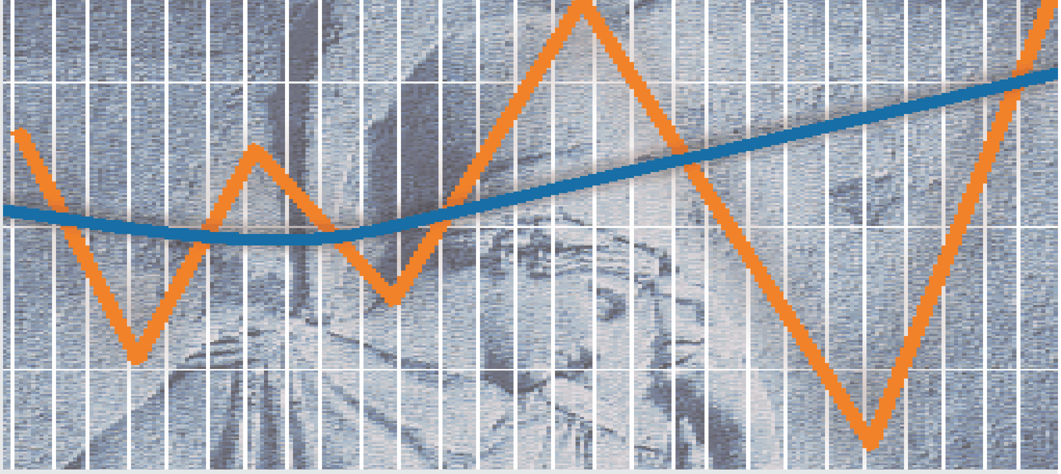

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60

Investment in ICT: Determinants and Economic Implications

Nadine Fabritz

ifo Institut
Leibniz-Institut für Wirtschaftsforschung
an der Universität München e.V.

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Preface

This study was prepared by Nadine Fabritz while she was working at the Ifo Institute for Economic Research in the Department for Human Capital and Innovation. It was completed in June 2014 and accepted as a doctoral thesis by the Department of Economics at the University of Munich in October 2014. It consists of four distinct empirical analyses in the field of the economics of Information and Communication Technologies (ICT). Three analyses address the economic effects of ICT investments, while one is concerned with determinants of investment in ICT networks. The study uses German firm-level data and regional-level data from Germany and the United Kingdom. The empirical strategies in all analyses attempt to establish causal relationships between the variables and outcomes of interest as much as possible by using panel models and controlling for unobserved, time-invariant individual factors. Chapter 2 tests the hypothesis that firms' investment in ICT enables product innovations using data from the Ifo Innovation Survey. Controlling for previous innovation activity, and thereby excluding invariant confounding firm-level factors, the results confirm a positive relationship between investments in new ICT capital and subsequent innovative activity. Chapter 3 draws on a large set of detailed firm characteristics to investigate the impact of local broadband infrastructure on firm performance, measured by employment size and revenue at the firm level. No overall effects of broadband on firm performance are found, but results suggest that certain subgroups profit from the infrastructure, such as firms in East Germany and small firms in the service sector. Chapter 4 equally deals with economic outcomes of broadband infrastructure and finds positive, albeit small, employment effects of broadband deployment in rural municipalities in Germany. Chapter 5 analyses the role of regulation in stimulating private investment in telecommunication infrastructure by exploiting a reform in the United Kingdom, where a broadband wholesale market was deregulated in some areas. The results show positive effects of deregulation on infrastructure investments by the incumbent, as well as its competitors.

Keywords: Innovation; Information and Communication Technologies; Broadband Internet; Infrastructure Investment; Regional Development; Regulation; Panel Estimation.

JEL-Codes: L5, L96, O1, O3, R1

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Referent: Prof. Dr. Ludger Wößmann
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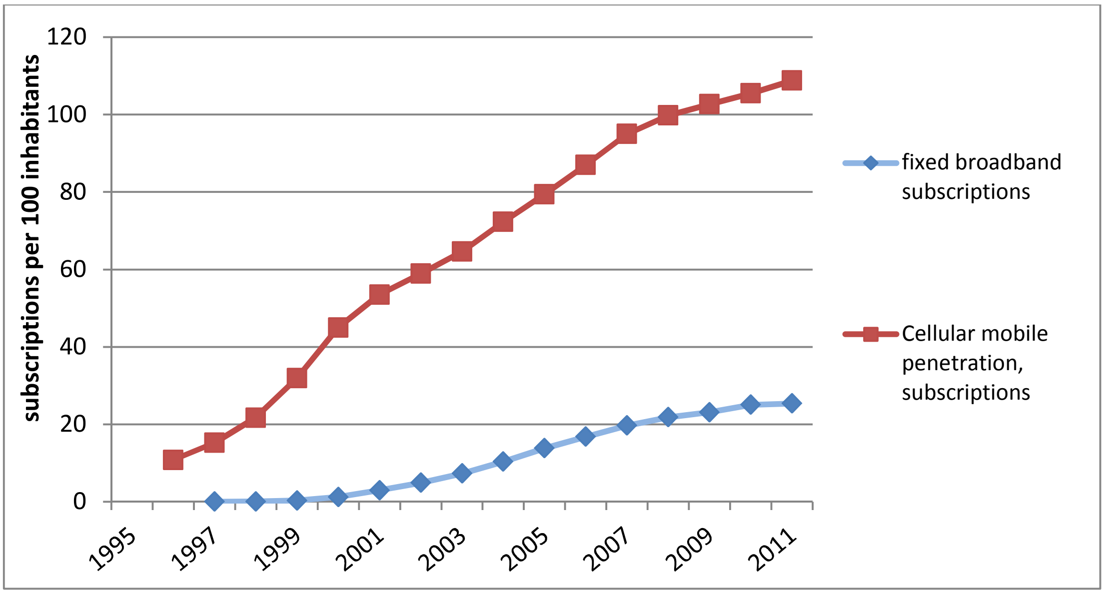
1 The Economics of ICT Investments

1.1 ICT as Driver of Economic Growth

Maintaining stable economic growth is of highest priority to policy makers because it promises high standards of living. Standard growth theory postulates ongoing technological progress as the most basic prerequisite to maintain a positive long-run growth rate in income per capita (Aghion and Howitt, 1998). This progress takes the form of innovations i.e. inventions that are implemented in the economy and that occur in the form of new products, processes, and marketing practices as well as organizational change (OECD, 2005). As already indicated by Schumpeter (1912), the major force behind economic growth is technological progress. He came up with the theory of “creative destruction” where the driving forces behind economic growth are innovative firms that replace existing enterprises. In classical growth models (Solow, 1956), technological progress plays a crucial role in determining growth by shifting the production function upward, thus increasing productivity for any given combination of production factors. However, the Solow growth model takes technological progress as given. More recent works of endogenous growth theory (see e.g. Romer, 1990; Grossman and Helpman, 1991; Aghion and Howitt, 1992; 1998) explicitly model technological process as the central cause of economic growth. Aghion and Howitt argue that innovations result from uncertain research activities that the firm undergoes in order to acquire monopoly profits over its competitors.

Information and Communication Technology (ICT) has been a key driver of technological progress in recent decades. The term ICT generally refers to equipment and services related to broadcasting, computing and telecommunications, all of which capture, process and display information electronically (United Nations, 2004). When considering ICT investments, we make a general distinction between two types. First, firms’ investment in ICT capital relates to computers, software and similar equipment used throughout firms of all industries. Second, telecommunication operators’ investment in ICT infrastructure, such as broadband or fiber networks, is important in connecting users of ICT capital to other users, for example through the Internet. As outlined below, all these components of ICT have the potential to generate direct benefits to the economy such as increasing productivity or enabling complementary innovations, thereby generating economic growth.

Figure 1-1: The Diffusion of ICT between 1995 and 2011 in OECD Countries



Data Source: based on OECD (2013).

1.1.1 The Emergence and Diffusion of New ICT

While telecommunication technology as such is not a new phenomenon, as telegraphs or the telephone already came into service in the nineteenth century, this dissertation is concerned with ICT innovations of recent decades. New ICT technologies, such as personal computers or the Internet, have emerged from niche products, designed for government institutions and university networks in the 1960ies, to ubiquitous, indispensable technologies in modern societies. The declining costs of communication equipment have led to the wide adoption of ICT. Figure 1-1 shows pervasive evidence on the rapid diffusion of ICT during the last two decades. The number of mobile phone subscribers, per 100 inhabitants in OECD countries, increased tenfold between 1996 and 2011. Nowadays, there is more than one mobile subscription per capita on average. Similarly, fixed broadband internet was practically non-existent before 1997. Statistics from the year 2011 reveal that there are 25 subscriptions per 100 inhabitants.[1] According to the OECD (2013), global telecommunication revenues were at 1.6 trillion USD. These ICT adoption rates are striking and show how universally present these technologies are today.

1.1.2 The Role of ICT in the Economic Literature

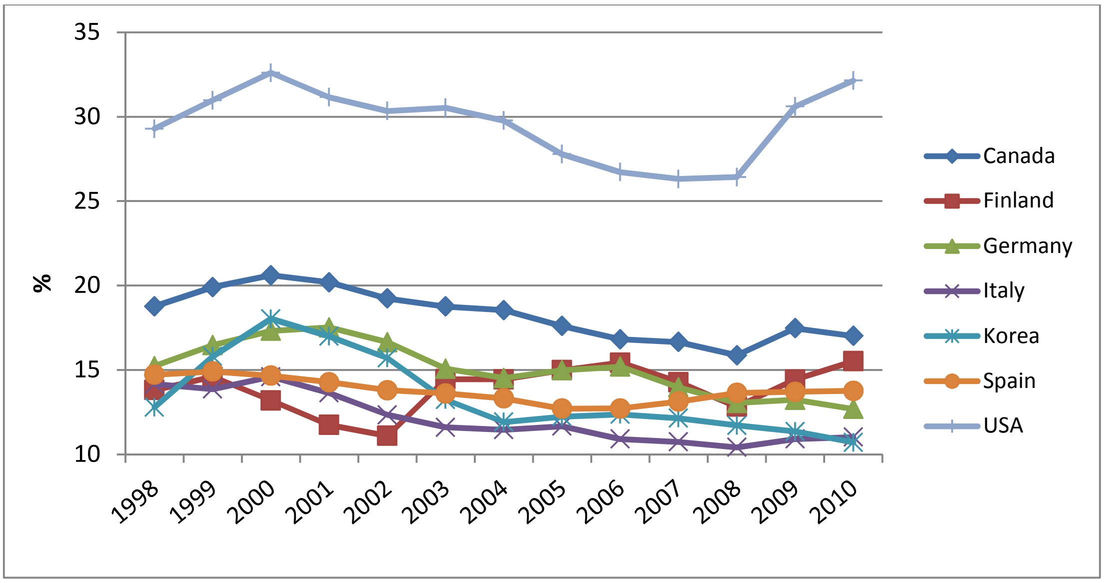
Economists have been studying the effects of ICT on economic performance for some time. In the 1980s and early 1990s, the debate was dominated by the phenomenon of the so-called

[1] The average household size in OECD countries was about 2.63 persons in 2009, which means that the effective percentage of the population with home access to broadband is considerably higher.

"productivity paradox", i.e. the perceived discrepancy between firms' investments in ICT and the productivity output it generated. The term developed with the observation of a considerable productivity slowdown in OECD countries since the early 1970s that persisted for about 20 years despite heavy investments in ICT (Macdonald et al., 2000). Robert Solow (1987) stated that "we see the computer age everywhere except in the productivity statistics". This view has changed over time and scholars came to the conclusion that ICTs offer potentially large benefits to the economy. Two main reasons for the productivity paradox emerged in the literature: First, flaws in the concept of measuring productivity as well as firm investments in ICT prevented the detection of returns on investment (Brynjolfsson, 1993). Second, a productivity lag of ICT made payoffs appear several years later in the official statistics (Brynjolfsson et al., 1994).

More recent studies have confirmed a positive link between the diffusion of ICT infrastructure and economic growth at the aggregate level (see. e.g. Czernich et al., 2011; Koutroumpis, 2009; Röller and Waverman, 2001). In addition to infrastructure, ICT capital used in firms plays an important role. In particular, van Ark et al. (2008) identified a low firm investment in ICT capital as the cause of the low productivity growth in European countries relative to the US during the 1990s. Figure 1-2 shows ICT investment as a share in gross fixed capital formation for selected OECD countries, where one can see the US exhibits high levels of ICT investment compared to other countries.

Figure 1-2: Shares of ICT investment in non-residential gross fixed capital formation



Data Source: based on OECD (2013)

Another indicator for the importance of ICT for the economy and the society is, that scholars consider ICT-related technologies as today's most important "general purpose technology" (The Economist, 2012; Harris, 1998). In the definition of Bresnahan and Trajtenberg (1995), a general purpose technology is characterized by "the potential for pervasive use in a wide range of sectors and by their technological dynamism" and in that it may bring "substantial productivity gains to the economy as an enabling technology that opens up new opportunities for complementary innovations". By this definition, ICT-related innovations – such as computers or the Internet – qualify as general purpose technologies as they found use in every industry branch. The ICT producing sector itself is characterized by fast technological change. Moreover, a growing body of literature has suggested that ICT use comes along with an increase in productivity and innovative activity as outlined below.

Previous studies suggest that the development of new ideas and products makes firms more productive and therefore creates additional capacities that may be used for the development of innovations. At the firm level, several studies confirm a positive association between ICT use and productivity (see, e.g. Brynjolfsson and Hitt, 1996; Forman et al., 2005, Gillett et al., 2006). However, the findings are not generalizable to all firms. Whether productivity gains from the use of ICT exist depends on complementary factors. Forman et al. (2005) for example find that firms that integrate complex ICT applications for new business models (such as online sales in new markets) experience the highest productivity improvements. A study by Gillett et al. (2006) investigates the economic effects of broadband infrastructure at the community level. They state that broadband may not be expected to enhance productivity in isolation, but that it depends on complementary factors, such as related information technologies, innovative business practices and more flexible organizational structures in firms.

Other studies investigated productivity gains of ICT at the individual worker level. Autor et al. (2003), for example, argue that the increasing computerization is responsible for a reduced labor input in routine tasks and a relative increase of complex problem-solving tasks. They explain this phenomenon with the latter being complementary to ICT capital, whereas the former acts as a substitute. As more ICT capital is used in the firms, high-skilled labor becomes relatively more productive and demand for it increases relative to labor based on routine tasks. A large fraction of rising wage inequality in most industrialized countries can be explained by this skill-biased technological change (see Autor et al., 2008, for an application to the US labor market).

Since the early 2000s, the literature turned to the role of ICT-enabled innovations. Various studies find that ICT enables innovations by capturing, organizing, and processing knowledge, all of which are important in the innovation process. Early studies on ICT investment focus on the role of ICT in organizational innovation and conclude that the successful implementation of ICT is tied to organizational changes. That is, firms need to engage in certain organizational "co-innovations" to fully capture the benefits of ICT (see, e.g., Brynjolfsson and Hitt, 2000). Examples of organizational change include flatter hierarchies in firms due to improved communication channels, resulting in the reorganization of responsibilities. Moreover, ICT capital facilitates the collection of information, as large amounts of data can be stored and processed. In addition, geographic limitations are reduced (Koellinger, 2005), which may open the door to new markets. Gretton et al. (2004) argue that ICT allows for new forms of coordination, such as more efficient communication within firms and with customers, and has the potential to create networks among business partners. Better coordination in R&D, among business partners and customers, may lead to the development of new products and processes.

