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Working Paper

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Non-Technical Summary

Numerous empirical studies at different levels of aggregation demonstrate the important role of information and communication technologies (ICT) for economic performance. As general purpose technologies ICT enable firms to reshape their business processes and to improve their products and services. Firms' innovation activity in turn increases labour productivity thereby entailing growth and competitiveness. Policy makers and industry representatives denote the availability of an efficient broadband Internet infrastructure to be essential in order to reap the potential benefits of ICT.

This paper provides empirical evidence on the causal impact of broadband Internet on firm performance using a sample of German manufacturing and services firms. Firm performance is measured in terms of labour productivity and realised product and process innovation. The analysis refers to the early phase of DSL expansion in Germany from 2001 to 2003, when roughly 60 percent of the German firms already used broadband Internet. Identification relies on instrumental variable estimation taking advantage of information on the availability of DSL broadband at the postal code level. The results show that broadband Internet has no impact on firms' labour productivity whereas it exhibits a positive and significant impact on their innovation activity. Thus, firms that used broadband Internet in the early phase of DSL expansion where more likely to reshape their business processes and to bring new or improved products and services to the market.

Das Wichtigste in Kürze

Zahlreiche empirische Studien belegen die Bedeutung von Informations- und Kommunikationstechnologien (IKT) für den ökonomischen Erfolg von Unternehmen, Branchen und ganzen Volkswirtschaften. Durch die Nutzung von IKT als Basistechnologien werden Unternehmen dazu befähigt, ihre Geschäftsprozesse neu zu organisieren und zu optimieren und neue oder verbesserte Produkte und Dienstleistungen anzubieten. Vertreter aus Wirtschaft und Politik betrachten eine leistungsfähige Internetinfrastruktur als wichtige Voraussetzung dafür, die wirtschaftlichen Potenziale von IKT auszuschöpfen.

Diese Studie liefert empirische Evidenz für den kausalen Effekt der Breitbandnutzung auf den Unternehmenserfolg. Die Untersuchung basiert auf Daten für Unternehmen des verarbeitenden Gewerbes und des Dienstleistungssektors in Deutschland. Die Arbeitsproduktivität sowie die Realisierung von Produkt- oder Prozessinnovationen dienen als Maße für den Unternehmenserfolg. Die Analyse bezieht sich auf den Zeitraum 2001 bis 2003, die frühe Phase der DSL-Einführung in Deutschland. Zu dieser Zeit verfügten ca. 60 Prozent der Unternehmen über einen Breitbandanschluss. Zur Identifikation des kausalen Effekts wenden wir einen Instrumentvariablenansatz an. Hierbei wird die Verfügbarkeit von DSL auf Postleitzahlebene als Instrumentvariable genutzt, die den Einsatz von Breitbandinternet auf Unternehmensebene erklärt. Die Ergebnisse der ökonometrischen Analyse ergeben keinen signifikanten Effekt der Breitbandnutzung für die Arbeitsproduktivität. Jedoch zeigen sich positive und signifikante Effekte der Breitbandnnutzung für die Innovationsaktivität. Unternehmen, die in oder kurz nach der Phase der DSL-Einführung Breitband nutzten, waren somit eher in der Lage, ihre Geschäftsprozesse zu optimieren und neue oder verbesserte Produkte und Dienstleistungen auf den Markt zu bringen.

More Bits - more Bucks? Measuring the Impact of Broadband Internet on Firm Performance[§]

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Abstract

The paper provides empirical evidence for the causal impact of broadband Internet on the economic performance of German firms. Performance is measured in terms of labour productivity and realised process and product innovations. The analysis refers to the early phase of DSL expansion in Germany from 2001 to 2003, when roughly 60 percent of the German firms already used broadband Internet. Identification relies on instrumental variable estimation taking advantage of information on the availability of DSL broadband at the postal code level. The results show that broadband Internet has no impact on firms' labour productivity whereas it exhibits a positive and significant impact on their innovation activity.

JEL-classification: D22, L23, O31

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1 Introduction

Numerous empirical studies at different levels of aggregation demonstrate the important role of information and communication technologies (ICT) for economic performance.[1] As general purpose technologies (Bresnahan and Trajtenberg, 1995) ICT enable firms to reshape their business processes and to improve their products and services (e.g. Brynjolfsson and Saunders, 2010). Firms' innovation activity in turn increases labour productivity thereby entailing growth and competitiveness.

In order to reap the potential benefits of ICT, policy makers and industry representatives denote the availability of an efficient broadband Internet infrastructure to be essential. Broadband Internet is defined as Internet access provided at a certain high level of speed. The particular definitions are heterogenous and cover a wide range of actual speed.[2] However, in many regions across the U.S. and in European countries Internet access is not available at any speed that can be defined as broadband. Fostering the availability of such infrastructures therefore has been declared a policy objective of European countries and of the U.S.[3]

Even though the benefits of broadband Internet seem to be undisputed among policy makers, empirical evidence on the benefits is inconclusive. A causal, positive effect of telecommunication infrastructure on economic performance has already been presented in the literature (Röller and Waverman, 2001). There are some studies (Koutroumpis, 2009; Czernich et al., 2011) showing positive effects of broadband Internet on economic growth at the aggregate level. By contrast, empirical evidence on the causal impact of broadband on firm performance is still lacking.

This paper provides empirical evidence on the causal impact of broadband Internet on firm performance using a sample of German manufacturing and services firms. Firm performance is measured in terms of labour productivity and realised product and process innovation. The data base stems from a business survey and was col-

[1]See for instance the recent comprehensive study by Van Reenen et al. (2010) as well as Draca et al. (2007), Van Ark et al. (2008) and Jorgenson et al. (2008).

[2]For instance, the OECD defines the lower bound of broadband Internet as Internet access with speeds above 256 kbits per second. However, they do also distinguish between different speeds in their analysis (OECD, 2009) that are by far more rapid.

