home on employees' performance. Godart and Görg (2014) find positive evidence for the impact of introducing trust-based working on plants' probability to realise product innovations. Thus, further analysis should take account of workplace models that are flexible with respect to working time and working place and that are supported by mobile devices, such as home office, co-working, working while traveling, etc.

Finally, improving work-life balance and creating the possibility to combine work and family i.e. working from home arrangements) 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 related to being always and everywhere online. This could, although not testable with our cross-sectional data set, diminish the positive productivity effect of mobile internet in the long run. For evaluating the potential of mobile internet, we need new concepts for measuring mobility not only with respect to the technical dimension but also with respect to working place and working time. Such a multi-dimensional concept, however, renders a causal analysis non-trivial, thus posing several challenges for future research.

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Appendix A. Appendix

A.1. Additional Graphs

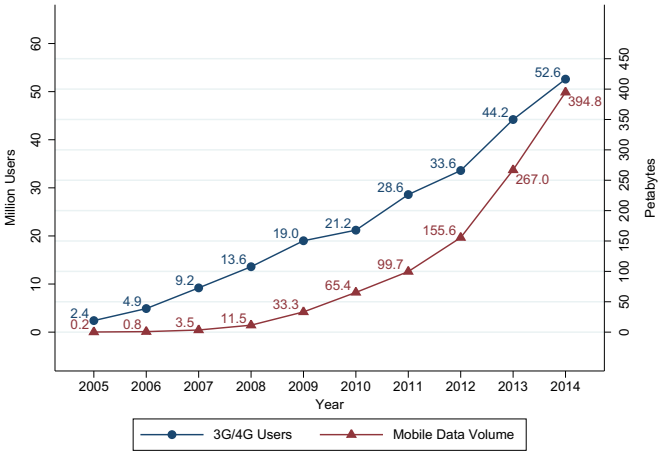

Fig. A.1. Mobile Data Volumes and 3G/4G Users in Germany 2005–2014.
Source: Bundesnetzagentur (2012, p. 83) and Bundesnetzagentur (2015, p. 40).

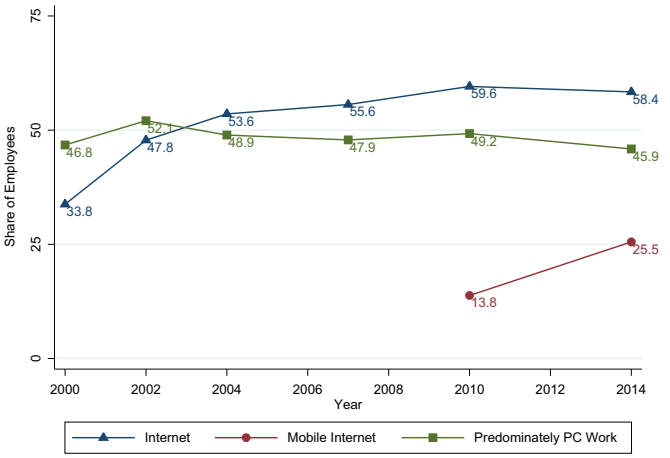

Fig. A.2. Share of Employees Using (Mobile) Internet/Predominately Work with Computers: Full Sample.
Source: ZEW ICT Surveys 2000, 2002, 2004, 2007, 2010 and 2014.

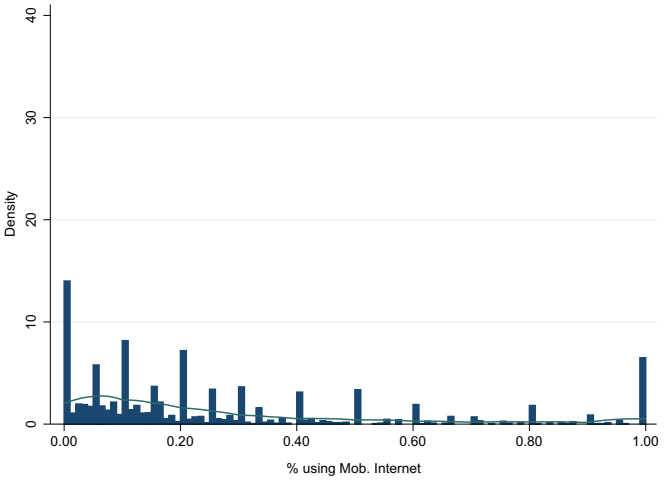

Fig. A.3. Share of Employees Using Mobile Internet: Estimation Sample.
Source: ZEW ICT Survey 2014.

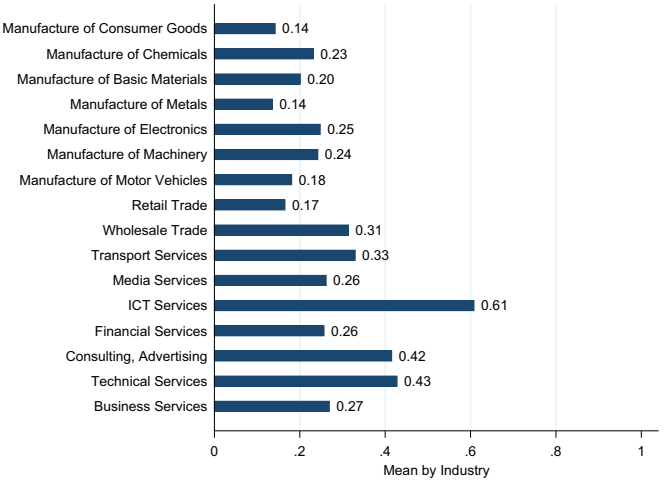

Fig. A.4. Industry Means of Mobile Internet Use: Estimation Sample.
Source: ZEW ICT Survey 2014.