ICT moreover likely affects firms' demand for labor through the increased innovative activity and productivity (see, e.g., Bertschek et al., 2013; Gillett et al., 2006; Koellinger, 2006; Kolko, 2012). On the one hand, an income effect may increase the labor demand of firms due to higher labor productivity. On the other hand, however, ICT might have a negative effect on employment since the new technology may facilitate the use of less labor (OECD, 2008). The overall employment effect depends eventually on the relative strength of substitution and income effects.

In the context of the provision of broadband infrastructure, multiple other channels have been discussed – besides higher labor productivity – through which ICT can affect local labor demand. One possibility is the settlement of firms in an area. Broadband infrastructure might affect their location decisions ex ante, which would increase demand for labor in a region. In theory, these may be newly founded enterprises, new branches of already existing firms, or relocated firms. Mack et al. (2011) find that broadband provision explains some decisions by knowledge-intensive industries to locate in U.S. metropolitan areas. Gillett et al. (2006) conclude that U.S. communities that had broadband by 1999 experienced higher growth in employment and in the number of businesses from 1998 to 2002 than other communities. Also households might choose their places of living according to the availability of broadband internet. In general, ICT advancement is assumed to increase telecommuting (see, e.g., Autor, 2001) and this may be especially relevant for rural areas. In addition, several studies suggest that broadband might improve job matching between employees and firms in that it reduces asymmetries and lowers the costs of job search (see, e.g., Autor, 2001; Stevenson, 2009; Mang, 2012).

1.2 Government Involvement in ICT Investment

Given its potential importance to and impact on the economy, investment in ICT turned out to be of strong political interest. While increasing infrastructure investment has been at the center of the debate, there are also some policies aiming at promoting investment in ICT capital and use of these technologies.

At the European level, the EU Digital Agenda lists as one goal the promotion of longer-term strategic ICT innovation as well as enhanced investment in research and development of ICT (European Commission, 2010a). The EC's ICT Policy Support Program aimed at encouraging the use of ICT applications in small and medium-sized enterprises to enhance their innovative capacity and competitiveness during the period 2007 to 2013. In the EU's Blue Card Program from 2012, IT-experts fall under less strict regulations for immigration due to a perceived shortage of IT-skills in the economy.

Also at the national level, governments are actively involved in ICT deployment. Broadband infrastructure in rural areas has been at the center of public debates, which – besides ensuring equivalent living conditions – is believed to make regions more competitive and to create employment by increasing productivity and innovations, as outlined before. Today, most OECD countries engage in expanding ICT infrastructure to their so-called white spots, which are predominantly rural municipalities that remained underprovided if left to market forces. In an effort to promote broadband Internet as a source of growth in Germany, a total of €587 million from European, national, and federal state funding has been made available for German municipalities between 2011 and 2013 to close these white spots (Goldmedia, 2013). While a basic provision of broadband speeds up to 1 Mbit/s has nearly been achieved in Germany at the time this thesis was written, the German government already aims at ensuring speeds of 50 Mbit/s for 75 percent of households by 2014, and full coverage by 2018.

Besides directly handing out subsidies and credits for infrastructure deployment, the government may consider changes in the regulation of the private sector in order to create investor-friendly environments. For a long time, incumbents in telecommunication markets used to face little to virtually no infrastructure-based competition due to prohibitively high costs of network replication. Opening the network via a strict regulation scheme was therefore necessary to allow for competition to develop. Nowadays, incumbents in many countries face increasing infrastructure-based competition. This has fuelled a debate among regulators how incentives can be designed to ensure future investment and innovation in network infrastructure. In this context, some voices raised among policy makers, that in fact the deregulation of competitive markets might stimulate investments in network infrastructure.

1.3 Causal Inference in the Economics of ICT

Measuring the effects of ICT and understanding its determinants is important in designing policies and regulation schemes. All government interventions, such as subsidies or changes in regulations should be evaluated empirically. However, at the basis of providing sound policy implications is the identification of causal effects. Even though the growing body of empirical literature of the economics of ICT becomes increasingly aware of the challenges in measuring the effects of ICT, estimating causal effects is still in its infancy. The basic problem in estimating the effect of ICT is that we cannot observe how firms (or regions) where ICT investment occurred would have developed, had no ICT investment taken place.

The most convincing way to identify causal effects is to use exogenous variation in the variable of interest. It should be exogenous in the sense that it affects investment in ICT but is not related to the outcome variable. Ideally, this would be the case in a controlled random experiment, where treatment (ICT investment) and control (no ICT investment) status are assigned to units in a lottery. In this case, the variable of interest can be assumed independent of the error term. Even though controlled experiments become increasingly popular to evaluate education policies (see e.g. Fairly and London, 2012, for an evaluation of the use of computers among students), in the evaluation of ICT capital in firms or ICT infrastructure at the regional level, this is still practically non-existent and researchers need to come up with alternative methods.

The simple comparison of firms which invested in ICT equipment or regions where telecommunication infrastructure investment occurred does not necessarily lead to the true effect of ICT. A higher economic performance of those units where investment occurred does not imply that ICT investment caused this increased performance. The estimated effect may be subject to bias since ICT investment does not occur randomly but rather through a selection process, which essentially leads to non-comparable investing and non-investing units. For example, firms with high innovative activity have the financial resources to invest in new ICT equipment at the same time as spending on R&D. If R&D expenses cannot be observed by the researcher, he cannot distinguish whether the higher innovation stems from investments in ICT or R&D spending. Another example relates to the decision of Internet providers to roll-out broadband infrastructure. They base their investment decisions on expected profits in the regions, i.e. on future demand structures. Economically strong regions will therefore be the first to obtain broadband Internet whereas structurally weak regions will remain underprovided. The relationship between infrastructure deployment and regional development will thus be positively biased. Similar arguments apply to the evaluation of regulatory measures in the telecommunication sector. With a lack of comparability between treatment and control groups, the key challenge of every credible study is to find or to construct a counterfactual world. The ways in which this may be done are outlined below.

The first way, in which researchers might be able to overcome these endogeneity biases with Ordinary Least Squares (OLS), is to include control variables in the analysis that affect the decision to invest in ICT at the same time as they affect economic performance. Next, matching methods, as applied in Chapters 2 and 5, can eliminate that part of the selection problem that stems from selection on observable characteristics. As a non-parametric method, matching allows for a more careful comparison of treated and control group than simply controlling for confounding factors does. Matching has the distinct advantage over OLS that it does not rely on linearity in the relationship between ICT investment and the outcome. The estimation strategy of propensity score matching generates in a first step the predicted probability of investing in ICT for every firm based on past innovative activity as well as the other covariates. In a second step, only firms with positive probabilities, of both investing and not investing in ICT, are compared to each other with respect to their innovations in order to ensure common support. But in the likely presence of unobserved characteristics, estimates remain biased under OLS and matching methods alike. One example is the firms' management style that typically cannot be observed and that determines the firm’s attitude to technological progress (and therefore ICT use) and the company’s innovation strategy.

One way to control for important forms of unobservable heterogeneities is provided by panel data methods. Observing the same unit, i.e. firm or geographic region at several points in time allows eliminating time-invariant, unit-specific, characteristics in difference-in-differences, within-transformation or first-difference estimates. The effect of ICT is then estimated by the variation over time within each unit of observation. All studies presented in Chapters 2 to 5 in this dissertation make use of time-varying data. A causal interpretation from panel data methods relies on the assumption that no unobserved, time-varying heterogeneities between the units exist that are at the same time correlated with the variable of interest.

“Natural experiments” or “quasi-experiments” are methods of obtaining causal effects with observational data through exogenous variation in the explanatory variable. One popular method is instrumental variables estimation, as applied in Chapter 2, where exogenous variation in the endogenous variable “ICT investment” is generated by a third variable. Kolko (2012) for example uses geographic conditions as a limiting factor in the deployment of broadband infrastructure. Another example of exogenous variation in broadband provision is presented in Bhuller et al. (2013). They rely on the fact that broadband in Norway was rolled out under a publicly funded program. The identifying assumption with instrumental variables is that the exclusion restriction holds, i.e. the instrumental variable does not itself take influence on the outcome. If the exclusion restriction holds, only the part of ICT investment, that is exogenous to economic performance, is used in the analysis.

1.4 Outline of the Dissertation

The first three chapters of this dissertation deal with the effects of ICT at the firm and at the regional level. Economic outcomes such as firm innovation, revenues, and employment, are chosen to study the channels through which ICT may affect the economy. Economists have been studying the economic effects of ICT for some time and find predominantly positive associations between the availability or the use of ICT and various economic indicators at all levels of aggregation. However, this positive relationship may be driven by reverse causality and omitted variables bias. The studies presented herein provide a deeper understanding of the channels at the micro level through which ICT may induce economic benefits. It explicitly deals with the endogeneity between ICT investment and economic activity as mentioned before. The fourth part analyses the role of the state in the provision of infrastructure. It contributes in providing first empirical evidence on the internationally much debated relationship between deregulation at the local level and subsequent investment in telecommunication infrastructure.

Chapter 2 empirically tests the hypothesis that investment in ICT enables product innovation at the firm level. Numerous productivity and efficiency gains can be realized from increased use of ICT, all of which may help in creating innovations. We use a sample of German manufacturing firms from the Ifo Innovation Survey. This survey annually gathers detailed information on firms' innovative activity as well as general firm characteristics. In 2011, we additionally constructed questions about investment in ICT and the use of these technologies. At the firm level, econometric challenges in measuring the benefits of ICT use stem from the fact that ICT capital is not exogenous to the innovation process. On the contrary, in most cases, such investment serves certain organizational purposes that are unobserved by the researcher, causing an omitted variables bias. Moreover, simultaneity bias exists, as to fully profit from the adoption of ICT, a firm must undergo complementary process innovations. In addition, already innovative firms find it easier to make use of new ICT, which gives rise to reverse causality.

We estimate a value added model in which we include lagged values of the dependent variable on the right hand side of the regression. This is to control for unobserved time-invariant firm characteristics as innovative behavior is persistent within a firm over time. Next, we exploit the fact that the survey provides information on whether external IT consultants have provided an impetus to invest in ICT capital. Conditional on our control variables, IT consultants are exogenous to the companies' product innovation strategy, but are highly predictive of ICT investment, which allows us to additionally employ an instrumental variable approach. To check for the robustness of the results, we employ semi-parametric propensity score matching and direct matching. These methods allow us to check the robustness of the results to the underlying functional form, as well as to exclude selection on observable firm characteristics.

The empirical findings establish a positive relationship between ICT investment at the firm level and subsequent innovative activity. According to the IV results, a manufacturing firm that made a major investment in ICT is roughly 11 percentage points more likely to introduce a product innovation within the next two years. Results from propensity score and direct matching methods corroborate the positive relationship. This indicates that ICT is indeed an important enabler of product innovations.

While Chapter 2 uses a direct measure of ICT investment and therefore ICT *use* in firms, the next two chapters consider local *availability* of telecommunication infrastructure. While benefits will be generated from the use of ICT, infrastructure availability is the policy relevant measure, since governments can directly influence it.

In Chapter 3, which is joint work with Oliver Falck and Christian Seiler, the impact of local broadband infrastructure on firm performance is investigated. We measure performance by employment counts as well as annual revenue. Broadband infrastructure is likely to affect demand for labor input: On the one hand it may be positive, since access to information and interregional exchange increases labor productivity and therefore increases demand for labor. On the other hand, broadband might decrease demand for labor, since the higher labor productivity allows the substitution of workers, especially in jobs that do not require problem-solving skills. The effect of broadband availability on revenues is equally ambiguous: On the one hand firms may explore new, geographically distant markets and use new methods of marketing their products, which increases sales and revenues. On the other hand, they may face a higher degree of competition, which decreases sales. Broadband availability is moreover likely to affect different types of firms differently. We consequently look more closely into the heterogeneous effects of broadband availability.

A potential concern in the estimation is that unobservable determinants of Internet providers' decisions to roll-out broadband infrastructure may be correlated with local firms' characteristics. In order to account for firm- and region specific, time persistent effects, we estimate a first-difference model. The dataset is a rich panel of German firms of all industry branches for the time between 2000 and 2005. In 2000, broadband started to spread in Germany. By 2005, already large parts of the country were covered with the infrastructure. We thus estimate an introduction effect of broadband availability.

According to our results, we find no overall effect of local broadband infrastructure on firm performance. However, we do find a positive relationship for firms located in East Germany and smaller firms in the service sector.

Chapter 4 investigates the impact of broadband infrastructure deployment on economic performance at the regional level, as measured by local employment rates. The chapter is motivated by the government efforts to close so-called white sport. These are predominantly rural areas, in which broadband infrastructure would not be rolled-out under market conditions. Considering the regional level offers the advantage over the previous chapter, that the available data will cover the entire rural population, whereas the large sample of firm level data underrepresents more remote areas, which are at the focus of the next analysis. Moreover, the analysis at the firm level only considers already existing firms and ignores the founding of new firms – as well as the exit of marginal firms, which will be included in regional statistics. The literature on how broadband infrastructure affects regional labor markets is growing, but only few studies consider heterogeneity in the effects of ICT by types of municipality. In general, we expect that broadband effects are heterogeneous for urban and rural municipalities. The economic literature offers two seemingly contradictory hypotheses as to how broadband availability and usage will impact rural areas: First, small municipalities might benefit over-proportionately from broadband usage. Broadband technology considerably reduces transport costs for the exchange of information, thus reducing the importance of agglomeration advantages for firms and citizens. Scholars even proclaimed "the death of distance" with the rise of the Information Age. Second, broadband Internet may over-proportionately benefit urban areas. It facilitates the exchange of information and therefore enables a more efficient production and diffusion of knowledge. ICT usage is therefore complementary to high-skilled human capital which is predominantly found in large cities.

We use panel data on broadband coverage in 8,460 West German municipalities for the period from 2005 to 2009. We estimate a fixed effects model to control for time-invariant municipality characteristics. To test whether broadband infrastructure does generate surplus in rural areas, we estimate the effect for subsamples with increasing degrees of rurality.

At the regional level, the provision of ICT infrastructure is highly endogenous to local development. Even after controlling for the main determinants of the supply of broadband infrastructure, there could be municipality characteristics, such as local governments, that influence the provision of broadband infrastructure as well as the local economy. Also, positive effects of ICT infrastructure on employment suffer from reverse causality. The spread of broadband infrastructure is largely market based, and spatial differences in broadband availability arise from expected local demand as well as the costs of supplying it. Regions with low per capita fixed costs and high expected demand, i.e. urban areas have the highest broadband penetration rates. In order to account for as much as possible of the unobserved heterogeneity, we make use of the panel structure of the data and estimate a model with municipality-fixed effects.

The estimates suggest that broadband infrastructure has a positive but, in terms of economic size, rather limited effect on the local employment rates in the sample that includes all municipalities. A 10 percentage point increase in local DSL availability increases the local employment rate by 0.08 to 0.17 percentage points. This effect is stronger in rural municipalities. In addition, we find no effects in the manufacturing sector, suggesting the effect occurs in the service sector.

Taken together, it is questionable, whether the economic payoffs from local telecommunication infrastructure fulfill the high expectations set in them by scholars and policy makers. But besides economic considerations, the government engages in infrastructure deployment to ensure equivalent living conditions between regions.