[3]For example, the Federal Communications Commission (2010) has published a detailed broadband strategy, the European Commission (2010) defines broadband deployment as one goal in its Europe 2020 strategy and the German Federal Ministry for Economy and Technology (Bundesministerium für Wirtschaft und Technologie, 2009) announced broadband deployment as a policy objective, too.

lected by the Centre of European Economic Research in the years 2002 and 2004 (ZEW ICT Survey). This data contains detailed information on the economic characteristics, performance and ICT use of the sampled firms for the years 2001 and 2003, including the use of broadband Internet. Given that broadband usage might be influenced by firms' economic performance (i.e. reverse causality), an instrumental variable approach is used to control for potential endogeneity of broadband usage at the firm level. We use DSL availability at the postal code level as instrumental variable for firms' broadband usage. The focus on the early phase of DSL expansion in Germany (from 2001 to 2003) allows us to exploit differences in the rate of broadband usage across German firms.[4]

The paper provides two main results. First, even though the econometric analysis shows a positive correlation between labour productivity and the use of broadband Internet, this effect is not robust when controlling for endogeneity and different sources of variation. Using an instrumental variable approach, we show that the impact of broadband Internet on firms' labour productivity is highly heterogenous among German firms and not statistically different from zero. Second, the impact of broadband Internet on firms' innovation activity is positive, significant and robust with respect to different specifications. This suggests that broadband Internet enabled firms to reorganise and reshape their business processes and to improve their products or services. This innovation activity induced by broadband usage may have been translated into productivity gains in later periods as suggested by the vast empirical evidence on the productivity effects of innovation.

The paper is organised as follows. Section 2 provides a background discussion and related literature, section 3 describes the empirical strategy, section 4 presents the data. Section 5 provides the empirical results. Section 6 concludes.

2 Background Discussion

In their seminal paper, Röller and Waverman (2001) show that investment in telecommunication infrastructure has causal positive and significant effects on economic growth. In order to identify causal effects and to take account of endogeneity they

[4]Due to the rapid diffusion of broadband Internet, subsequent surveys do not provide this variation, because DSL diffusion had reached almost 100 percent. DSL was the dominant broadband technology during that time such that the focus is on this technology.

estimate a structural multi-equation model. Their data base comprises a time period of 20 years and 21 OECD countries. The results suggest that the positive effect resulting from investment in telecommunication infrastructure is stronger as soon as a critical level of telecommunication penetration is reached.

Previous work shows evidence for the economic impact of telecommunication investment on growth for developing versus developed countries (Hardy, 1980), for the U.S. (Cronin et al., 1991) and for manufacturing versus services sectors (Greenstein and Spiller, 1995). Subsequent studies support the results found by Röller and Waverman (2001) for OECD countries (Datta and Agarwal, 2004) and for Chinese regions (Shiu and Lam, 2008).

A recent study by Czernich et al. (2011) provides empirical evidence for the growth effects of broadband infrastructure at the aggregate level.[5] The authors use a panel data base of OECD countries comprising the years 1996 to 2007. They apply a technology diffusion model explaining the availability of broadband Internet. They thereby take account of the fact that investment in infrastructure takes place in prospering regions or countries first, i.e. the investment decision itself depends on the economic potential of a region or country and is thus endogenous. The results show that after having introduced broadband Internet, GDP increased by 2.7 to 3.9 percent. In the years after the introduction of broadband Internet a further increase of broadband penetration by 10 percentage points leads to an increase of GDP per head by 0.9 to 1.5 percentage points per year.

Further studies support the important role of broadband Internet for the economy, for example Duggal et al. (2007) and Koutroumpis (2009).[6] Gillett et al. (2006) consider different measures of economic performance. They analyse the impact of broadband Internet availability in the U.S. on employment, wages and the number of IT intensive firms.

A further strand of literature that is related to our study focuses on investment in public infrastructure and its impact on productivity and growth and mainly refers to the early nineties. Results, however, are rather inconclusive (see for instance the surveys by Munnell, 1992, and Gramlich, 1994).

Polder et al. (2009) take a firm-level perspective to analyse the role of ICT and R&D for innovation success and productivity of Dutch firms. They find that the

[5] In this study, Internet access with at least 256 kbit/s is defined as broadband independent on whether it is DSL, fibre or any other kind of connection.

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

use of broadband Internet is particularly important for services firms. Broadband is positively related to product and process innovation as well as to organisational innovation. By contrast, in the manufacturing sector broadband is significant only for product and organisational innovation. For process innovation it is rather e-commerce that plays a significant role.

Our study also takes a firm-level perspective. It analyses whether broadband usage has affected firms' innovation activity and labour productivity in a time period when DSL started to become available. In contrast with Polder et al. (2009) we attempt to identify causal effects of broadband usage. Therefore, we use DSL availability at the postal code level as an instrumental variable for explaining firms' broadband usage.

3 Econometric Implementation

We consider two measures of firm performance: labour productivity and innovation activity. In order to analyse the impact of broadband Internet on labour productivity we apply a production function framework. Firms are supposed to produce according to a Cobb-Douglas production technology with various input factors. Output Y_i is a function of labour L_i, non-ICT capital C_i, ICT capital ICT_i, broadband Internet BB_i, and a vector of control variables X_i:

$$Y_i = f(A_i, L_i, C_i, ICT_i, BB_i, \mathbf{X_i}) \tag{1}$$

Parameter A_i measures total factor productivity and reflects differences in production efficiency across firms. In the econometric estimations, labour productivity defined as the logarithm of sales per employee (Y_i/L_i), is used as a dependent variable. The estimation equation can be described as follows:

$$ln\left(\frac{Y_i}{L_i}\right) = lnA_i + (\alpha_L - 1)lnL_i + \alpha_C lnC_i + \beta_{ICT}ICT_i + \beta_{BB}BB_i + \beta_{\mathbf{X}}\mathbf{X_i} + u_i \tag{2}$$

where u_i is a normally distributed error term. Firm i's use of broadband Internet, BB_i, is assumed to positively affect labour productivity.

Innovation activity is measured by a binary variable taking the value one if an innovation has been realised and the value zero otherwise. The probability of realising a process innovation (or product innovation) is assumed to be related to factor inputs labour L_i, non-ICT capital C_i and ICT capital ICT_i, to the use of broadband Internet BB_i and to control variables X_i comprising for instance previous innovation success. The relationship is specified as:

$$\Pr[Y_i^J = 1|x] = \Phi(\alpha_L lnL_i + \alpha_C lnC_i + \beta_{ICT} ICT_i + \beta_{BB} BB_i + \beta_{\mathbf{X}} \mathbf{X_i}) \qquad (3)$$

with $j \epsilon \{IC, ID\}$ and IC = process innovation and ID = product innovation, and $\Phi(\cdot)$ representing the cumulative normal distribution function. Broadband Internet is assumed to shift firm i's probability to innovate.