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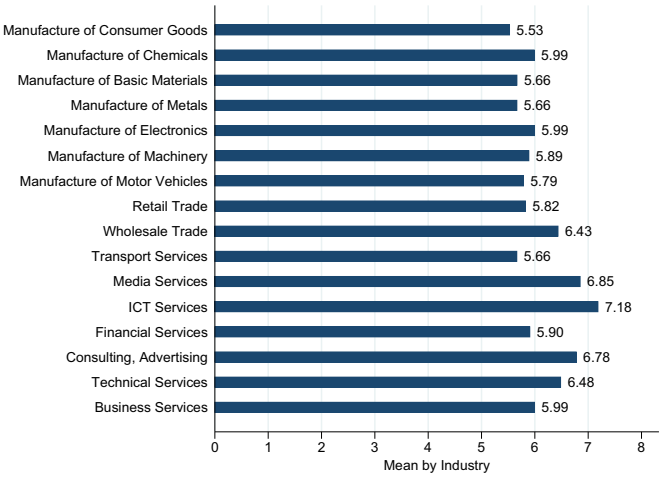

Fig. A.5. Industry Means of the Number of Years the Interviewee owns a Smartphone: Estimation Sample.
Source: ZEW ICT Survey 2014.

A.2. Additional Tables

Tables A.1, A.2, A.3.

Table A.1.
Dependent Variable: Percentage of Employees using Mobile Internet - 2SLS Regression – First Stage of Table 5.2.

	(1)	(2)	(3)
Smartphone since t Years (logs)	0.038[a]		0.035[a]
	(0.008)		(0.008)
Av. % Mob. Inter.		0.741[a]	0.728[a]
		(0.096)	(0.096)
% of Emp. Predom. Using PC	−0.022	−0.032	−0.032
	(0.032)	(0.031)	(0.031)
% of Emp. Using Internet	0.201[a]	0.210[a]	0.206[a]
	(0.026)	(0.026)	(0.025)
Employees (in logs)	−0.057[a]	−0.048[a]	−0.049[a]
	(0.007)	(0.006)	(0.006)
Investment (in logs)	0.015[a]	0.014[a]	0.012[a]
	(0.005)	(0.004)	(0.004)
Constant	0.200[a]	0.130[a]	0.082[b]
	(0.035)	(0.038)	(0.039)
Industry Dummies	Yes	Yes	Yes
Additional Controls	Yes	Yes	Yes
Observations	2143	2143	2143

Robust standard errors in parentheses *p < 0.10.
[a] p < 0.01.
[b] p < 0.05.

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Table A.2.
Summary Statistics by Mobile Internet Use of Firms: Estimation Sample.

	Without Mobile		With Mobile		Total	
	N	Mean	N	Mean	N	Mean
Sales in Mill. Euro	299	3.29	1844	29.26	2143	25.63
Employees	299	30.17	1844	140.32	2143	124.95
Labour Productivity (Sales per Emp.)	299	0.12	1844	0.16	2143	0.16
Investment in Mill. Euro	299	0.22	1844	1.43	2143	1.26
% of Emp. Predom. Using PC	299	0.34	1844	0.50	2143	0.48
% of Emp. Using Internet	299	0.44	1844	0.63	2143	0.60
% of Emp. Using Mob. Internet	299	0.00	1844	0.31	2143	0.27
Smartphone since t Years	299	5.23	1844	6.16	2143	6.03
Remote Email Access	299	0.34	1844	0.80	2143	0.74
% Highly Qualified Employees	299	0.11	1844	0.22	2143	0.21
% of Employees <Age 30	299	0.25	1844	0.24	2143	0.24
East Germany Dummy	299	0.19	1844	0.23	2143	0.23
Export Dummy	299	0.36	1844	0.50	2143	0.48
Labour Productivity (in logs)	299	−2.40	1844	-2.12	2143	−2.16
Employees (in logs)	299	2.89	1844	3.75	2143	3.63
Investment (in logs)	299	−2.79	1844	−1.61	2143	−1.78
Smartphone since t Years (logs)	299	1.42	1844	1.64	2143	1.61
Av. % Mob. Inter.	299	0.19	1844	0.26	2143	0.25

Table A.3.
Distribution of Firms across Industries.

	Estimation sample		Full sample	
	N	Percentage	N	Percentage
Manufacture of Consumer Goods	320	14.93	607	15.75
Manufacture of Chemicals	78	3.64	140	3.63
Manufacture of Basic Materials	202	9.43	329	8.54
Manufacture of Metals	151	7.05	279	7.24
Manufacture of Electronics	144	6.72	237	6.15
Manufacture of Machinery	124	5.79	231	6.00
Manufacture of Motor Vehicles	61	2.85	110	2.85
Retail Trade	119	5.55	228	5.92
Wholesale Trade	106	4.95	193	5.01
Transport Services	121	5.65	217	5.63
Media Services	86	4.01	164	4.26
ICT Services	137	6.39	223	5.79
Financial Services	105	4.90	231	6.00
Consulting, Advertising	138	6.44	231	6.00
Technical Services	114	5.32	191	4.96
Business Services	137	6.39	242	6.28
Total	2143	100.00	3853	100.00

Since some firms have industry affiliation that are not conform with the list of industries in our stratification, the total number of firms in the full sample is lower than the 4400 mentioned in Section 4. Additionally, we dropped the very heterogeneous industry 'Manufacture of Furniture and Other Manufacturing' in our estimation sample and therefore also in the full sample for comparability.

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