Chapter 5, which is joint work with Oliver Falck, analyzes the role of regulation in stimulating private investment in telecommunication infrastructure. Traditionally, it was considered necessary among scholars and policy makers to regulate the telecommunication sector so as to foster competition by opening former incumbents' network infrastructure. Over the last decade, telecommunication markets in most European markets have developed well and incumbents in many countries face increasing infrastructure-based competition. Therefore, regulators are nowadays increasingly concerned with providing environments for infrastructure investments. At the same time, infrastructure-based competition has developed unequally within countries, with some regions enjoying more competitive markets than others. As a reaction to this development, the idea formed among national authorities that regulators should withdraw from competitive markets and only focus on geographic areas, in which little competition occurs.

To investigate private infrastructure investments by the incumbent as well as its competitors, we study the effects of a local deregulation of the wholesale broadband access market that took place in the UK in 2008. Using a panel dataset covering all regions in the United Kingdom, we exploit regional differences in deregulation following the reform. We measure broadband providers' investment incentives in response to local deregulation on two dimensions. First, we investigate the number of local loop unbundling operators in an exchange to capture the extent of infrastructure-based competition the incumbent faces in local markets. Local loop unbundling operators made large investments in installing and maintaining their own infrastructure. Second, we analyze the incumbent's infrastructure investments by its roll-out of fibre-based networks (FTTC), which enable higher transfer rates and allow the incumbent to differentiate itself from the competitors.

We find positive, economically important effects of deregulation on infrastructure-based competition. The number of local loop unbundling operators increases more in deregulated exchange areas than in regulated areas between 2007 and 2012. On average, upon being deregulated, an exchange gains one additional local loop unbundler. Furthermore, deregulation increased British Telecom's investment in FTTC infrastructure: in deregulated areas, British Telecom is 16 percentage points more likely to roll out FFTC.

2 ICT as an Enabler of Innovation: Evidence from German Microdata[2]

2.1 Introduction

Investment in ICT is commonly believed to fundamentally have changed and to continue changing firms' business practices, thereby enabling innovations (Bresnahan and Trajtenberg, 1995; Spiezia, 2011). Various studies find that ICT enables innovation by capturing, organizing, and processing knowledge, all of which are important in the innovation process. Numerous efficiency gains can be realized from increased use of ICT, all of which may help in creating innovations. New forms of coordination, such as more efficient communication within firms and with customers, as well as networks among business partners, may occur. ICT applications allow for flatter hierarchies in firms, which result in the reorganization of responsibilities. Moreover, collecting information is facilitated as large amounts of data can be stored and processed. Better coordination in R&D, among business partners and customers may lead to the development of new products and processes. Geographic limitations are reduced as ICT allows reaching a bigger market and expands the universe of possible business partners (Forman et al., 2014; Koellinger, 2005). In addition, ICT makes firms more productive and therefore creates capacities that may be used for the development of innovations.

Investment in ICT capital has moreover economic implications beyond the single firm since it has been a crucial determinant of aggregate economic growth and productivity (e.g., van Ark et al., 2008). Given its importance to and impact on the economy, enhancing ICT investment is of strong political interest. The EU Digital Agenda lists as an explicit goal the promotion of longer-term strategic ICT innovation as well as enhanced investment in research and development of ICT (European Commission, 2010a). The EC's ICT Policy Support Program aimed at encouraging the use of ICT applications in small and medium-size enterprises to enhance their innovative capacity and competitiveness during the period 2007 to 2013.

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[2] This chapter is available as Ifo Working Paper No. 195, 2015, "ICT as an Enabler of Innovation: Evidence from German Microdata".

To date, few studies tackle the endogeneity in the relationship between firms' investment in ICT and innovation. Disentangling the effect is not trivial since, in most cases, ICT investment and innovation occur together. Econometric challenges in measuring the benefits of ICT use stem from the fact that investment in ICT capital cannot be assumed to be exogenous to the innovation process, since ICT investment does not occur randomly across firms. On the contrary, in most cases, such investment serves certain organizational purposes that are unobservable by the researcher, causing an omitted variables bias. A large body of literature concludes that in order to fully profit from the adoption of ICT, a firm must engage in complementary co-innovation (see, e.g., Bresnahan et al., 2002; Brynjolfsson et al., 2002), which gives rise to a simultaneity bias. In addition, whether a firm successfully adopts ICT depends on its innovative history (Hempell et al., 2004), that is, already innovative firms find it easier to make use of new ICT, giving rise to reverse causality.

This chapter provides empirical evidence on how investing in ICT impacts firm innovation. We use a cross-sectional sample of German manufacturing firms from the Ifo Innovation Survey. This survey annually gathers detailed information on firms' innovative activity as well as general firm characteristics. In 2011, it additionally asked about investment in ICT and the use of these technologies. We focus on product innovations in the empirical analysis, which allows us to exploit some exogenous variation. Controlling for lagged values of the dependent variable, we estimate a value added model that allows us to control for time-invariant firm characteristics.

Next, we further exploit the fact that the survey provides information on whether external IT consultants have provided an impetus to invest in ICT capital. Conditional on our control variables, we argue that IT consultants are exogenous to the companies' product innovation strategy, but are highly predictive of ICT investment, which allows us to additionally employ an instrumental variable approach.[3] We then provide alternative methods to get around endogeneity bias, we employ semi-parametric propensity score matching and direct matching. These methods allow us to check the assumptions on the underlying functional form, as well as to exclude selection on observable firm characteristics.

The empirical findings establish a positive relationship between ICT investment at the firm level and subsequent innovative activity. Results from propensity score and direct matching methods corroborate this relationship. According to the IV results, a manufacturing firm that made a major investment in ICT is roughly 11 percentage points more likely to introduce a

[3] IT consultants cannot be regarded exogenous to the innovation of new processes. We therefore concentrate on product innovation in this analysis.

product innovation within the next two years. This indicates that ICT is indeed an important enabler of product innovations.

The chapter proceeds as follows. Section 2.2 introduces previous studies on the relationship between ICT investment and firm performance. Sections 2.3 and 2.4 introduce the data and the identification strategy, respectively. Section 2.5 presents and discusses the results from OLS, the value added model, matching, and IV approaches. Section 2.6 concludes.

2.2 Previous Evidence on ICT Investment and Firm Performance

Numerous empirical studies show the importance of ICT for firm performance, measured as innovation or productivity. The causal, positive link between ICT infrastructure and economic performance has been established at the aggregate level (Czernich et al., 2011; Röller and Waverman, 2001). In particular, the lower ICT intensity of the European economy has been identified as one explanation for the lower growth in productivity in European firms relative to U.S. establishments during the second half of the 1990s (van Ark et al., 2008).

At the firm level, various studies find that ICT enables innovation by capturing, organizing, and processing knowledge, all of which are important in the innovation process. Early studies on ICT investment focus on the role of ICT in organizational innovation and conclude that the successful implementation of ICT is tied to organizational changes. That is, firms need to engage in certain organizational “co-innovation” to fully capture the benefits of ICT (see, e.g., Brynjolfsson and Hitt, 2000). Examples of organizational change include flatter hierarchies in firms due to improved communication channels, resulting in the reorganization of responsibilities.

Moreover, collecting information is facilitated by ICT capital, as large amounts of data can be stored and processed. In addition, geographic limitations are reduced (Koellinger, 2005), which may open the door to new markets and news ways of conducting business. Gretton et al. (2004) argue that ICT allows for new forms of coordination, such as more efficient communication within firms and with customers, and has the potential to create networks among business partners. Better coordination in R&D, among business partners and customers may lead to the development of new products and processes.

All these changes may plausibly facilitate the development of new ideas and products in that they make firms more productive and therefore create additional capacities that may be used for the development of innovations. Findings are heterogeneous with regard to which sector of the economy benefits most from ICT, but the weight of the evidence to date points to the service sector. For example, using panel data, Hempell et al. (2004) find that ICT capital increased productivity in German and Dutch firms in the service sector. Polder et al. (2009) stress the importance of ICT in all sectors of the economy, but nevertheless find that ICT investment plays a rather limited role in manufacturing and is, moreover, only marginally significant for organizational innovation. A survey among firms in the Madrid metropolitan area finds that benefits of ICT are most prevalent in the IT and services sector (Gago and Rubalcaba, 2007). By contrast, a study among German firms by Bertschek et al. (2013) finds that local broadband infrastructure positively affects innovations of firm in manufacturing and service sectors.

The studies mentioned so far have confirmed a strong association between ICT and business innovation. However, they do not take into account the pronounced endogeneity between firm performance and ICT. ICT use, organizational change, and product innovation can be complementary (Bresnahan et al., 2002). Moreover, whether a firm successfully adopts ICT depends on its innovative history (Hempell et al., 2004), that is, already innovative firms find it easier to make use of new ICT. One study that directly addresses the endogenous nature of ICT use in firms is Spiezia (2011). Using a comprehensive dataset on firms in OECD countries, the author employs an instrumental variables approach in which he instruments ICT use with lagged values of ICT (which addresses a bias from simultaneity, but not from omitted variables). He also uses an indicator for whether a firm made use of e-government – i.e., whether it interacted with authorities online – as instrument. Spiezia finds that ICT enables innovation, particularly product and marketing innovation, in the manufacturing as well as the services sector. He finds no evidence that ICT use increases the capability of a firm to cooperate, develop innovation in house, or introduce new products to the market. Hall et al. (2012) also try to model the endogeneity of ICT. Rather than treating it as a mere input to the production function, they investigate ICT in parallel with R&D as an input to innovation. They thus take into account the possible complementarities among different types of innovation activities. Using Italian firm-level data, they find that R&D and ICT are both strongly associated with innovation and productivity, with R&D being more important for innovation and ICT for productivity.

2.3 Data from the Ifo Innovation Survey

The data we use in this analysis are from the Ifo Innovation Survey, which aims at mapping innovative activity in Germany. The paper based survey has been conducted annually since 1979 among German manufacturing firms (for a detailed description, see e.g. Penzkofer, 2004; Lachenmaier, 2007). In 2012, the paper based questionnaire on activity in 2011 was sent out to 2,124 firms, out of which 744 replied. The response rate is therefore 35 percent. Information on ICT investment and use was obtained only for the year 2011 as a special feature. Our data are thus of cross-sectional nature regarding ICT investment, while innovative activity and other firm characteristics are available as a panel.

The unit of observation is a single firm or, respectively, a product range in the case of multi-product firms. Throughout the paper, we refer to the observations as “firms” for ease of exposition. In 2012, 744 firms participated in the survey, and it is from these that we obtain information for the year 2011. The actual wording of the questions relevant for this study can be found in Figure 2-3 in Appendix 2.7.

The centerpiece of the questionnaire is information on innovative activity in the preceding year. Innovations are defined as "the implementation of a new or significantly improved product (or process), as well as production and process techniques including the information technique in office and administration." Specifically, firms are asked annually whether they started or completed a product innovation during the preceding year. Table 2–1 reveals that 42 percent of the firms completed, and 44 percent started, a product innovation. Combining the information, we find that 59 percent of the firms engaged in innovative activity in 2011, defined as an indicator variable that takes the value 1 if a firm either started or completed a product innovation, and zero otherwise. We use a dummy variable for completed product innovations as the main measure of innovative activity. This variable captures an informal and direct measure of innovative output at the firm level, and thus reflects an actual benefit to the economy as opposed to started innovations that have not yet been introduced to the market. Our innovation holds certain advantages over alternative measures such as patent counts or R&D expenditure: patents capture only a fraction of all innovations; R&D may not necessarily lead to innovations (for an overview of different innovation measures and their characteristics, see Hagedoorn and Cloodt, 2003).

Our measure is a more direct indicator of innovative activity, and yet has certain disadvantages. In general, the indicator variable we observe is a crude measure of innovative activity that does not allow for further differentiation. The Ifo Innovation Survey captures major technological breakthroughs and minor inventions alike; changes in an existing product receive the same weight as completely new products. We thus cannot draw conclusions as to the size or importance of the innovations enabled by ICT investment. Neither does the dummy information on innovative activity provide a count of the number of product innovations realized in the previous year.

In addition to product innovations, firms are asked about their process-innovation behavior. The question is worded identically to that about product innovations, that is, firms are asked whether they introduced, started, or aborted a process innovation during the previous year. In 2011, 49 percent of firms introduced at least one process innovation.

In 2012, the survey collects data on firms' ICT investment and usage in the years 2011 and 2010 as a special feature. First, and most importantly, firms are asked whether they invested in new ICT equipment during the preceding two years. This was the case for 58 percent of the responding firms. This dummy information is a measure of ICT at the firm level in that it captures any notable changes in a firm's ICT capital stock. We prefer this measure over, for instance, the level of capital stock. The latter will not be readily known to most respondents, and even if they do know, they may be reluctant to disclose it, a problem that also plagues other financial measures in the Ifo Innovation Survey. In this way, we capture some information with the investment dummy and all respondents reply to this question. As Table 2–1 reveals, in our sample, 59 percent of firms made considerable investment in ICT innovations during the previous two years.

Table 2-1: Descriptive Statistics for 2011, Firms Participating in the Ifo Innovation Survey

	Obs.	Mean	Std. Dev.	Min	Max
Product innovation					
Started	744	0.44	0.50	0	1
Realized	744	0.42	0.49	0	1
Started or realized	744	0.59	0.49	0	1
Process innovation started	744	0.49	0.50	0	1
ICT investment and use					
ICT investment	744	0.59	0.49	0	1
IT equipment	744	0.53	0.50	0	1
Communications equipment	744	0.26	0.44	0	1
Software	744	0.50	0.50	0	1
Investment impulse from IT consultancy	744	0.15	0.35	0	1
Share of employees using computer	744	0.52	0.27	0	1
General firm characteristics					
Share academics	744	0.11	0.13	0	1
No. employees	744	539.58	3,810.80	1	83,156
Total sales (in million €)	744	357.93	3,049.69	38	57,400
Firm exports	744	0.75	0.43	0	1
Previous innovations and panel survival					
Product innovation realized in t-1	744	0.44	0.42	0	1
Product innovation realized in t-2	744	0.43	0.40	0	1
Non-response in t-1	744	0.33	0.47	0	1
Non-response in t-2	744	0.41	0.49	0	1

Notes: Data Source: Ifo Innovation Survey (Ifo Institute, 2012). The number of employees variable contains 39 missing values; total sales contains 102 missing values. Previous innovations in t-1 are imputed for 242 observations and for 308 in t-2. Variables are imputed with the annual average of their respective NACE code at the two-digit level.