The use of broadband Internet might be part of a firm's strategy and therefore possibly endogenous with respect to firm performance.[7] In particular, high performing firms may be more likely to adopt broadband Internet than firms with a lower performance, possibly indicating a reverse causality. This issue is tackled by applying an instrumental variable approach for analysing labour productivity and a bivariate recursive probit for analysing innovation activity. For this purpose, broadband Internet use is instrumented by DSL availability. The latter is defined as the time lag (in years) between the deployment date for the postal code area where a firm is located and the benchmark date 31.12.2001. Due to the fact that DSL is the most widely used broadband technology in Germany and also requires the same backbone infrastructure as leased lines,[8] DSL availability is highly correlated with actual broadband Internet use. While DSL availability is related to regional economic performance, i.e. Internet infrastructure providers prefer to invest first in well-performing regions, it can be assumed to be exogenous to a single firm's performance.

We instrument firms' broadband usage by DSL availability at the corresponding postal code level.[9] For the labour productivity estimations, we also instrument production function inputs, capital and labour, with their corresponding lagged values in order to take account of possible endogeneity. The estimations are performed by the general method of moments approach.

[7]Recall that our analysis refers to the period when DSL started to diffuse. Of course, meanwhile almost all firms have broadband Internet connection.

[8]All broadband Internet connections require fast backbone nets. When DSL became available those backbone nets have presumably been made easily accessible and capable for DSL broadband, this also reduces costs for leased line deployment.

[9]See for example Wooldridge (2002) for further details on instrumental variable estimation.

For the innovation estimations we have to take into account that the dependent variables of the two equations that are to be estimated, i.e. the use of broadband Internet as well as process or product innovation, respectively, are binary. Therefore, a recursive bivariate probit approach is applied.[10] DSL availability in years is the exclusion restriction in the broadband usage equation. From the estimations we derive the marginal effects of the probability of introducing an innovation conditional on the use of broadband Internet. Moreover, the average treatment effect is calculated according to the following equation:

$$ACE = \Phi(\gamma \mathbf{Z} + \beta_{BB} BB) - \Phi(\gamma \mathbf{Z}) \quad (4)$$

where γ is the vector of the coefficients according to equation (3) excluding broadband usage while β_{BB} refers to broadband usage. The standard errors are then calculated using the delta method.

4 Data and Descriptive Analysis

For the empirical analysis three different data sets are used: (i) The ZEW ICT survey which is a firm-level data set comprising information about firms' performance, broadband usage and firm characteristics; (ii) data on DSL availability at the postal code level provided by Deutsche Telekom AG; (iii) the INKAR database with information on regional economic characteristics provided by the German Federal Institute for Research on Building, Urban Affairs and Spatial Development.

4.1 Firm-level Variables

The analysis is based on two waves of a representative business survey carried out by the Centre for European Economic Research (ZEW) in 2002 and 2004 (ZEW ICT Survey). Most of the survey questions refer to the years 2001 and 2003, respectively. The advantage of restricting the analysis to these particular surveys, is that with approximately 60 percent of firms using broadband in 2002, there is a significant variation in this variable which is helpful for identifying the impacts of broadband Internet on firm performance.

[10]See for example Heckman (1978), Maddala (1983, p.123), Angrist and Pischke (2009, pp.197-204) and Greene (2008, pp.823-826) for further details.

The sample is stratified according to sectors (seven manufacturing sectors and seven business-related service sectors), three size classes and two regions (East/West Germany). Each wave comprises 4,400 firms located in Germany. The data set contains detailed information on the use of ICT applications, innovation activity, sales, number and qualification structure of employees and many further firm characteristics.

Broadband Internet is measured by a dummy variable and is defined as a firm's use either of leased lines, or DSL broadband. In particular, the relevant question in the survey is "What kind of Internet connection does your company have?". The list of possible answers is (i) modem, (ii) ISDN, (iii) DSL, (iv) leased line, (v) others. At the time considered here, DSL Internet access provided an access speed of at least 768 kbits per second. This is clearly above the lower bound of the OECD broadband definition of 256 kbits per second (OECD, 2009). Importantly, at this time, DSL was, beside leased lines for larger firms, the dominant broadband technology capturing nearly the entire market. Alternative broadband technologies such as satellite connection and powerline were not of relevance for firms at that time.

Labour productivity is measured as sales per employee. Realised *process innovation* is measured by a dummy variable, indicating whether a firm has internally introduced new or significantly improved processes between the years 2001 to 2003. Realised *product innovation* accordingly measures whether the firm has introduced new or significantly improved products or services.[11] Moreover, we take account of the success breads success hypothesis (see for example Flaig and Stadler, 1994, and Peters, 2009) by including innovation activity from the previous period and thus controlling for firms' previous experience in innovation.

Since *non-ICT capital* is not observed in our data set, it is proxied by *total investment* in million euros. *ICT capital* is proxied by three variables: The ICT survey provides information about firms' *ICT intensity* measured as the percentage share of employees working predominately at a computer. In addition, two dummy variables capture whether a firm applies Supply Chain Management (*SCM*) or Enterprise Resource Planning (*ERP*).

The *qualification of employees* is captured by the proportion of employees being high-skilled (degree from university, university of applied sciences or university of cooperative education). Medium-skilled (master craftsman, engineer or vocational

[11]These definitions follow the OSLO manual (OECD and Eurostat, 2005).

training) and low-skilled (without formal qualification) workers are the reference categories.

Descriptive statistics are presented in Table 1. The average value of labour productivity is 0.19 million Euros of sales per employee.[12] The firms have on average 166 employees, 21% of the employees are high-skilled. The average investment is 1.95 million Euros.

On average, 52% of a firm's employees work mainly with a computer. 22% of the firms use Supply Chain Management (SCM) and 77% apply an Enterprise Resource Planning (ERP) system. Broadband Internet is used by 61% of the firms. Most of the firms without broadband use alternative Internet technologies such as a modem. Only about two percent of the firms do not have an Internet connection.

Concerning innovative activity, 75% of all firms have introduced new or significantly improved processes (process innovations) between 2001 and 2003, while 65% of the firms have brought new or significantly improved products or services to the market (product innovations) within that time.