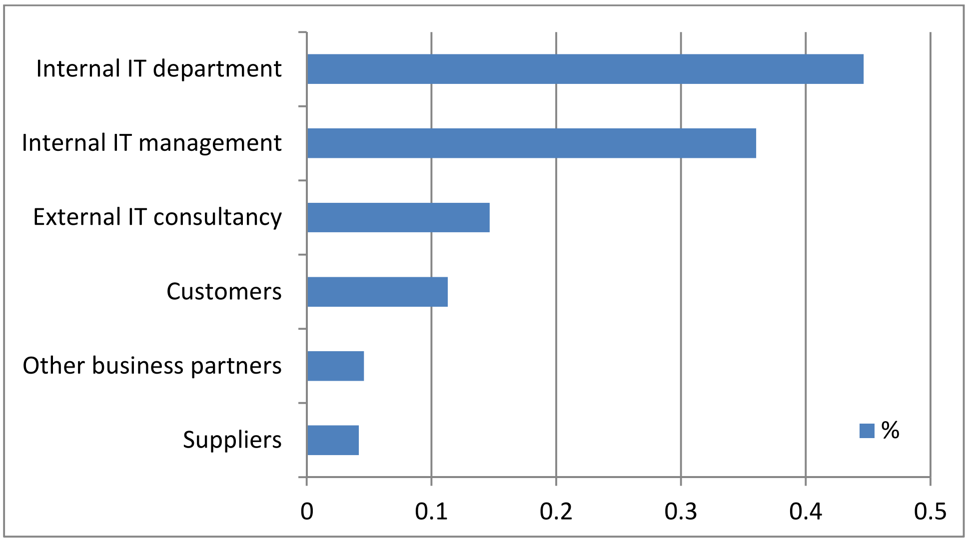
Investment in ICT capital is then divided into three categories, in accordance with the classification of the OECD (2010a).[4] Firms are asked to indicate the type of ICT capital in which they predominantly invested: *information technology equipment* (computers and related hardware), *communications equipment* (infrastructure to make the hardware interconnect), or any type of *software*. Table 2–1 reveals that about 53 percent of all firms (90 percent of the investing firms) invested in IT equipment, followed by software at 50

[4] According to the OECD (2010a), investment in ICT is defined as "the acquisition of equipment and computer software that is used in production for more than one year. ICT has three components: information technology equipment (computers and related hardware); communications equipment; and software. Software includes acquisition of pre-packaged software, customized software and software developed in-house".

percent (84 percent of investing firms) and communications equipment at 26 percent (48 percent of investing firms).

To glean some understanding of firms' investment behavior, they are asked what motivated them to invest in ICT. All firms are asked this question, irrespective of whether they undertook major investment in ICT. Figure 2-1 displays the results: most ICT investments are initiated by internal sources, namely, internal IT management or the IT department in general (at 44 and 36 percent, respectively). About 15 percent of firms invest in ICT based on advice from external IT-consultancies; another 13 percent are inspired by customer suggestions. Suppliers and other business partners play a minor role in the decision to acquire new ICT equipment, at 4 and 5 percent, respectively. The survey also inquired about the number of employees who use a computer. On average, just over half the employees (53 percent) use a computer as part of the job on a daily basis. Moreover, as of 2011, 12 percent of the employees are academics in our sample of manufacturing firms, defined as employees who have a university degree.

Figure 2-1: Catalysts for investing in ICT

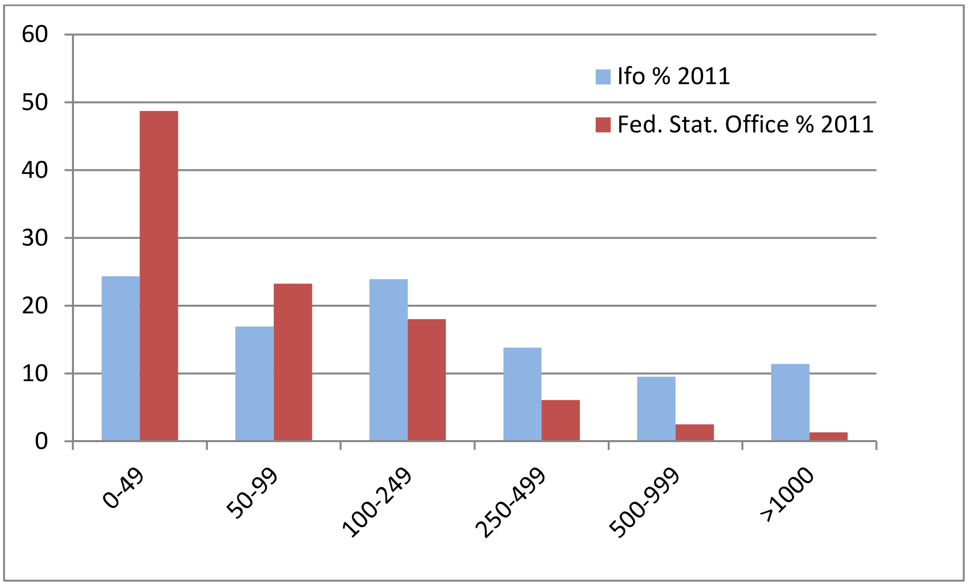


Data Source: Ifo Innovation Survey (Ifo Institute, 2012).

The firms participating in the Ifo Innovation Survey are a subset of the firms that take part in the Ifo Business Survey, a monthly survey that measures the business climate in Germany (for a detailed description, see Becker and Wohlrabe, 2008). We therefore obtain more general firm characteristics, such as size and general performance, from the Ifo Business Survey. The average firm in our sample has around 540 employees and annual sales of 368 million euros. 75 percent of responding firms report that they engage it export activity. We also have information on firms' locations from the Ifo Business Survey but, due to privacy concerns, a firm's location can be identified only at the level of German Federal States.

The analysis relies in part on information about innovative activity in previous periods for product innovation. We thus use information from previous waves. On average, the sample's product innovation behavior is relatively stable over time, with 44 percent of firms having realized a product innovation in 2010 and 43 percent in 2009. Over time, the number of observations decreases, which is due to firms dropping out of the panel. Kipar (2012) calculated an average annual dropout rate of 20 percent and a survival of 4.6 years in each wave since 1981. The number of firms whose innovative behavior can be followed over time is considerably smaller compared to the cross-section in 2011. Out of the 744 respondents in 2011, 502 firms are contained in the 2010 survey and 361 can be observed in 2009. To retain the remaining information for the firms that cannot be observed in previous periods, we impute the missing values of innovative activity in each year with the annual average of each two-digit NACE code for product and process innovations, respectively.[5]

Figure 2-2: Representativeness of the Ifo Innovation Survey by number of employees



Data Source: Ifo Innovation Survey (2012) and Federal Statistical Office (2014).

The Ifo Innovation Survey is paper based and participation is voluntary, both aspects that may raise concern as to its representativeness. This section compares the firms in the Ifo Innovation Survey with official statistics on German establishments in the manufacturing business from the Federal Statistical Office. Our sample of 744 firms captures about 2.5 percent of all employees in the manufacturing sector in Germany.[6] But large firms are overrepresented in this sample with an average of about 540 employees. The average firm in the German manufacturing sector employs 130 people in 2011 (Federal Statistical Office, 2014). Figure 2-2 highlights the relative distribution of firm sizes. Compared to the distribution of all manufacturing businesses in Germany (as of 2011), firms up to 100 employees are under- and firms with 100 or more employees are oversampled relative to the

[5] We test for the robustness of the results with respect to the imputation when we present the results.

[6] The sum of employees captured by the survey is 401,448. According to the Federal Statistical Office (2014), in 2011 15,867,580 people were employed in the German manufacturing sector.

full population of manufacturing firms. This selection bias of the Ifo Innovation Survey toward larger firms stems from the fact that the survey is intended to capture as much of the workforce in the manufacturing business as possible (Kipar, 2012). Comparisons between the 2011 sample of the Ifo Innovation Survey and the official statistics by industry branch and location are presented in Appendix 2.7.

Figure 2-4 and Figure 2-5 reveal that overall, the distribution of the Ifo survey follows the distribution of German manufacturing firms quite well. Regarding the three largest sectors, one can see in Figure 2-4 that the Survey over-represents machinery and equipment and firms in fabricated metal products and food products and beverages are underrepresented by about 9 and 8 percentage points, respectively. Also if plotted by Federal State, the two distributions are largely congruent, merely Bavaria is notably over-represented in our sample.

2.4 Identification Strategy

2.4.1 Value Added Model

We want to determine the extent to which ICT capital enables product innovation. Since many firm characteristics remain unobserved, we use the fact that we can follow the firms' innovation behavior over time and employ a value-added model.[7] In this setup, lagged values of the dependent variable are included on the right hand side of the estimation equation to account for time-persistent firm characteristics. The basic equation we estimate thus takes the following form:

$$Y_{i,2011} = \alpha + \beta_1 ICT_{i,2011/2010} + \beta_2 Y_{i,2010} + \beta_3 Y_{i,2009} + X'_{i,2011}\gamma + \varepsilon_i \quad (2.1)$$

where the dependent variable Y is a dummy variable that takes the value 1 if firm i introduced a product innovation to the market during 2011. ICT is a binary indicator for whether the firm made substantial investments in ICT during the period 2010 to 2011. We control for lagged values of product innovation activity in the previous two periods.[8] This is intended to account for the fact that, overall, generally more innovative firms are likely to persist in innovation over time. They may also exhibit a different ICT investment pattern than generally less innovative firms. X contains several characteristics at the firm level. We control for differences in scale by including turnover and number of employees, both scaled

[7] This estimation strategy has found predominant use in education economics to evaluate teacher effectiveness. See Kim and Lalancette (2013) for a detailed description and a review of the studies using value-added models.

[8] We furthermore provide robustness tests for including one and three lags when we present the results.

as logarithms. Firms with a high share of skilled labor are likely to adopt new ICT more quickly and are likely to innovate more. To reflect the skill level as well as IT intensity in the firm, the share of employees using a computer, as well as the share of employees with an academic degree, are included. A dummy for whether a firm exports is included, since exports have been established as a cause of innovation by the literature on endogenous innovation and economic growth (cf. Grossman and Helpman, 1991). Moreover, we include industry fixed effects, at the NACE two-digit level, to capture sector-specific differences in innovative activity, and regional fixed effects to capture influences such as innovation policy and subsidy programs that may occur at the Federal State level.

Ordinary least squares (OLS) is likely to yield biased estimates due to a selection bias that arises from the fact that firms do not randomly invest in ICT, but instead choose to invest in a certain technology at a certain point in time. For a causal interpretation of OLS we would have to make the assumption that ICT investment occurred randomly conditional on the control variables. But despite the fact that we control for pre-treatment innovations, the treatment and comparison groups may systematically differ from each other, leading to a biased estimation of the effect of ICT. We generally expect the ICT coefficient to be upward biased due to endogeneity concerns that arise from the fact that firms may simultaneously decide to engage in innovative activity and invest in the needed ICT equipment. Furthermore, there may be an omitted variables bias if more innovative firms simply invest a larger share of their total sales in capital – and therefore in ICT equipment – as part of the general management strategy or for other reasons we cannot observe. In principle, including the lagged dependent variable should account for a large part of this effect. Nevertheless, there may still be unobserved heterogeneity that is unaccounted for by including previous innovations in the analysis. We refrain from including lagged innovations that exceed the second lag, since the number of firms that can be continually observed over three years already dropped by around 41 percent.

A bias in the opposite direction is also possible. Consider the case where generally non-innovative firms purposely invest in ICT capital in order to improve their innovation record. If the time lag between ICT investment and product innovations is longer than the two years we assume, we might actually underestimate the effect of ICT.

Also, the data may suffer from measurement error due to questionnaire design, which might lead to a downward bias under certain circumstances. As the survey is paper based and filled out by one representative (the position held by which may vary across firms), answering the questions on completed innovations as well as on ICT investment both involves subjective assessments. It is up to the respondent to decide whether the introduction of a new product or the “substantial improvement” of an already existing product occurred. Similarly, the regressor is unity when “considerable investments” in new ICT equipment were made. It is thus up to the respondent to decide on the importance of the innovation or the size of the investment. Since the values of both variables are generated by the same person, the measurement errors of the dependent variable and the regressor are most likely correlated. In the case of correlated measurement errors – provided they are correlated with the error term in Equation (2.1) – it is not possible to determine the direction of the bias of the coefficient of ICT in Equation (2.1) (see, e.g., Hyslop and Imbens, 2001).

2.4.2 Instrumental Variables

To test whether ICT investment does in fact lead to an increase in innovations, we need an empirical strategy that identifies variation in ICT investment that is exogenous to product innovation. To address remaining endogeneity concerns, as well as the potential measurement error, and to isolate the effect of ICT as much as possible, we use an instrumental variable approach to identify the effect of ICT investment on product innovation. To qualify as a valid instrument in this context, a variable must fulfill two crucial prerequisites: first, it must be highly predictive of ICT investment (relevance) and, second, it must have no other relation with innovation activity than through ICT investment (exogeneity) conditional on the other covariates. We propose the information on a catalyst for ICT investment as an instrument, specifically whether a firm received an impulse to invest in ICT from external IT consultancies.[9] We therefore estimate:

$$Y_{i,2011} = \alpha + \delta_1 I\hat{C}T_{i,2011/2010} + \delta_2 Y_{i,2010} + \delta_3 Y_{i,2009} + X'_{i,2011}\upsilon + \varepsilon_i \qquad (2.2)$$

with

$$I\hat{C}T_{i,2011/2010} = \mu + \xi_1 IT\_Consult_{i,2011/2010} + \xi_2 Y_{i,2010} + \xi_3 Y_{i,2009} + X'_{i,2011}\rho + \nu_i$$

(2.3)

The first prerequisite – the instrument's relevance – will be tested in the following analysis; however, the second cannot be tested. For the instrumental variable to be valid, we have to assume that external IT consultants do not directly affect product innovations. We defend the validity of the instrument with the argument that, typically, IT consultancies are not involved in the firms' business strategies and do not directly make decisions concerning the product range. There is one way, however, in which IT consultancies may have a connection to product innovations. Process innovations are considered complementarities to new products (Bresnahan et al., 2002). If a firm engages an IT consultant as part of implementing a new strategy, for example, following a change in the management, and at

[9] An IV approach that is similar in spirit to ours and that uses the Ifo Innovation Survey can be found in (Lachenmaier and Woessmann, 2006) where exogenous impulses to firms' innovative activities are used as instruments in order to analyze the impact of innovation on exports.

the same time changes the product portfolio and the internal organization of processes, our assumption of strict exogeneity would be violated. To reduce the likelihood, that our instrument affects the outcome through this channel, we control for a firm's current activity in process innovations. We thus argue that conditional on the covariates (including the process innovation channel), our instrument likely fulfills conditional exogeneity.

In interpreting the instrumental variable results, it must be kept in mind that the variation in ICT investment caused by external IT consultants is not the same for the entire population of firms. We expect to identify a local average treatment effect (LATE) from the instrumental variables estimation (Angrist and Pischke, 2009). Our instrument identifies the average treatment effect for that subgroup of firms that change their ICT investment behavior because they engaged an external IT consultant. In the spirit of Angrist and Pischke, we call these "compliers", i.e. the firms that change their treatment status due to the instrument. That is, these firms will not invest in ICT unless induced by a consultant and likewise, if induced, they will follow the advice and invest. Such firms may well differ from others in the quantity as well as the quality of ICT investments. If our assumption that external IT consultants are not directly linked to product innovations holds, the IV estimation will identify the causal effect of ICT investment on product innovation for the complier group. Normally, we would expect to overestimate the population effect of ICT in OLS. However, due to the LATE interpretation of our instrument it seems plausible that firms that undergo the effort and incur the expense of consulting external IT experts will invest in different types of ICT, or in larger amounts of ICT capital as part of a general reorganization campaign. Firms that do not need an IT consultant to accompany the ICT investment may on average replace already existing equipment rather than buying disruptive new technology. The local average treatment effect we estimate therefore might well be above the expected population effect.

2.4.3 Matching

We moreover propose matching (Rosenbaum and Rubin, 1983) as an alternative way to get around certain estimation biases. Matching methods eliminate that part of the selection problem that stems from selection on observable characteristics. As a non-parametric method, matching allows for a more careful comparison of treated and control group. We propose two kinds of matching methods, propensity score matching (see, e.g., Heckman et al., 1998) and direct matching (e.g., Abadie and Imbens, 2002). Both methods have the distinct advantage that they do not rely on linearity in the relationship between ICT investment and innovation, an assumption that may be especially hazardous in our case where the outcome variable as well as the main explanatory variable of interest is a dummy indicator. The estimation strategy of propensity score matching generates in a first step the predicted probability of investing in ICT for every firm based on past innovative activity as well as the other covariates. Common matching algorithms are nearest neighbor, radius caliper, or kernel (e.g., Epanechnikov) matching. In a second step, only firms with positive probabilities of both investing and not investing in ICT are compared to each other with respect to their innovations in order to ensure common support.

A slightly different approach to the propensity score – direct matching – is proposed as an alternative method that is considered superior to propensity score matching, at least in some aspects (Stuart, 2010). Direct matching relies on pairs of observations that are not only similar, but identical in all the required dimensions, that is, the method results in closer matches than does propensity score matching. We therefore chose to use exact matching as a supplementary tool for analysis. Unfortunately, the high comparability of treatment and control group comes at the cost of losing many observations – a problem that is aggravated as the number of covariates, for which identical characteristics are required, increases. Nonetheless, this method allows us to impose identical histories of innovative behavior on firms that invested in ICT and those that did not. Many of the covariates, such as innovation in previous periods, are binary. The small number of values that the covariates can take enables us to directly match on several characteristics without losing too many observations. The continuous variables "share of employees using a computer" and "share academics" are recoded into categories by quartiles, thus allowing exact matching. We create groups that are identical with respect to the size range of academics and range of computer use, whether the firm exports, the industry branch at the NACE one-digit level, and their history of product and process innovation, as well as non-response in the two previous periods. In addition, a propensity score for firm size, measured as the number of employees and annual turnover is generated and included in the matching process. The number of employees as a continuous variable contains valuable information that would be unused if this variable was converted into a categorical variable.

Post-matching, we apply the baseline regression in both methods to control for any differences that may remain in the matched sample. This procedure allows us to impose common support in the sample and it provides a convincing way to select observations on which the analysis is based. Moreover, the estimated ICT effect from the matching approaches may be interpreted as the average treatment effect under the assumption of conditional independence (or unconfoundedness), that is, if we observe everything that influences product innovations as well as ICT investment. Nonetheless, a positive association can – again – not necessarily be interpreted as a causal effect. In the presence of unobservable influences, however, neither ordinary least squares nor the matching approaches will isolate the causal effect of ICT investments.

Finally, we combine the instrumental variable and matching approaches and apply IV estimates to the matched samples.

2.5 ICT Investment and Innovation – Empirical Results

This section presents results from our empirical models. The basic results from the value-added model are introduced first as a benchmark, followed by the instrumental variables approach. Results from propensity score and exact matching methods and the combined approach of IV and matching are then presented to verify the plausibility of our findings.

2.5.1 Baseline Results from Value Added Model

Results from OLS (Columns (1) to (3)) and the value added regression (Column (4)) are reported in Table 2–2. ICT has a positive, statistically significant impact on innovative activity. If a firm made substantial investments in ICT within the previous two years, it is 19.5 percentage points more likely to have completed a product innovation, according to Column (1) of the table, in which we include only few firm controls. All control variables exhibit the expected signs. Firm size – measured by the number of employees (in logs) – , the share of highly educated employees, the share of employees that uses a computer on a daily basis as well as export activity are all positively related to and significant predictors of product innovation. We consecutively introduce the industry branch fixed effects (at the NACE two-digit level, Column (2)) and the Federal State fixed effects (Column (3)) in the regression. Controlling for these does not considerably change the estimated ICT coefficient.

This pattern changes considerably when we control for the lagged dependent variables, defined as product innovations in *t-1* and in *t-2*. The size of the ICT coefficient decreases by about 30 percent to 13.4 percentage points in Column (4).[10] In this estimation, the share of academics and the share of employees using the computer lose much of their predictive power, whereas past product innovations are highly indicative of contemporaneous activity. The coefficients of the number of employees and export activity considerably decrease in magnitude. This finding is in line with our expectations, and it supports the hypothesis that innovative behavior is highly persistent over time. We choose the specification in Column (4) as our baseline specification. The R-squared is 47.4 percent, indicating that the set of covariates explains much of the variation in the dependent variable.[11]

There is substantial fluctuation with regard to the firms responding in the survey. This situation necessitates a large number of imputed values, which might raise concern despite

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[10] The two coefficients are statistically different from each other on a 1 percent level.

[11] We test the robustness of our general specification by 1) restricting the first lagged dependent variable to 1, and 2) by restricting the average value of the two lags to 1. The ICT coefficients remain in the same order of magnitude (around 11 percentage points) and are statistically significant at the 99 percent level. Results are not shown and can be provided on request.

the fact that we control for imputed values in all specifications. Columns (5) and (6) in Table 2–2 therefore report results from a sample that consists of a panel of firms that can be observed in the survey between 2011 and 2009. Only firms that did not respond in 2010 (but are observed before and after) are imputed with the average value of product innovations of 2011 and 2009.

Table 2-2: Association between Investment in ICT and Innovation, Dependent Variable: Product Innovation Realized

	Fully Imputed OLS			Fully Imputed VAD	2010 imputed VAD		Without Imputation VAD	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Firm invested in ICT	0.195***	0.193***	0.193***	0.134***	0.162***	0.085**	0.191***	0.098**
	(0.034)	(0.033)	(0.033)	(0.030)	(0.033)	(0.034)	(0.037)	(0.039)
Log employees	0.001**	0.001	0.001	0.001	0.000	0.000	0.000	0.000
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Share academic	0.085***	0.091***	0.088***	0.036***	0.028**	0.025**	0.035***	0.036***
	(0.011)	(0.012)	(0.012)	(0.011)	(0.012)	(0.012)	(0.013)	(0.013)
Share using computer	0.213***	0.171***	0.174***	0.111***	0.076*	0.025	0.081*	0.038
	(0.039)	(0.044)	(0.046)	(0.041)	(0.043)	(0.043)	(0.047)	(0.046)
Firm exports	0.005***	0.003**	0.003**	0.001	0.002	0.001	0.002	0.001
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.002)	(0.001)
Product innovation realized in t-1				0.350***	0.573***	0.468***	0.519***	0.410***
				(0.050)	(0.043)	(0.069)	(0.046)	(0.070)
Product innovation realized in t-2				0.376***		0.308***		0.345***
				(0.053)		(0.068)		(0.070)
Industry branch fixed effects		yes	Yes	yes	yes	yes	yes	yes
Federal State fixed effects			Yes	yes	yes	yes	yes	yes
Observations	744	744	744	744	577	436	502	361
R-squared	0.234	0.301	0.311	0.474	0.553	0.662	0.529	0.665

Notes: VAD = Value Added Model. The dependent variable is product innovation realized. The sample consists of firms that responded to the Ifo Innovation Survey in 2012. Columns (1) to (8) contain imputed values for “share using computer” (56 firms), “log no. employees” (39 firms), “log turnover” (101 firms), and “share academic” (118 firms). Column (4) contains imputed values for previous innovations (242 firms in t-1 and 308 firms in t-2). Missing values are imputed with the NACE two-digit average value in the respective year. Columns (5) and (6) shows results for the sample of firms that can be observed in 2011 and 2009 (firms missing in 2010 but responding in 2009 and 2011 are imputed with the average innovation value of 2011 and 2009). Column (7) and (8) are estimations without imputed lags. All specifications contain a full set of dummies for imputed values. A constant is included, but not reported. Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Table 2-3: Association between Investment in ICT and Innovation, Robustness

	Prod. Innovation Realized	Prod. Innovation started	Prod. Innovation Realized/Started
	(1)	(2)	(3)
Firm invested in ICT	0.090**	0.105***	0.139***
	(0.045)	(0.036)	(0.032)
Log employees	0.022	0.039***	0.030***
	(0.015)	(0.013)	(0.011)
Share academic	0.001	0.003**	0.003***
	(0.001)	(0.001)	(0.001)
Share using computer	0.001	0.002**	0.002**
	(0.001)	(0.001)	(0.001)
Firm exports	0.006	0.035	0.080*
	(0.053)	(0.046)	(0.044)
Product innovation realized in t-1	0.311***	0.157***	0.328***
	(0.092)	(0.055)	(0.049)
Product innovation realized in t-2	0.272***	0.207***	0.279***
	(0.092)	(0.059)	(0.051)
Product innovation realized in t-3	0.242***		
	(0.085)		
Industry branch fixed effects	yes	yes	yes
Federal State fixed effects	yes	yes	yes
Observations	265	744	744
R-squared	0.715	0.272	0.426

Notes: The sample consists of firms that responded to the Ifo Innovation Survey in 2012. All specifications contain imputed values for “share using computer” (56 firms), “log no. employees” (39 firms), “log turnover” (101 firms), and “share academic” (118 firms). They also contain imputed values for previous innovations (242 firms in t-1 and 308 firms in t-2). Missing values are imputed with the NACE two-digit average value in the respective year. A full set of dummies for imputed values is included. A constant is included, but not reported. Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Albeit the number of observations decreases by roughly 22 percent in the two-year panel in Column (5), and by about 41 percent in the three-year panel in Column (6), the effect of ICT investment is persistently positive and statistically significant. In addition, Columns (7) and (8) show results for the samples without any imputation for lagged innovation. The number of observations decreases further to 502, respectively 361. The estimates remain statistically significant and within the same order of magnitude as the previous specifications.

Table 2–3 reports some robustness checks of the presented results. In the first column, we introduce a third lag to the information on previous product innovations. The coefficient remains positive; it decreases slightly in magnitude and is statistically significant at 5 percent. The number of observations is only 265. The share of responding firms is already reduced considerably when two lags are included. We therefore refrain from making further use of information prior to two lagged time periods.

Table 2-4: Results from Instrumental Variables Estimation

	First Stage	2SLS	2SLS
	(1)	(2)	(3)
IT consultant	0.394***		
	(0.030)		
Firm invested in ICT		0.181*	0.113
		(0.098)	(0.093)
Log employees	0.022*	0.035***	0.015
	(0.013)	(0.011)	(0.010)
Share academic	-0.001	0.002	0.002
	(0.002)	(0.001)	(0.001)
Share using computer	0.001	0.001	0.001
	(0.001)	(0.001)	(0.001)
Firm exports	-0.080	0.114***	0.109***
	(0.052)	(0.041)	(0.038)
Product innovation realized in t-1	0.077	0.346***	0.304***
	(0.053)	(0.042)	(0.039)
Product innovation realized in t-2	0.143**	0.369***	0.293***
	(0.058)	(0.047)	(0.043)
Process innovation realized			0.337***
			(0.032)
Industry branch fixed effects	yes	yes	yes
Federal State fixed effects	yes	yes	yes
F-stat. of excluded instruments	66.87		
Observations	744	744	744
R-squared	0.225	0.473	0.554

Notes: The dependent variable is product innovation realized. The sample consists of firms that responded to the Ifo Innovation Survey in 2012. All specifications contain imputed values for “share using computer” (56 firms), “log no. employees” (39 firms), “log turnover” (101 firms), and “share academic” (118 firms). They also contain imputed values for previous innovations (242 firms in t-1 and 308 firms in t-2). Missing values are imputed with the NACE two-digit average value in the respective year. A full set of dummies for imputed values is included. A constant is included, but not reported. Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

The way in which we define ICT investment does not capture innovations that take longer than two years to complete. To test whether ICT investment has economic implications beyond this time span, we introduce two alternative innovation measures. Columns (2) and (3) of Table 2–3 display the association between ICT investment and an indicator for whether product innovations were begun in 2011 and an indicator that combines all innovative activity. The latter takes the value unity when a product innovation had either been started or completed in 2011. As expected, the ICT coefficients are also positive and statistically significant at 10.5 and 13.9 percentage points, respectively. This indicates that ICT investment might indeed have some longer-run implications for the economy.

2.5.2 Instrumental Variable Results

We now present results from our instrumental variable approach, which is based on the fact that advice from external IT consultants is often the impetus behind a firms’ investment in

ICT but that these consultants do not directly affect changes in the firms' product portfolio themselves. The first-stage regression in Column (1) of Table 2–4 shows that when a firm received an impulse to invest in ICT, it is 39.4 percentage points more likely to have invested in ICT than otherwise. This is after controlling for firm size, industry branch, and Federal State, along with other firm characteristics. At an F-value of 66.87, the instrument is highly relevant. In the second stage, the loss of efficiency that accompanies instrumental variables estimation is notable. The standard error of the ICT effect is about three times larger than the corresponding OLS specification.

The 2SLS estimates are still statistically significant at the 10 percent level when controlling for the same set of covariates as the baseline specification. The estimated effect in Column (2) of Table 2–4 is, at 18.1, about 4.7 percentage points higher compared to the latter. The increase in the point estimate from IV – compared to the previously obtained 13.4 percentage points (cf. Table 2–2) – may be due to the LATE interpretation of our instrument that we observe IV estimates above the expected population effect. Maybe firms who hire an IT consultant are different in their innovation and investment behavior from those who do not.

As discussed in Section 2.3, there are circumstances under which the exclusion restriction could be violated. A general, firm-wide reorganization is one way in which external IT consultants might be linked to product innovation other than through ICT investment. IT consultants will likely affect process innovations which often come along with product innovations. If this reorganization were connected to redirecting a firm's general strategy, for example, due to a change in the top management, such an event would be one obvious threat to the validity of the instrumental variable. We account for this possibility of contemporaneous correlation and additionally include current process innovations in the regression. This dummy variable takes the value unity if a process innovation has been started or introduced in the current year. Column (3) shows this specification: when controlling for current process innovations, the ICT coefficient is no longer statistically significant at conventional levels; it decreases in magnitude to 11.3 percentage points, a value that is within the same order of magnitude as our baseline result. Process innovations might in fact be a bad control to product innovations as the literature sees them as complementary (Bresnahan et al., 2002). If this were the case, controlling for process innovations would lead to the underestimation of the total effect of ICT investments.

2.5.3 Propensity Score and Direct Matching

Table 2–5 provides results for regression-adjusted matching for different matching algorithms. The algorithms we use are nearest neighbor, five-nearest neighbors, Epanechnikov kernel, and radius caliper matching. Overall, the results are of the same order of magnitude as the OLS estimates. They range between 13.2 and 14.2 percentage points and they remain highly statistically significant for all algorithms used. The need for carefully chosen comparison groups is highlighted in the Appendix. Figure 2-7 in the Appendix displays the distribution of propensity scores for treated and untreated firms. Only a few firms fall off support at the left tale and the distribution of the likelihood of investing in ICT is slightly less flat and somewhat more skewed to the left for firms that actually invested. Table 2–7 provides t-tests for the hypothesis that the means of the firm characteristics do not differ by ICT investment status. The test is conducted before and after matching. The table reveals large, significant differences in the characteristics between investing firms and non-investing firms. In the absence of propensity score matching, the two types of firms differ in every characteristic, apart from the share of academics and non-response in *t-1*. After matching has been conducted, the means no longer statistically differ from each other.

The pattern shown in the propensity score matching is seen again in the direct matching approach presented in Table 2–6. Here, the estimated ICT coefficient ranges between 15.0 and 20.4 percentage points. The coefficient remains significant at the 1 percent level throughout all specifications despite the low number of observations that remain in the matched sample after imposing identical firm characteristics in multiple dimensions. Depending on the matching algorithm, only between 214 and 315 firms remain in the matched sample. Table 2–7 in the Appendix shows the balancing test for the group means by ICT investment. Here, the matched sample exhibits identical means for all characteristics that were exactly matched. The means of the number of employees are not identical since for this variable no exact match is imposed. Nevertheless, the means are not statistically distinguishable.