Additionally, a set of dummy variables controls for differences across location (East or West Germany), export activity and sector affiliation. On average, 21% of the firms are located in East Germany, 53% export their products or services. In order to take account of regional disparities, we use a set of 10 regional dummies controlling for the postal code area the firm is located in.[13]

Table 1 also reveals systematic differences between firms with and firms without broadband Internet. Firms with broadband Internet are larger with respect to total investment and number of employees. In firms with broadband a larger share of employees works mainly with a computer (59% compared to 40%). Firms with broadband Internet have an only slightly higher labour productivity than firms without broadband (20% versus 18%). By contrast, in the group of broadband users, there is a considerably higher share of process and product innovators than in the group of non-broadband users (80% compared to 68% in case of process innovation, and 71% compared to 57% in case of product innovation).

[12] Since there are a few very large firms in the sample, we drop 5% of the firms with largest number of employees, thus firms with more than 1,500 employees. Moreover, we omitted outliers with labour productivity being at least five times larger than the sector mean.

[13] These 10 postal code areas cover much wider regional units than those at which DSL availablity is measured. In the estimation sample, DSL availability is observed for 815 postal code areas.

Table 2 shows descriptive statistics of the subsample used for the estimations. While firms in the subsample tend to be smaller in terms of employees than in the full sample, all other variables show more or less the same structure implying that the reduced sample does not suffer from systematic bias.

4.2 DSL Availability at Postal Code Level

We use information on regional DSL availability to instrument firms' actual broadband usage. The data is provided by Deutsche Telekom AG and contains information about the main distribution frames and the dates when these distribution frames were equipped with DSL.[14]

DSL deployment in Germany began for a couple of test regions in 1999, but officially started in 2000. As shown in Table 3, by the end of 2001, DSL was available already in 75.57% of the postal code regions in Germany, this means that in these postal code regions at least one distribution centre was equipped with DSL.

In our analysis DSL availability is defined as the time lag (in years) between the deployment date for the postal code where a firm is located and the benchmark date 31st of December, 2001.[15]

Table 4 shows mean and percentiles of days of DSL availability by the 31st of Decembre, 2001, for the estimation sample. This comprises 815 postal code areas. On average, firms are located in postal code areas where DSL is available for 332 days. 25% of the firms are located in areas with DSL availability for 180 days and 75% of the firms in areas with DSL availability for 458 days. Thus, our measure of DSL availability is characterised by large variation.

There are at least three reasons why DSL availability at the regional level can be considered to be an appropriate instrument for a firm's broadband Internet use: First, DSL is the dominant broadband technology at this time and the availability of backbone infrastructure needed for DSL also facilitates and reduces prices for the use of leased lines.[16] Second, DSL availability is exogenously determined by the

[14]We consider only postal code regions in which a DSL main distribution frame is located. We do not know if this distribution frame provides also neighbouring postal code areas with DSL.

[15]For the estimations, we divide the variable DSL availability in days by 365 in order to obtain the number of years of availability. This is without loss of precision, but simply increases coefficients, such that the interpretation becomes more convenient.

[16]The results derived in the following sections are also robust if we exclude the observations for leased lines.

telecommunication provider and not influenced by a single firm and its strategies. Third, for the time period considered in this study, DSL availability shows still enough variation for identifying broadband Internet use at the firm level.

4.3 Regional Information

Further information on regional economic characteristics, stems from the INKAR database provided by the German Federal Institute for Research on Building, Urban Affairs and Spatial Development. GDP per capita at the county level[17] measures regional performance and takes account of the fact that Internet infrastructure providers invest in prospering regions first. The estimation sample comprises 223 counties.

5 Empirical Results

5.1 Labour Productivity

Table 5 shows the results from estimating the production function according to equation (2). Column (1) refers to a simple OLS specification, including broadband usage, labour and investment as well as controls for sectors and location. The estimation shows a positive and significant relationship between the use of broadband Internet and labour productivity at the firm level. This result is not surprising given the potential embedded in a broadband Internet infrastructure at the firm level, as it can increase efficiency of business processes (i.e. E-commerce and global networking).

The optimal choice of inputs and strategies, however, might be affected by firm performance rendering the results of an OLS estimation inconsistent. In order to derive consistent estimates we apply an instrumental variable approach the results of which are presented in columns (2)-(6) of Table 5.[18]

The first stage regressions show positive and significant coefficients of the instrumental variable, i.e. years of DSL availability. Moreover, firms that are larger and

[17] In German: Kreisebene.

[18] For all specifications, the Wald endogeneity test suggests that there is endogeneity. Therefore, an IV strategy seems to be appropriate to derive consistent estimates.

more IT intensive have a higher probability of using broadband Internet. The second stage regressions reveal a positive and significant impact of broadband Internet on labour productivity. In all estimations, however, the broadband coefficient is considerably larger than in the OLS regression and it is estimated with less precision as indicated by the large standard errors.

While specification (2) corresponds to the OLS specification, specifications (3)-(6) extend the analysis by including additional variables that are supposed to be important determinants of labour productivity such as the computerisation of workplaces, the application of ERP and SCM, the share of highly qualified employees, as well as firms' previous experience with innovation.

Specification (3) introduces the percentage of employees working predominantly with computers as a measure of firms' ICT intensity. In accordance with the literature, ICT intensity is positively related to labour productivity. The impact of broadband Internet on labour productivity remains positive and weakly significant. When dummies for ERP and SCM are introduced as further measures of ICT (specification 5) only SCM turns out to be positively related to labour productivity while leaving the impact of broadband Internet unaffected. The share of highly qualified employees as well as the realisation of product innovation in previous periods do not play any significant role for labour productivity. Although the impact of broadband Internet remains weakly significant in columns (3)-(5), this impact is measured with low precision as the standard errors show.

Finally, specification (6) introduces regional variables, i.e. postal code dummies and GDP per head at the county level in order to control for regional economic characteristics. As outlined before, telecommunication providers are likely to invest in regions with greater economic potential first. The coefficient of broadband Internet in the labour productivity equation is reduced and turns to be insignificant.

5.2 Innovation

Table 6 presents the estimation results for process innovations. The first column refers to the probit estimation. As expected it shows a positive and significant coefficient of broadband use. The recursive bivariate probit estimations are depicted in columns (2) to (5). They take account of the fact that firms' broadband usage might be endogenous to process innovation activity. The regressions with broadband as dependent variable all reveal a positive and highly significant coefficient of the instrumental variable (or exclusion restriction) years of DSL availability. This together with the likelihood ratio tests suggests that the application of a bivariate probit is preferable to a simple probit approach and that DSL availability seems to be an appropriate instrument.

In particular, analogously to the previously described productivity estimation, specifications (2) to (5) take into account additional factors relevant for explaining the realisation of process innovations. Investment, the percentage of employees working predominantly with computers as well as the previous realisation of product innovations turn out be positively related to the probability of realising process innovations.[19] Although the coefficient of broadband use decreases when the number of additional explanatory variables increases, it remains positive and highly significant suggesting that broadband usage has a positive impact on the probability to realise a process innovation.

Table 7 presents the marginal effects for the probit and the bivariate probit estimations. According to the simple probit estimation broadband Internet use has an impact of 7.96 percentage points on the probability to innovate. Column (2) provides the first recursive bivariate probit's marginal effects yielding a severe increase to 63.00 percentage points in the probability to innovate. The marginal effect is measured at the mean of all variables and conditional on broadband Internet being used. This marginal effect decreases as further variables are included in the regressions reaching a – still very high – value of 56.01 in specification (5).

Table 8 presents the average marginal effects of the probit estimations and the average causal effects derived from the bivariate probit estimations. According to the probit estimation, on average, broadband Internet use increases the probability of realising a process innovation by 7.80 percentage points, which is close to the marginal effect at the mean. The average causal effects resulting from the recursive bivariate probit are much larger lying between 40.57 (specification 5) and 45.30 (specification 2) percentage points.

While the common probit model, not taking into account potential endogeneity of firms' broadband usage, is likely to underestimate the effect of broadband Internet use, the bivariate probit seems to overestimate it. One possible reason is that there are unobserved factors driving firms' innovative activity that are negatively

[19]The 2002 ZEW ICT Survey did not ask for process innovations, such that product innovations are used as a proxy for previous innovation experience.

correlated with the firms' broadband usage. For instance, the adoption of broadband Internet might induce a process of internal reorganisation (e.g. online presence) that reduces the contribution of some existing practices to the firms' innovative output (e.g. printed advertising versus online advertising).

Moreover, the estimations may suffer from a small sample size. Even though the exact quantification of the impact of broadband usage on process innovations remains difficult due to these sources of imprecision, the positive and highly significant effects suggest that, during or right after the phase of DSL expansion, broadband Internet boosted the probability to reshape and reorganise business processes. Interestingly, the large size of the coefficient might reflect how the use of broadband Internet, as General Purpose Technologies (GPT), benefits from adoption externalities and knowledge spillovers as its usage is diffused throughout the economy.

Turning to product innovations, Table 9 presents the estimation results. Column (1) refers to the results of the simple probit estimation and shows a significant and positive correlation between broadband use and product innovation, as it was the case for process innovations. Columns (2)-(5) present the results of the recursive bivariate probit model that takes into account potential endogeneity of broadband use. In the boradband equations, the variable years of DSL availability is positive and highly significant in explaining firms' broadband use.[20]

In the product innovation equation the coefficient of broadband use is robust with respect to the different specifications (2) to (5). In all estimations, it is positive and highly significant. While former product innovations, highly qualified employees and export activity are positively and significantly related to the probability of realising product innovations, all other explanatory variables are insignificant.

Table 10 provides estimates of the marginal effects for the case of product innovations. Column (1) shows the marginal effect resulting from the simple Probit estimation. It implies that broadband use increases the probability of successfully realising product innovation by 6.93 percentage points. The marginal effects resulting from the recursive bivariate probit range from 35.71 (specification 2) to 48.73 (specification 5) percentage points.

As Table 11 shows the average marginal effect of broadband use on the probability of innovation is 6.26 percentage points according to the simple probit estimate. The

[20]The likelihood ratio test holds in the two richer specifications (4 and 5) suggesting endogeneity of broadband use. Therefore the recursive bivariate probit is preferable to the common probit model.

average causal effect stemming from the bivariate probit estimates varies between 28.29 percentage points in the sparse specification (2) to 34.58 percentage points in the richest specification (5). While the causal effects are quite large and much larger than in the case of simple probit they are lower than in the case of process innovation. The simple probit model might underestimate the effect of broadband use due to neglecting potential simultaneity between broadband use and firms' innovation activity. By contrast, the causal effects estimated by the recursive bivarite probit seem to be quite large. Possible explanations are the same as in the case of process innovation. Applying the recursive bivariate model might lead to less precision of the estimations as reflected by the large increase in standard errors. The positive and significant effects of broadband use being robust across all specifications, however, suggests that broadband Internet has enabled firms to develop and offer new or considerably improved products and services.

6 Conclusions

The purpose of the paper is to provide empirical evidence on the causal impact of broadband Internet on firms' performance in terms of labour productivity and innovation activity. Focusing on the early phase of DSL expansion in Germany we use information on DSL availability at the postal code level as an instrument for firms' broadband usage.

While broadband Internet does not have a significant impact on labour productivity it positively affects firms' probability to realise process or product innovations. Although the coefficients and marginal effects in case of innovation might be overestimated, they are highly significant and robust with respect to different specifications.

These findings support the hypothesis that broadband Internet in its expansion phase enabled firms to reshape and optimise business processes and to develop new or improve existing products and services. The fact that the impact on labour productivity turns out to be insignificant suggests that this process of reorganisation was accompanied by a phase of experimenting and learning, which is typical for the introduction of a general purpose technology. Broadband effects on labour productivity might arise in the long run, a perspective that we could not take into account due to data limitations, and that is left for future research.