Taken together, the characteristics we control for should be a good reflection of a firm's situation. The results indicate that the propensity score and the direct matching processes successfully generated comparable counterfactual observations as each investing firm has common support. We thus conclude that ICT investment has a positive effect on product innovation.

In a next step, we estimate our instrumental variable regression on the matched sample. The results are shown in Table 2–9 in the Appendix. Columns (1) to (4) are based on samples generated with propensity score matching algorithms, Columns (5) to (8) on samples obtained with direct matching. The ICT investment coefficient ranges between 11 (rounded) and 19.5 percentage points. The only exception is Column (5), which also contains the least observations with only 230 firms in the sample. In this specification the coefficient is practically zero. The results are not statistically significant –apart from Column (7) – which is statistically significant at the 10 percent level. The small sample sizes may well be the reasons for the imprecisely estimated coefficients of ICT investment.

Table 2-5: Propensity Score Matching Results, Dependent Variable: Product Innovation Realized

	1-n-n	5-n-n	kernel	caliper
	(1)	(2)	(3)	(4)
Firm invested in ICT	0.137***	0.132***	0.134***	0.142***
	(0.032)	(0.029)	(0.029)	(0.032)
Log employees	0.047***	0.051***	0.054***	0.044***
	(0.013)	(0.012)	(0.012)	(0.014)
Share academic	0.003*	0.002*	0.002	0.003*
	(0.001)	(0.001)	(0.001)	(0.001)
Share using computer	0.002***	0.001	0.001	0.002***
	(0.001)	(0.001)	(0.001)	(0.001)
Firm exports	0.148***	0.110**	0.112**	0.161***
	(0.053)	(0.047)	(0.046)	(0.054)
Product innovation realized in t-1	0.278***	0.289***	0.282***	0.277***
	(0.048)	(0.045)	(0.045)	(0.048)
Product innovation realized in t-2	0.382***	0.378***	0.367***	0.379***
	(0.054)	(0.049)	(0.049)	(0.054)
Industry branch fixed effects	yes	yes	yes	yes
Federal State fixed effects	yes	yes	yes	yes
Observations	600	712	723	588
R-squared	0.479	0.448	0.450	0.476

Notes: The dependent variable is product innovation realized. The matching algorithms in Column (1) are nearest neighbor (with replacement), in Column (2) five-nearest-neighbors (with replacement), in Column (3) Epanechnikov kernel, and in Column (4) radius caliper (0.01). Missing values are imputed with the NACE two-digit average value in the respective year. A full set of dummies for imputed values is included. A constant is included, but not reported. Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

2.5.4 General Discussion

The results presented in the previous subsections of Section 2.5 mostly suggest that ICT investment does enable manufacturing firms to innovate. Controlling for pre-treatment outcomes and Federal State and industry fixed effects, the ICT coefficient remains relatively stable throughout OLS, matching, and IV regressions. According to our estimations, a manufacturing firm that made a major investment in ICT is between 11 and 18 percentage points more likely to introduce a product innovation within the next two years. Evaluated at the average probability of introducing a product innovation of 42 percent, this is an economically important effect.

Our dataset raises some issues concerning the generalizability of the presented findings to the entire population of firms. First, our study uses only firms in the manufacturing sector, which differs from other sectors in the way firms use ICT. Second, maybe the results are not applicable to all other countries. Germany is specific in its ICT capacity, i.e. in the way in which relevant stakeholders such as businesses, governments and private users make use of ICT. In 2013, it ranked among the top 13 countries (out of 144) in the World Economic Forum’s (2013) Network Readiness Index (NRI). This implies that lower ranked countries with less capacity to make use of ICT may not benefit as much from an increased investment.

Furthermore, the time span we can observe is relatively short. We can follow the aftermath of ICT investment for only two years, which raises the following issues: first, is it realistic that benefits of ICT manifest within two years and, second, if there are economic benefits of ICT investment beyond this period, our results would underestimate its effect. We argue that due to the fast-developing nature of ICT, the assumption of a short lag until manifestation of effects from new ICT equipment is realistic. Firms invest in these technologies with the expectation that they will pay off in the near future.

Table 2-6: Direct Matching Results, Dependent Variable: Product Innovation Realized

	1-n-n (1)	5-n-n (2)	kernel (3)	caliper (4)
Firm invested in ICT	0.204***	0.168***	0.159***	0.150***
	(0.054)	(0.040)	(0.042)	(0.043)
Log employees	0.049**	0.037**	0.032*	0.047**
	(0.024)	(0.017)	(0.019)	(0.018)
Share academic	0.004**	0.003**	0.002	0.003*
	(0.002)	(0.001)	(0.002)	(0.002)
Share using computer	-0.001	-0.000	0.000	-0.000
	(0.001)	(0.001)	(0.001)	(0.001)
Firm exports	0.036	0.076		
	(0.083)	(0.060)		
Product innovation realized in t-1	0.337***	0.292***	0.392***	0.300***
	(0.090)	(0.077)	(0.089)	(0.082)
Product innovation realized in t-2	0.408***	0.462***	0.382***	0.470***
	(0.092)	(0.077)	(0.086)	(0.082)
Industry branch fixed effects	yes	yes	yes	yes
Federal State fixed effects	yes	yes	yes	yes
Observations	230	328	277	288
R-squared	0.573	0.633	0.666	0.645

Notes: The dependent variable is product innovation realized. The matching algorithms in column (1) are nearest neighbor (with replacement), in Column (2) five-nearest-neighbors (with replacement), in column (3) Epanechnikov kernel, and in Column (4) radius caliper (0.01). Missing values are imputed with the NACE two-digit average value in the respective year. A full set of dummies for imputed values is included. A constant is included, but not reported. Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

In line with this reasoning, most of the economic benefits of ICT should occur within the first few years after acquisition. The common depreciation period for IT equipment in Germany covers three years. This is the expected time span of use for the equipment in the firm before it is replaced. But if the time span employed is not sufficiently long to capture all future benefits that ICT investment generates for the firms, our estimates would provide a lower bound to the longer-term effect.

There are moreover other characteristics that are likely to influence firm's investment in ICT and that may be correlated with innovative activity. One example would be an increased aggregate demand for ICT capital since the end of the recent economic crisis. But this would occur on a national level and affect all firms in Germany, and should not bias our results.

2.6 Conclusion and Outlook

Investment in ICT is generally believed to be an important factor in increasing firm performance. We provided micro evidence at the firm level on how ICT investment affects product innovation. The results reveal that ICT investment has a consistently positive effect on firms' innovative behavior. This finding holds across the value-added model, instrumental variables estimations, and regression-adjusted matching. Our estimates suggest that there are substantial economic benefits from increased spending on ICT. Controlling for firms' history of innovative activity, we find in various specifications that a manufacturing firm that made major investments in ICT is between 11 and 18 percentage points more likely to introduce a product innovation within the following two years. Evaluated at the average probability of introducing a product innovation of 42 percent, this is an economically important effect. Our findings have important implications beyond the single firm. Innovations are major drivers of aggregate growth and ICT investments thus have the potential to benefit the aggregate economy.

Our results may not necessarily be generalizable to the entire population of firms. First, the instrumental variable approach most likely identifies a local average treatment effect that may not apply to all firms since we expect it to measure the effect for a subset of firms that were induced to invest in ICT by external consultants. Moreover, our study uses only manufacturing firms, an industry that differs from other sectors in the way ICT is used. Moreover, the data allow us to study only relatively short-term effects of ICT investment, and thus we cannot predict the effect of this type of investment on long-run development.

Nevertheless, we contribute to the literature by providing firm-level evidence in which we account for the self-selection of firms to invest in ICT. Our findings are important as they suggest that new ICT capital acts as an important catalyst for new products in the manufacturing sector. Further research should be conducted – ideally using panel data – to provide a better understanding of the role that ICT investment may play in innovative behavior, to discover the kinds of processes it is a substitute for, and to look more closely at how the decision to invest in ICT is formed.

2.7 Appendix

Figure 2-3: Excerpt from the Ifo Innovation Survey, 2012 Questionnaire

1. Product innovations: In 2011, we

   Introduced ☐

   Started ☐

   Aborted ☐ a product innovation

2. Process innovations: In 2011, we

   Introduced ☐

   Started ☐

   Aborted ☐ a process innovation

3. What percentage of employees (in %) need the following equipment on a daily basis in order to perform their professional activities?

   Computer ______%

   Internet ______%

4. Did you invest in the **last two years** in substantial innovations of ICT-equipment?

   Yes ☐ ____________€ (if unknown, please estimate)

   No ☐ (proceed to question 7)

5. If yes, which type of ICT-equipment did you invest in mostly?

   ☐ IT-Equipment (computers und hardware)

   ☐ Communications-equipment

   ☐ Software

6. If yes, to what degree did the ICT-Investments require internal reorganizations?

   ☐ No restructuring

   ☐ Low degree of restructuring

   ☐ High degree of restructuring

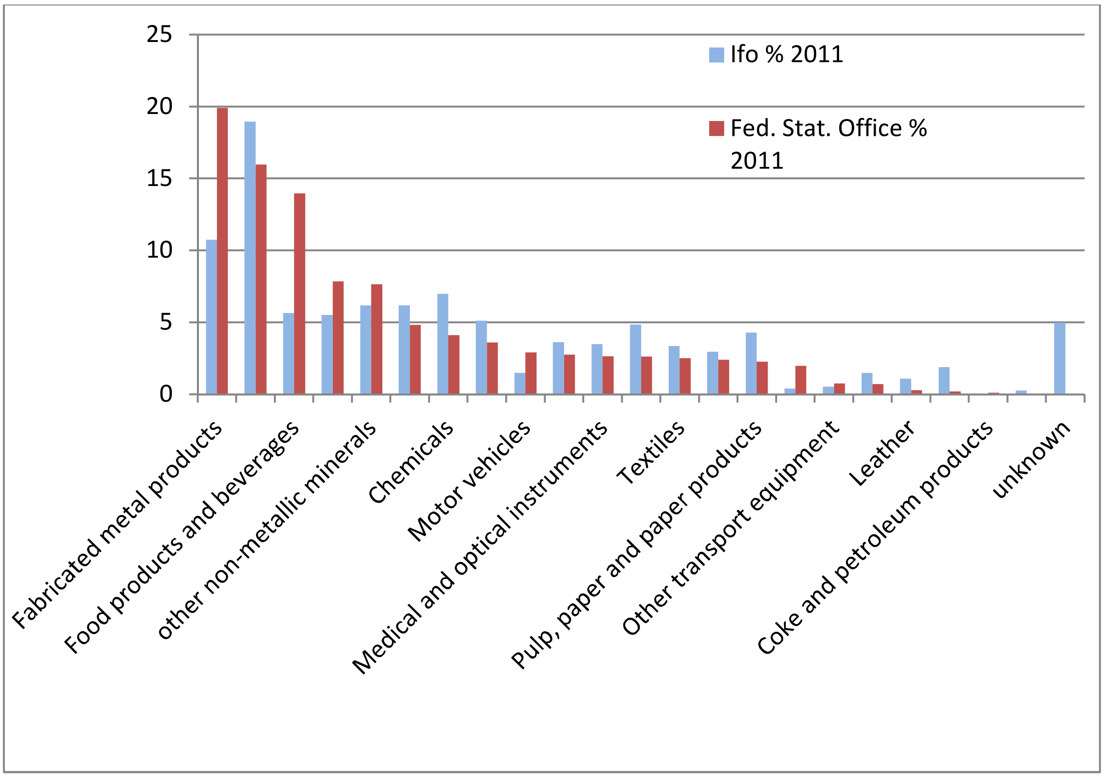
7. Impulses to invest in ICT stem from

   ☐ Internal IT-department ☐ Suppliers

   ☐ Internal IT-management ☐ Other business partners

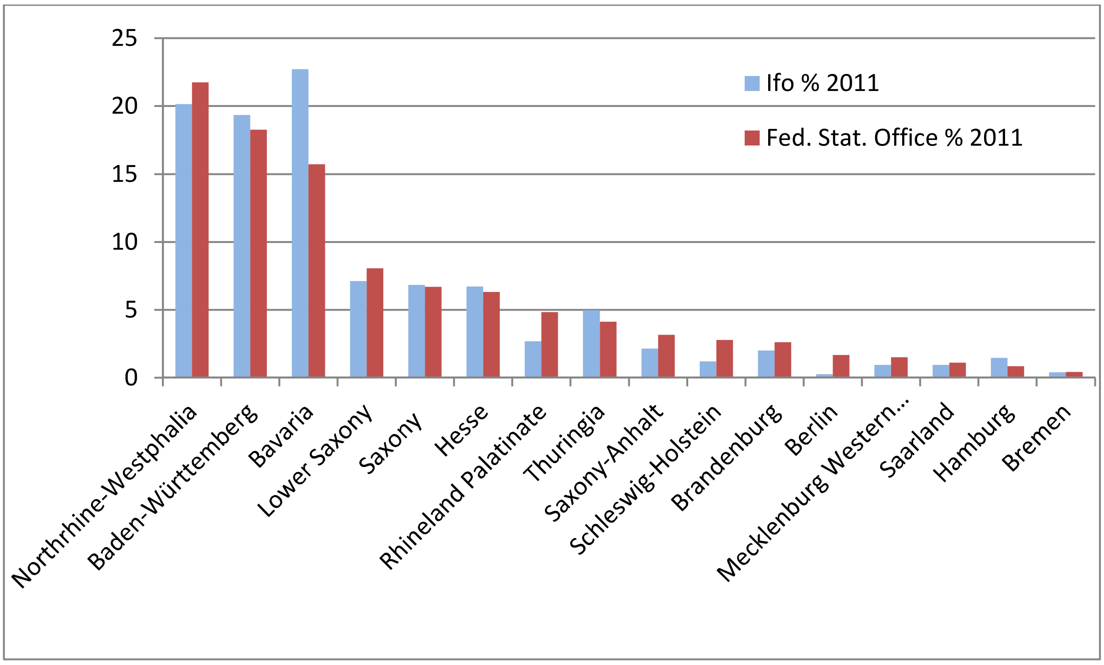
   ☐ External IT consultancy ☐ Customers

Figure 2-4: The distribution of NACE codes in the Ifo Innovation Survey 2011



Data source: Ifo Institute (2012) and Federal Statistical Office (2014)

Figure 2-5: The distribution of Federal States in the Ifo Innovation Survey 2011



Data source: Ifo Institute (2012) and Federal Statistical Office (2014)