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A Appendix

Table 1: Descriptive Statistics, Full Sample

Variable	**Mean**	**with broadband**	**without broadband**	**Number of obs.**
Labour Productivity 2003	0.19	0.20	0.18	1437
	(0.24)	(0.26)	(0.21)	
Process Innovation 2001 - 2003	0.75	0.80	0.68	1789
	(0.43)	(0.40)	(0.47)	
Product Innovation 2001 - 2003	0.65	0.71	0.57	1783
	(0.48)	(0.46)	(0.50)	
Broadband Internet Use 2002	0.61			3901
	(0.49)			
Internet Use 2002	0.98	1.0	0.95	4030
	(0.14)	(0.0)	(0.23)	
Total Employees 2001	166.11	205.46	94.90	4037
	(260.80)	(290.45)	(176.29)	
Investment 2001 (in Millions)	1.95	2.48	1.00	2594
	(6.25)	(7.35)	(3.40)	
% of Employees using a Comp.	0.52	0.59	0.40	4030
	(0.34)	(0.33)	(0.32)	
% of High Qualified Employees	0.21	0.25	0.15	3871
	(0.25)	(0.27)	(0.21)	
Product Innovation 1999 - 2001	0.65	0.71	0.55	3997
	(0.48)	(0.46)	(0.50)	
Enterprise Resource Planning	0.77	0.84	0.67	4012
	(0.42)	(0.37)	(0.47)	
Supply Chain Management	0.22	0.26	0.15	3993
	(0.41)	(0.44)	(0.35)	
Export Dummy	0.53	0.56	0.47	4000
	(0.50)	(0.50)	(0.50)	
East Dummy	0.21	0.20	0.23	4036
	(0.41)	(0.40)	(0.42)	
GDP	28.38	29.17	26.99	4020
	(13.10)	(13.47)	(12.28)	

Source: ZEW ICT survey 2002 and 2004. Standard errors in brackets.

Table 2: Descriptive Statistics, Estimation Sample

Variable	**Mean**	**with broadband**	**without broadband**	**Number of obs.**
Labour Productivity 2003	0.18	0.19	0.18	849
	(0.21)	(0.20)	(0.24)	
Process Innovation 2001 - 2003	0.76	0.80	0.71	985
	(0.43)	(0.40)	(0.45)	
Product Innovation 2001 - 2003	0.65	0.70	0.58	985
	(0.48)	(0.46)	(0.49)	
Broadband Internet Use 2002	0.58			985
	(0.49)			
Internet Use 2002	0.99	1.0	0.97	985
	(0.11)	(0.0)	(0.17)	
Total Employees 2001	136.19	167.71	92.54	985
	(223.37)	(251.46)	(168.04)	
Investment 2001 (in Millions)	1.59	1.96	1.08	985
	(3.94)	(4.60)	(2.72)	
% of Employees using a Comp.	0.51	0.59	0.40	985
	(0.34)	(0.33)	(0.32)	
% of High Qualified Employees	0.21	0.24	0.16	985
	(0.24)	(0.26)	(0.22)	
Product Innovation 1999 - 2001	0.66	0.71	0.58	985
	(0.47)	(0.45)	(0.49)	
Enterprise Resource Planning	0.77	0.84	0.67	980
	(0.42)	(0.37)	(0.47)	
Supply Chain Management	0.23	0.28	0.15	981
	(0.42)	(0.45)	(0.36)	
Export Dummy	0.53	0.57	0.49	985
	(0.50)	(0.50)	(0.50)	
East Dummy	0.22	0.22	0.21	985
	(0.41)	(0.41)	(0.41)	
GDP	27.81	28.66	26.64	985
	(13.39)	(14.03)	12.37	

Source: ZEW ICT survey 2002 and 2004. Standard errors in brackets.

Table 3: Postal Code Regions with DSL Availability

Postal Code Regions with DSL Availability			
Year	Number	Percentage	Cumulative Percentage
2000	1249	21.73	21.73
2001	3094	53.84	75.57
2002	625	10.88	86.45
2003	69	1.2	87.65
2004	277	4.82	92.47
2005	200	3.48	95.95
2006	125	2.18	98.12
2007	80	1.39	99.51
2008 & 2009	28	0.48	100

Mean values. A postal code region has broadband availability
if at least one main distribution frame in the area
is equipped with DSL. Source: Data from Deutsche Telekom AG.

Table 4: DSL Availability measured in Number of Days

	Mean	25%	50%	75%	90%
Days of DSL Availability	332	180	328	458	607

Reading help: On average, firms are located
in postal code areas where DSL is available for 332 days.
Source: Data from Deutsche Telekom AG. Estimation Sample.

Table 5: Results for Labour Productivity; OLS and IV

Labour Productivity	*OLS*			*IV GMM*		
	(1)	(2)	(3)	(4)	(5)	(6)
Broadband Use in 2002	0.1127**	0.7997*	0.6576	0.7037*	0.6899*	0.3430
	(0.0456)	(0.4360)	(0.4139)	(0.4165)	(0.4122)	(0.3700)
Employees (in logs)	-0.1571***	-0.2854***	-0.2596***	-0.2514***	-0.2623***	-0.2531***
	(0.0279)	(0.0817)	(0.0801)	(0.0801)	(0.0772)	(0.0736)
Investment (in logs)	0.1511***	0.2247***	0.2130***	0.2060***	0.2112***	0.2226***
	(0.0201)	(0.0819)	(0.0757)	(0.0758)	(0.0732)	(0.0706)
% of Employees using			0.4902***	0.5398***	0.5258***	0.6091***
a Computer			(0.1874)	(0.1889)	(0.1806)	(0.1586)
Enterprise Resource Planning					-0.0497	0.0064
					(0.0886)	(0.0828)
Supply Chain Management					0.1160	0.1383**
					(0.0728)	(0.0680)
% of High Qualified Employees				-0.1660	-0.1745	-0.1139
				(0.1387)	(0.1377)	(0.1329)
Product Innovation (1999-2001)				-0.0843	-0.0870	-0.0908
				(0.0695)	(0.0700)	(0.0656)
GDP per Capita						-0.0012
						(0.0019)
Postal Code Dummies						x
Export Dummy	0.1666***	0.0475	0.0426	0.0603	0.0498	0.0583
	(0.0526)	(0.0815)	(0.0755)	(0.0797)	(0.0800)	(0.0755)
Constant	-1.3465***	-1.0650**	-1.2632***	-1.2852***	-1.1838**	-1.1063**
	(0.1519)	(0.5244)	(0.4702)	(0.4741)	(0.4605)	(0.4654)
Broadband Use,						
first stage						
Years of DSL availability		0.2396***	0.1917**	0.1941**	0.1863**	0.1966**
		(0.0788)	(0.0803)	(0.0809)	(0.0814)	(0.0854)
Employees (in logs)		0.1928***	0.2156***	0.2176***	0.1843***	0.1745***
		(0.0459)	(0.0468)	(0.0476)	(0.0487)	(0.0495)
Investment (in logs)		0.0602*	0.0451	0.0455	0.0397	0.0414*
		(0.0312)	(0.0319)	(0.0322)	(0.0326)	(0.0331)
% of Employees using			1.1162***	1.1035***	1.044***	1.0031***
a Computer			(0.1590)	(0.1696)	(0.1713)	(0.1744)
Enterprise Resource Planning					0.3135***	0.3585***
					(0.1073)	(0.1101)
Supply Chain Management					0.1482	0.1508
					(0.1146)	(0.1158)
% of High Qualified Employees				0.0014	-0.0071	0.0500
				(0.2316)	(0.2320)	(0.2479)
Product Innovation (1999-2001)				-0.0410	-0.0702	-0.0685
				(0.0994)	(0.1004)	(0.1025)
GDP per Capita						0.0014
						(0.0036)
Postal Code Dummies						x
Export Dummy		0.2203**	0.1676*	0.1843*	0.1755*	0.1213
		(0.0982)	(0.1000)	(0.1020)	(0.1027)	(0.1054)
Constant		-1.0705***	-1.4635***	-1.4546***	-1.5777***	-1.6129***
		(0.2620)	(0.2735)	(0.2761)	(0.2846)	(0.3313)
Number of Observations	1137	770	770	759	752	751
Wald test		0.00	0.00	0.00	0.00	0.00
R^2	0.2101	0.0268	0.1232	0.1049	0.1041	0.2392

Robust Standard errors are in brackets. The table only shows the first stage for broadband use and not for the inputs. All estimations include controls for industries and location.
Significant at 1% ***, significant at 5% ** , significant at 10% *

Table 6: Results for Process Innovation, Probit and Bivariate Probit

Process Innovation 2003-2001	***Probit*** (1)	***Recursive Bivariate Probit*** (2)	(3)	(4)	(5)
Broadband Use in 2002	0.2599***	1.4082***	1.3985***	1.2976***	1.2878***
	(0.0931)	(0.1792)	(0.1823)	(0.2340)	(0.2389)
Employees (in logs)		-0.0461	-0.0615	-0.0594	-0.0589
		(0.0481)	(0.0482)	(0.0513)	(0.0516)
Investment (in logs)		0.0720**	0.0684**	0.0781**	0.0785**
		(0.0324)	(0.0323)	(0.0330)	(0.0330)
Product Innovation (1999-2001)			0.2541**	0.3053***	0.3022***
			(0.0997)	(0.1006)	(0.1008)
% of Employees using a Comp.				-0.3166	-0.3458*
				(0.1974)	(0.2025)
% of High Qualified Employees					0.1693
					(0.2306)
Exports	0.2700***	0.0363	-0.0103	0.0116	0.0068
	(0.1017)	(0.0995)	(0.1003)	(0.1022)	(0.1025)
GDP per Capita		-0.0039	-0.0030	-0.0021	-0.0022
		(0.0033)	(0.0034)	(0.0034)	(0.0034)
Postal Code Dummies		x	x	x	x
Constant	0.5523***	0.3850	0.2970	0.3875	0.3967
	(0.1689)	(0.3066)	(0.3084)	(0.3143)	(0.3152)
Broadband Use					
Years of DSL Availability		0.2791***	0.2654***	0.2415***	0.2415***
		(0.0727)	(0.0734)	(0.0764)	(0.0766)
Employees (in logs)		0.1796***	0.1732***	0.2026***	0.2025***
		(0.0470)	(0.0473)	(0.0483)	(0.0484)
Investment (in logs)		0.0562*	0.0565*	0.0483	0.0485
		(0.0325)	(0.0324)	(0.0331)	(0.0331)
Product Innovation (1999-2001)			0.0883	-0.0202	-0.0194
			(0.0979)	(0.1012)	(0.1014)
% of Employees using a Comp.				1.0549***	1.0632***
				(0.1643)	(0.1728)
% of High Qualified Employees					-0.0374
					(0.2382)
Exports		0.1804*	0.1610	0.1335	0.1348
		(0.1002)	(0.1021)	(0.1040)	(0.1045)
GDP per Capita		0.0034	0.0037	0.0012	0.0012
		(0.0035)	(0.0035)	(0.0036)	(0.0036)
Postal Code Dummies		x	x	x	x
Constant		-1.1047***	-1.1001***	-0.9558***	-0.9425***
		(0.2935)	(0.2935)	(0.3009)	(0.3020)
ρ		-0.8022***	-0.8005***	-0.7424**	-0.7364**
		(0.1046)	(0.1054)	(0.1350)	(0.1382)
Number of Observations	985	985	985	985	985
Likelihood Ratio Test		0.0033	0.0042	0.0128	0.0145

Standard errors are in brackets. All estimations include controls for industries and location.
Significant at 1% ***, significant at 5% ** , significant at 10% *

Table 7: Marginal Effects Process Innovation

Process Innovation 2003-2001	***Probit*** (1)	***Recursive Bivariate Probit*** (2)	(3)	(4)	(5)
Broadband Use in 2002	0.0796***	0.6300***	0.6257***	0.5660***	0.5601***
	(0.0288)	(0.1045)	(0.1066)	(0.1336)	(0.1361)
Employees (in logs)		0.0064	0.0008	0.0039	0.0039
		(0.0134)	(0.0134)	(0.0141)	(0.0142)
Investment (in logs)		0.0291***	0.0279***	0.0295***	0.0296***
		(0.0091)	(0.0090)	(0.0092)	(0.0092)
Product Innovation (1999-2001)			0.0950***	0.0971***	0.0960***
			(0.0303)	(0.0308)	(0.0308)
% of Employees using a Comp.				0.0180	0.0093
				(0.0521)	(0.0532)
% of High Qualified Employees					0.0483
					(0.0663)
GDP per Capita		-0.0008	-0.0005	-0.0005	-0.0006
		(0.0009)	(0.0010)	(0.0010)	(0.0010)
Export Dummy	0.0819***	0.0327	0.0155	0.0184	0.01670
	(0.0309)	(0.0279)	(0.0280)	(0.0289)	(0.0289)
Number of Observations	985	985	985	985	985