Figure 2-6: The distribution of firms, by size of employment

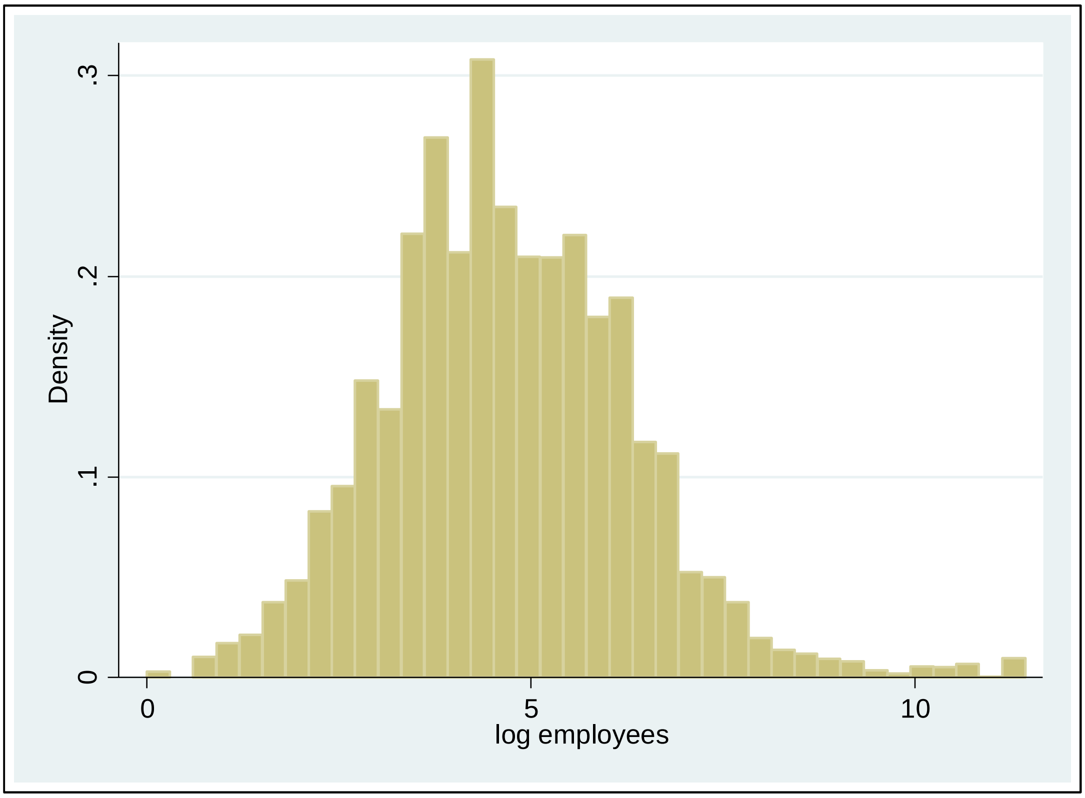
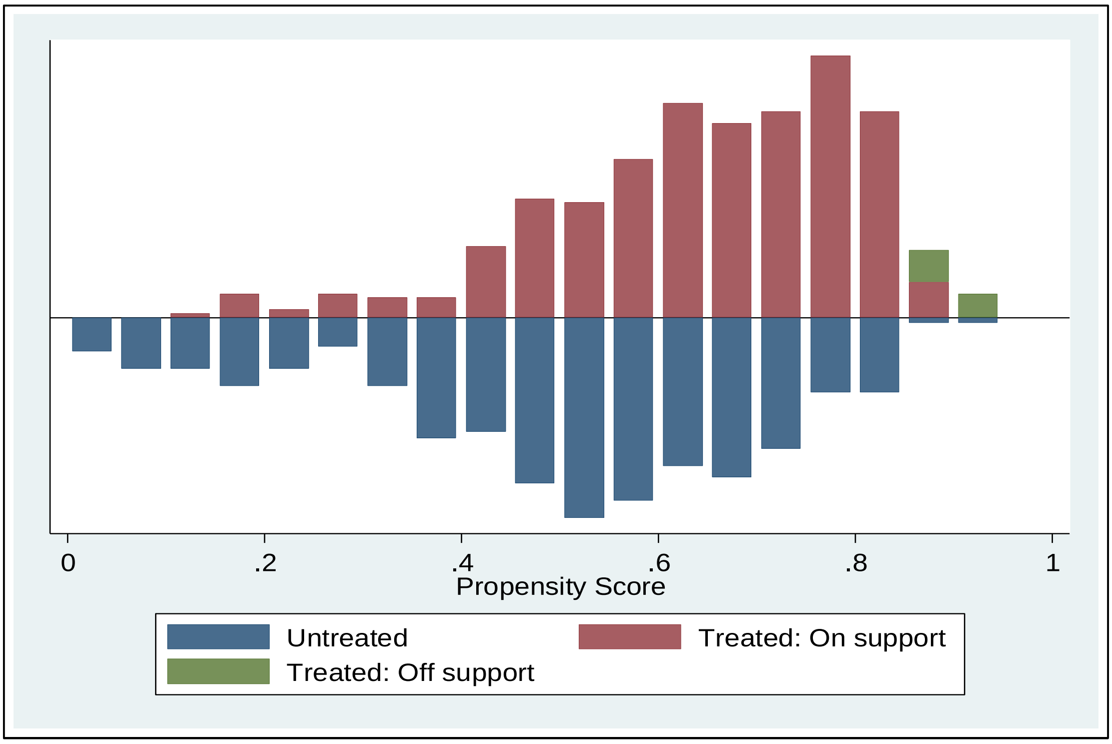


Figure 2-7: The distribution of propensity scores for treated and untreated firms



Notes: The graph shows the distribution of the probabilities of firms to invest in ICT, by their respective treatment status. The algorithm used in obtaining the graph is radius caliper (0.01) matching.

Table 2-7: Balancing Score Test, Mean Comparison by ICT Investment, Before and After Propensity Score Matching

		Mean			t-test	
Variable	Sample	Treated	Control	%bias	t-test	p>|t|
Product innovation realized	unmatched	0.54	0.30	50.40	6.71	0.00
	matched	0.53	0.42	23.60	3.32	0.00
Log no. employees	unmatched	4.76	4.30	30.70	4.09	0.00
	matched	4.64	4.77	-8.40	-1.30	0.19
Share academic	unmatched	12.12	10.94	9.10	1.25	0.21
	matched	12.03	12.28	-1.90	-0.31	0.76
Share using computer	unmatched	53.59	49.03	16.80	2.25	0.03
	matched	53.55	53.90	-1.30	-0.19	0.85
Firm exports	unmatched	0.79	0.70	22.10	3.00	0.00
	matched	0.80	0.84	-9.80	-1.60	0.11
Product innovation realized in t-1	unmatched	0.49	0.37	28.60	3.82	0.00
	matched	0.47	0.51	-10.00	-1.45	0.15
Product innovation realized in t-2	unmatched	0.48	0.36	32.40	4.35	0.00
	matched	0.47	0.49	-6.00	-0.89	0.37
Non-response in t-1	unmatched	0.34	0.30	8.20	1.09	0.27
	matched	0.34	0.36	-3.00	-0.43	0.67
Non-response in t-2	unmatched	0.46	0.35	21.50	2.87	0.00
	matched	0.46	0.49	-6.80	-0.96	0.34

Notes: Radius caliper (0.01) matching, 588 observations are in the sample. Federal State dummies, industry branch dummies (at NACE two-digit), and a full set of dummies for missing values as well as dummies for non-response enter the matching process but are not reported.

Table 2-8: Balancing Score Test, Mean Comparison by ICT Investment, Before and After Direct Matching

		Mean			t-test	
	Sample	Treated	Control	%bias	t-test	p>|t|
Product innovation realized	unmatched	0.54	0.30	50.40	6.71	0.00
	matched	0.58	0.44	29.60	2.74	0.01
Log no. employees	unmatched	4.76	4.30	30.70	4.09	0.00
	matched	4.69	4.57	8.30	0.88	0.38
Share academic	unmatched	2.65	2.43	19.50	2.60	0.01
	matched	2.88	2.88	0.00	0.00	1.00
Share using computer	unmatched	2.72	2.50	19.40	2.59	0.01
	matched	2.79	2.79	0.00	0.00	1.00
Firm exports	unmatched	0.79	0.70	22.10	3.00	0.00
	matched	0.80	0.64	35.30	3.30	0.00
Product innovation realized in t-1	unmatched	0.49	0.37	28.60	3.82	0.00
	matched	0.49	0.49	0.00	0.00	1.00
Product innovation realized in t-2	unmatched	0.48	0.36	32.40	4.35	0.00
	matched	0.48	0.48	0.00	0.00	1.00
Non-response in t-1	unmatched	0.34	0.30	8.20	1.09	0.27
	matched	0.21	0.21	0.00	0.00	1.00
Non-response in t-2	unmatched	0.46	0.35	21.50	2.87	0.00
	matched	0.28	0.28	0.00	0.00	1.00

Notes: Radius caliper (0.1) matching. All variables except “log no. employees” are used for exact matching. This variable enters the matching process as propensity score from a probit regression. “Share using computer” and “share academic” are rescaled as size ranges to allow for exact matching within four categories (by quartile).

Table 2-9: Instrumental Variables Results on Matched Samples

	Propensity Score Matching Samples				Direct Matching Samples			
	1-n-n	5-n-n	kernel	caliper	1-n-n	5-n-n	kernel	caliper
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Firm invested in ICT	0.105	0.110	0.112	0.109	0.006	0.175	0.195*	0.172
	(0.120)	(0.093)	(0.093)	(0.122)	(0.145)	(0.110)	(0.109)	(0.135)
Log employees	0.001	0.001	0.001	0.001	-0.001	-0.000	0.000	-0.000
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Share academic	0.015	0.013	0.014	0.013	0.015	0.011	-0.004	0.014
	(0.012)	(0.011)	(0.011)	(0.012)	(0.022)	(0.015)	(0.017)	(0.017)
Share using computer	0.130***	0.117***	0.120***	0.138***	0.064	0.063	0.092*	0.082
	(0.044)	(0.039)	(0.039)	(0.045)	(0.075)	(0.052)	(0.055)	(0.061)
Firm exports	0.002	0.002	0.002	0.002	0.003*	0.003**	0.003*	0.003*
	(0.001)	(0.001)	(0.001)	(0.001)	(0.002)	(0.002)	(0.002)	(0.002)
Product innovation realized in t-1	0.284***	0.297***	0.296***	0.285***	0.232***	0.199***	0.277***	0.214***
	(0.044)	(0.040)	(0.039)	(0.044)	(0.081)	(0.066)	(0.078)	(0.071)
Product innovation realized in t-2	0.329***	0.302***	0.299***	0.331***	0.363***	0.405***	0.329***	0.388***
	(0.048)	(0.044)	(0.044)	(0.049)	(0.081)	(0.066)	(0.074)	(0.071)
Industry branch fixed effects	yes	yes	yes	yes	yes	yes	yes	yes
Federal State fixed effects	yes	yes	yes	yes	yes	yes	yes	yes
Observations	600	712	723	588	230	328	277	288
R-squared	0.543	0.547	0.549	0.537	0.582	0.666	0.686	0.638

Notes: The dependent variable is product innovation realized. All specification show instrumental variables estimations applied to matched samples. Columns (1) to (4) are based on samples obtained with propensity score matching methods, Columns (5) to (8) are based on samples obtained with direct matching methods. The matching algorithms in column (1) and (5)are nearest neighbor (with replacement), in Column (2) and (6) five-nearest-neighbors (with replacement), in column (3) and (7) Epanechnikov kernel, and in Column (4) and (8) radius caliper (0.01). Missing values are imputed with the NACE two-digit average value in the respective year. A full set of dummies for imputed values is included. A constant is included, but not reported. Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

3 The Economic Impact of Local Broadband Infrastructure: Firm Level Evidence[12]

3.1 Introduction

The emergence of broadband infrastructure over the last two decades is claimed to have caused structural changes in the economy as broadband generally facilitates the fast distribution of large amounts of information at low cost (see, e.g. OECD, 2008). For firms as well as consumers it creates greater market transparency and enables the interplay of geographically distant economic agents, thereby promoting inter-regional trade. Broadband furthermore raises firms' labor productivity in that it allows a faster acquisition of information and knowledge and facilitates the communication with external partners. As a consequence, the deployment of broadband infrastructure as an important location factor has been at the focus of national as well as local governments in advanced nations since several years.

To date, these are no evaluations of the causal effect of local broadband infrastructure on firm performance at the individual level. Several studies have investigated the financial effects of broadband infrastructure (or online content) on firms in single markets, typically with the focus on a specific media market. Moreover, a number of papers have confirmed a positive association between broadband deployment and subsequent employment effects. Few of these studies tackle the obvious endogeneity issues associated with the provision of broadband infrastructure.

We present first evidence of how broadband relates to financial success throughout all industries. In addition, we contribute to the literature in providing firm-level employment effects of broadband infrastructure. We moreover look more closely into the heterogeneities of broadband benefits to explore whether certain groups profit more from broadband infrastructure than others. For example small firms may be expected to depend more on the local networks than larger firms. Also, firms in certain service sectors might benefit more as

[12] This chapter was coauthored by Oliver Falck (LMU München and Cesifo) and Christian Seiler (Ifo Institute).

broadband facilitates the globalization of many services, allowing producers and consumers of services to be in different geographical locations.

We study two firm outcomes, revenue and the number of employees. It is a priory not clear, whether these increase or decrease in reaction to broadband availability. Concerning revenues, on the one hand, the Internet offers a firm the possibility to present itself to a larger customer base, e.g. through the use of a company website. New marketing practices such as online sales enlarge the geographic radius of sales markets. At the same time local broadband infrastructure may increase the amount of competition that a local business faces. With a higher market transparency and the possibility to order online, customers may substitute away from local businesses' products towards geographically distant firms. It is thus not clear beforehand, whether local broadband Internet affects revenues of the average firm positively or negatively.

As regards to employment, broadband infrastructure is generally expected to affect firms' demand for labor through higher labor productivity (see, e.g. OECD, 2008). High-speed Internet access facilitates the acquisition and exchange of large batches of information. It moreover may foster collaborations with external business or research partners due to lower costs of communications over long distances. Moreover, efficiency gains can be realized in the firm, which may lead to the complementary reorganization of internal processes. While it seems plausible that broadband does increase labor productivity through these channels, it is not clear in which direction the higher productivity changes firms' demand for labor: On the one hand, an income effect increases the labor demand of firms. On the other hand, however, ICT might have a negative effect on employment since the new technology may facilitate the use of less labor. The overall employment effect depends eventually on the relative strengths of substitution and income effects.

For the analysis, we make use of Amadeus, a comprehensive database that allows us to follow more than 220,000 German firms of all industries (including manufacturing *and* services) over time. We combine the firm level data with detailed information on broadband availability as well as local official statistics at the municipality level. Identifying the causal effect of broadband infrastructure is not trivial since broadband providers' decisions to roll-out infrastructure to certain municipalities may be correlated with local firms' characteristics. As broadband infrastructure follows demand, the economic situation of the municipality a firm is located in will determine the speed of the diffusion of broadband Internet. To solve this endogeneity problem, we employ a first-difference model for the years from 2000 to 2005, which allows us to account for firm specific, time persistent unobserved heterogeneities. Estimating a first-difference model is equivalent to the inclusion of firm-fixed effects. In addition, we control for industry and regional fixed effects as firms are likely to follow industry, respectively location specific trends.

We find no general effects of broadband availability on employment and revenue. The detailed firm-level dataset allows us to differentiate the effect of broadband by several dimensions. Testing for heterogeneities at the municipality and firm level typically does not change the result of no notable effects. We do find, however, that smaller firms in the service industries exhibit a positive reaction in response to local broadband infrastructure deployment. It should be kept in mind that our data explicitly describe the technical possibility of using broadband Internet; we therefore capture the effect of broadband availability as the politically relevant measure, not the effect of broadband use in firms. This estimator is likely to give smaller results than actual use would as it only captures a fraction of the effect of usage.