Marginal effects at the mean in column (1). Marginal effects
at the mean, conditional on broadband being used in columns (2)-(5),
except of coefficient for broadband use. Standard errors in brackets.
Significant at 1% ***, significant at 5% ** , significant at 10% *

Table 8: Average Marginal Effect (Probit) and Average Causal Effects (Recursive Probit) Process Innovation

Process Innovation 2003-2001	***Probit*** (1)	***Recursive Bivariate Probit*** (2)	(3)	(4)	(5)
Broadband Use in 2002	0.0780***	0.4530***	0.4470***	0.4093***	0.4057***
	(0.0254)	(0.0687)	(0.0688)	(0.0788)	(0.0807)
Number of Observations	985	985	985	985	985

Column (1) provides average marginal effects. Columns (2)-(5)
provide average causal effects. Standard errors in brackets.
Significant at 1% ***, significant at 5% ** , significant at 10% *

Table 9: Results for Product Innovation, Probit and Bivariate Probit

Product Innovation 2003-2001	***Probit*** (1)	***Recursive Bivariate Probit*** (2)	(3)	(4)	(5)
Broadband Use in 2002	0.1893**	0.8529*	0.9717**	1.0862***	1.1048***
	(0.0891)	(0.4435)	(0.4913)	(0.3867)	(0.3901)
Employees (in logs)		0.1221*	0.0638	0.0500	0.0467
		(0.0671)	(0.0702)	(0.0660)	(0.0670)
Investment (in logs)		0.0175	0.0007	-0.0010	-0.0007
		(0.0332)	(0.0334)	(0.0322)	(0.0324)
Product Innovation (1999-2001)			0.8624***	0.8450***	0.8291***
			(0.1668)	(0.1380)	(0.1392)
% of Employees using a Comp.				-0.1544	-0.2997
				(0.2438)	(0.2416)
% of High Qualified Employees					0.6728***
					(0.2548)
Export Dummy	0.5763***	0.3923***	0.2370*	0.2272**	0.2004*
	(0.0982)	(0.1227)	(0.1233)	(0.1143)	(0.1145)
GDP per Capita		-0.0028	0.0000	0.0003	-0.0001
		(0.0034)	(0.0036)	(0.0035)	(0.0035)
Postal Code Dummies		x	x	x	x
Constant	-0.1097	-1.0635***	-1.4653***	-1.4139***	-1.3794***
	(0.1570)	(0.3095)	(0.3426)	(0.3494)	(0.3532)
Broadband Use					
Years of DSL Availability		0.2426***	0.2249***	0.1987**	0.1954**
		(0.0799)	(0.0796)	(0.0792)	(0.0793)
Employees (in logs)		0.1848***	0.1755***	0.2015***	0.2009***
		(0.0474)	(0.0482)	(0.0489)	(0.0490)
Investment (in logs)		0.0600*	0.0602*	0.0515	0.0525
		(0.0323)	(0.0324)	(0.0330)	(0.0331)
Product Innovation (1999-2001)			0.0979	-0.0019	-0.0022
			(0.0992)	(0.1021)	(0.1023)
% of Employees using a Comp.				1.0950***	1.0910***
				(0.1646)	(0.1726)
% of High Qualified Employees					0.0155
					(0.2348)
Exports		0.1648	0.1438	0.1037	0.1009
		(0.1016)	(0.1037)	(0.1049)	(0.1056)
GDP per Capita		0.0029	0.0031	0.0004	0.0004
		(0.0035)	(0.0035)	(0.0036)	(0.0036)
Postal Code Dummies		x	x	x	x
Constant		-0.5671	-0.6986	-0.8494**	-0.8697**
		(0.3645)	(0.4606)	(0.4254)	(0.4413)
ρ		-0.5132	-0.6035	-0.6907*	-0.7012*
		(0.2684)	(0.2929)	(0.2224)	(0.2243)
Number of Observations	985	985	985	985	985
Likelihood Ratio Test		0.1676	0.1967	0.0871	0.0927

Standard errors in brackets. All estimations include controls for industries and location.
Significant at 1% ***, significant at 5% ** , significant at 10% *

Table 10: Marginal Effects Product Innovation

Product Innovation 2003-2001	***Probit***	***Recursive Bivariate Probit***			
	(1)	(2)	(3)	(4)	(5)
Broadband Use in 2002	0.0693**	0.3571*	0.4168*	0.4776**	0.4873**
	(0.0327)	(0.2074)	(0.2392)	(0.1942)	(0.1977)
Employees (in logs)		0.0668***	0.0476**	0.0505**	0.0492**
		(0.0180)	(0.0194)	(0.0199)	(0.0203)
Investment (in logs)		0.0132	0.0080	0.0073	0.0076
		(0.0115)	(0.0118)	(0.0121)	(0.0119)
Product Innovation (1999-2001)			0.3640***	0.3562***	0.3496***
			(0.0372)	(0.0375)	(0.0379)
% of Employees using a Comp.				0.1018	0.0439
				(0.0662)	(0.0686)
% of High Qualified Employees					0.2741***
					(0.0933)
GDP per Capita		-0.0008	0.0004	0.0002	0.0000
		(0.0013)	(0.0013)	(0.0013)	(0.0013)
Export Dummy	0.2091***	0.1685***	0.1170***	0.1080***	0.0966**
	(0.0350)	(0.0371)	(0.0394)	(0.0397)	(0.0401)
Number of Observations	985	985	985	985	985

Marginal effects at the mean in column (1). Marginal effects at the mean, conditional on broadband being used in columns (2)-(5), except of coefficient for broadband use. Standard errors in brackets. Significant at 1% ***, significant at 5% ** , significant at 10% *

Table 11: Average Marginal Effects (Probit) and Average Causal Effects (Recursive Probit), Product Innovation

Product Innovation 2003-2001	***Probit***	***Recursive Bivariate Probit***			
	(1)	(2)	(3)	(4)	(5)
Broadband Use in 2002	0.0626***	0.2829***	0.3024**	0.3425***	0.3458***
	(0.0284)	(0.0944)	(0.1220)	(0.1110)	(0.1168)
Number of Observations	985	985	985	985	985

Column (1) provides average marginal effects. Columns (2)-(5) provide average causal effects. Standard errors in brackets. Significant at 1% ***, significant at 5% ** , significant at 10%*