The remainder of this chapter is organized as follows. Section 3.2 discusses the channels through which broadband infrastructure may affect firms' revenues and demand for labor on the basis of already existing studies. Section 3.3 introduces the data used in the analysis. Section 3.4 describes the empirical estimation strategy. In Sections 3.5 and 3.6 baseline results and heterogeneous findings in the effect of broadband infrastructure are presented, respectively. Section 3.7 provides a general discussion and Section 3.8 briefly summarizes and concludes.

3.2 The Effect of Broadband Infrastructure on Firms in the Previous Literature

The emergence of new ICT technologies, such as broadband infrastructure in the early 2000s is generally expected to affect firms' demand for labor through higher labor productivity (see, e.g. OECD, 2008). There are several ways in which broadband infrastructure may influence labor productivity of already existing firms. First, high-speed Internet access facilitates the acquisition and exchange of large batches of information. It moreover may foster collaborations with external business or research partners due to lower costs of communications over long distances. With these changes, efficiency gains can be realized in the firm, which may lead to the complementary reorganization of internal processes. While it seems plausible that broadband does increase labor productivity through these channels, it is not clear in which direction the higher productivity changes firms' demand for labor: On the one hand, an income effect increases the labor demand of firms. On the other hand, however, ICT might have a negative effect on employment since the new technology may facilitate the use of less labor. The overall employment effect depends eventually on the relative strength of substitution and income effects.

One strand of literature investigates productivity gains of ICT use in firms at the individual worker level. They come to the conclusion, that the implementation and operation of the technologies requires skilled labor. Autor et al. (2003), for example, argue that the increasing computerization is responsible for a reduced labor input in routine tasks and a relative increase of complex problem-solving tasks. They explain this phenomenon with the latter being complementary to ICT capital, whereas the former acts as a substitute. As more ICT capital is used in the firms, high-skilled labor becomes relatively more productive and demand for it increases relative to labor based on routine tasks. A large fraction of rising wage inequality in most industrialized countries can be explained by this skill-biased technological change (see Autor et al., 2008, for an application to the US labor market). However, a higher relative demand for higher skills does not necessarily increase total labor demand.

The relationship between ICT on employment has been subject to several studies at the local level, which find predominantly positive effects. Gillett et al. (2006) were the first to find a positive association between broadband availability in US communities between 1998 and 2002 and the growth of employment in communities. Forman et al. (2012) find in an application to US counties positive effects of firms' ICT use and employment and wage growth between 1999 and 2000. One study that aims at identifying the causal effect of broadband infrastructure at the regional level is Kolko (2012). He provides instrumental variables estimates in which he uses exogenous variation from the costs of broadband provision (the slope of terrain) and finds that local broadband expansion is associated with employment growth between 1999 and 2006 at the local level.

In addition to already existing firms, broadband infrastructure might affect the settlement of firms in an area. We cannot investigate this channel since we only observe firms that did already exist in 2000. Some descriptive evidence points towards firms' location decisions being influenced by local broadband infrastructure. A study by Mack et al. (2011) finds that broadband provision explains some decisions by knowledge-intensive industries to locate in U.S. metropolitan areas. Gillett et al. (2006) conclude that U.S. communities that had broadband by 1999 experienced higher growth in the number of businesses from 1998 to 2002 than other communities.

The literature moreover states that possible positive effects of broadband infrastructure on firms are not generalizable to all firms and regions. Whether gains from ICT exist in firms depends on complementary factors, such as the information technologies already present, innovative business practices as well as organizational structures in firms. Some studies analyze heterogeneities by the type of region. Forman et al. (2005) for example find that firms that integrate complex ICT applications for new business models (such as online sales in new markets) experience the highest productivity improvements from ICT. Forman et al. (2012) investigate the effects of the use of ICT in firms at the regional level. They state that the US counties that experienced the highest wage growth were already well off prior to broadband diffusion, with high incomes, large populations, a high-skilled local labor force and an already concentrated use of IT.

Moreover, the effects of broadband may be specific to certain industries. We are aware of no studies that directly analyze the effect of broadband infrastructure on firms' financial performance on a large scale. But so far, several studies investigated the effect of online markets on conventional sales in single markets with a predominant focus on media markets. Danaher and Smith (2014) for example find in a cross-country study that piracy websites negatively affect movie sales. Smith and Telang (2010) focus on the local level and investigate the effect of broadband infrastructure penetration on DVD sales in US counties for the time period 2000-2003. They find that local broadband infrastructure is positively related to local DVD sales, which they explain by a better marketing promotion of movies through the Internet to raise consumer awareness. Further examples of studies that analyze the substitution effects of the Internet on media markets are Gentzkow (2007) or Falck et al. (2014) for newspapers or Liebowitz and Zentner (2012) for television. While the effect of the Internet on revenues at the firm level has been studied for single markets, to the best of our knowledge no study investigates the overall effects of local broadband infrastructure on local firms' revenues across all industries.[13]

3.3 Data

3.3.1 Firm-Level Data on Employment and Revenue

Firm-level data for the years 2000 and 2005 are taken from Amadeus, a comprehensive database that provides financial information on over 7 million public and private companies across 38 European countries. Previous studies that make use of the Amadeus database include Budd et al. (2005), Helpman et al. (2004) or Konings and Murphy (2006). We only use information on German firms. The dataset is administered and regularly updated by Bureau van Dijk, a publisher of company information and Business intelligence. Bureau van Dijk obtains firm information on German firms from Creditreform, a private agency for business credit reporting. While comparisons of financial firm data across countries may pose an issue due to different accounting practices, within Germany, comparability among firms is high. We use the non-restrictive version of Amadeus, which contains all companies with publicly available information.[14] This means that there exist no minimum thresholds with regards to revenue, assets or the number of employees in order for the firm to be included. The database became more comprehensive over time and contains a larger number of firms in more recent years. The basic dataset we use henceforth is a balanced panel of 210,760 firms for which employment information in both years, 2000 (i.e., pre broadband Internet) and 2005 (i.e., emergence of broadband Internet), exists. The top and low 1 percent

[13] Koellinger (2005) provides some descriptive evidence, that US firms, which invest in ICT, exhibit a higher growth in turnover.

[14] Other versions of Amadeus are available as "Top 250,000 firms" and "Top 1.5 million firms". These have minimum criteria for inclusion in terms of annual revenue, assets or the number of employees.

of the distribution of the differences in employees between 2000 and 2005 are not contained in this sample in order to account for outliers that may be due to measurement error.

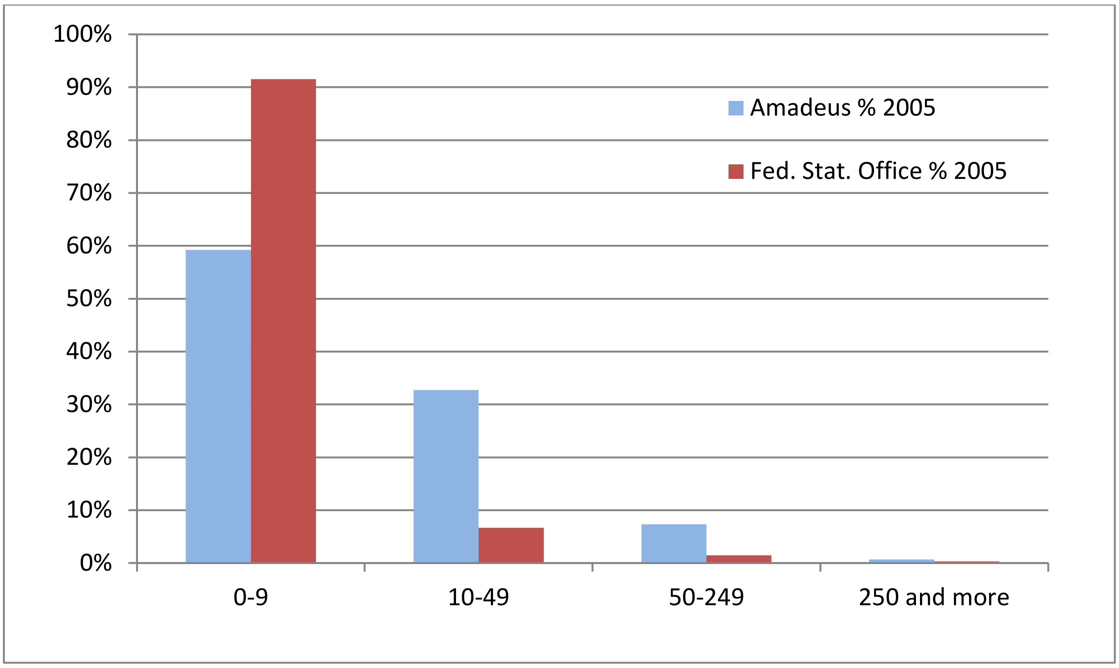
Table 3–1 reveals that the average firm size in our sample is 19.31 employees in 2000 and increases by 0.75 to 20.06 employees in 2005.[15] The positive saldo may be due to the fact that in addition to firms that have existed for at least 5 years, we also only observe firms that survived in the market during the same time period. While the number of employees is a baseline characteristic that is reported for the majority of firms, the number of firms for which financial information is available is considerably smaller. Amadeus names this a problem specific to Germany: Despite a legal requirement for firms to file their accounts at the government registries – and thus make them publicly available –, many firms do not comply. We still observe the operating revenue of 152,363 firms in 2000 and 2005. On average it is around 4.2 million euros (operating revenue is reported in real terms, expressed in prices of 2005) and increases by 0.349 million euros during five years to 4.5 million. The sample of firms reporting their operating revenues is based on the employment sample introduced earlier. It furthermore does not contain the top and low 1 percent of the distribution of the differences in revenues between 2000 and 2005 to account for potential measurement error. The operating revenue measure refers to one balance period, which takes one year and coincides with the calendar year for most firms. Operating revenue includes all “regular” revenues that the company obtains from selling its products to its clients – i.e. mostly sales figures – plus all other revenue linked to the company’s everyday operations. Examples for other revenues are subsidies or variation in stock. We consider absolute values of revenue a preferable measure of firm success over revenues per capita, since the former is a criterion for evaluation by management and stockholders as it directly reflects firm success (March and Sutton, 1997).

Table 3–1 also reports that 0.09 percent of the companies are publicly quoted. Moreover, industry classifications are available as two-digit NACE codes. 64.30 percent of the firms are in the service sector (defined as NACE Codes 50-99 in the EU classification of 2003).

The Amadeus database obtains information on German firms from a private credit reporting company, which may raise concerns about the dataset’s representativeness. Table 3–1 reveals the distribution of firm size categories, according to the class size definition of the EU. The majority of firms, namely 59.1 percent in 2000 fall under the smallest category of 0

Figure 3-1: The Distribution of Firms in Amadeus 2005, by Employment Size Categories

[15] Amadeus offers to impute missing values with estimates. We did not make use of this option and only use observational data.



Data Source: Amadeus database (2005) and Destatis (2014a).

to 9 employees in 2000. 33.49 percent count 10 to 49 employees, and another 6.73 percent have 50-249 employees. Few observations – 0.68 percent – fall under the largest class size of 250 and more employees. Only few firms change their class size status over time. Comparing the class size distribution of 2005[16] in our dataset to official figures from the Federal Statistical Office in Figure 3-1 one can see that the smallest category is underrepresented in Amadeus by approximately 33 percentage points, whereas the two medium categories are overrepresented by 26 and 6 percentage points, respectively. The largest category is overrepresented by about 0.4 percentage points. This selection bias towards larger firms may be explained by an easier data collection for larger firms since these more readily available in official registries and they often publish information online. This finding becomes of relevance when we discuss the results, since the probability to depend on local broadband infrastructures as the sole Internet access declines with increasing company size.

Further comparisons for the distribution of firms and revenues between the 2005 sample in Amadeus and the official statistics are presented in Appendix 3.9. Figure 3-2 and Figure 3-3 reveal that the distribution of the number of firms and generated revenues overall reflect the geographic distribution across German Federal States very well. Figure 3–4 and Figure 3-5 exhibit the relative distributions of the number of firms and revenue by industry branch (by

[16] Comparisons to the official statistics are based on data for 2005, since the Federal Statistical Office does not offer detailed statistics for 2000.

Table 3-1: Firm and Municipality Level Summary Statistics

	2000		2005		Change (2000 -2005)	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Broadband Internet						
Share DSL availability	0	0	0.83	0.16	0.83	0.16
Outcome Variables						
No. of employees	19.31	258.28	20.06	258.60	0.75	9.23
Operating revenue (in 1,000€)	4,203.55	61,085.81	4,553.12	71,997.74	349.57	41,457.62
General firm characteristics						
Publicly quoted	0.09	3.08	0.09	3.08	0	0
% service sector	64.30	47.91	64.30	47.91	0	0
% knowledge intensive	22.42	41.71	22.42	41.71	0	0
% 0-9 employees	59.10	49.16	59.21	49.14	0.11	32.30
%10-49 employees	33.49	47.20	32.66	46.90	-0.83	35.18
% 50-249 employees	6.73	25.05	7.39	26.16	0.66	15.55
% > 250 employees	0.68	8.23	0.74	8.57	0.06	3.24
Municipality level characteristics						
% West Germany	82.79	37.75	82.80	37.80	0.01	1.670
Population size (in 1,000)	345.27	756.50	341.99	752.74	-3.28	148.65
Population density (per km^2)	1,092.92	1,108.06	1,086.61	1,105.24	-6.31	224.06
Business tax rate (in %)	382.62	57.21	382.34	57.19	-0.28	12.57
% Cities with council status	35.43	47.83	35.14	47.74	-0.29	11.57
% Rural region	13.50	34.17	13.51	34.19	0.01	3.03
% Urban region	31.23	46.34	31.25	46.35	0.02	3.49
% Agglomerated region	55.27	49.72	55.24	49.72	-0.03	3.75

Notes: Figures are based on the sample of 210,760 firms used in the analysis. These do not contain observations in the upper and lower 1 percent of the distribution of absolute changes in employment. Operating revenue is observed for 152,363 firms. These do not contain observations in the upper and lower 1 percent of the distribution of absolute changes in revenue. Operating revenue is expressed in real prices of 2005.

2003 classification of 2-digit NACE codes), respectively. While Amadeus contains firms from all industries, one can see in Figure 3–4 that in terms of the number of businesses, trade, manufacturing and construction are overrepresented in Amadeus. Real estate, community, social and personal service activities as well as hotels and restaurants are underrepresented. This pattern generally remains when considering the relative distribution of revenue by industry branch in Figure 3-5, but it seems to fit the official statistics quite well. This may be explained by the underrepresentation of very small firms in our dataset whose revenues do not weigh as much in the revenue distribution. Overall, the statistics show that our dataset covers firms of all sizes and industries. It should thus give a good reflection of the economy in Germany.

3.3.2 Broadband Diffusion across German Municipalities

We make use of data on high-speed Internet (broadband) coverage at the municipality level. We match the firms in our sample to municipalities via the postcodes that Amadeus reports for the year 2000.[17] In Germany, municipalities are the smallest administrative level at which local elections take place.

The data on broadband availability stem from the Broadband Atlas by the Federal Ministry of Economics and Technology, in which broadband providers report the coverage of their infrastructure. Broadband availability is measured as the percentage of households in a municipality that is covered with DSL[18] infrastructure. DSL describes a high-speed Internet connection that uses the copper-based telephone network for data transfer. It allows for greater transfer rates than the ISDN enabled speeds. Our broadband measure is based on self-reported data by the largest Internet providers in a municipality. The Broadband Atlas considers a household to have broadband access if there was a downstream transfer rate of at least 124 kbit/s at the time the service was activated (i.e., if the household had chosen to subscribe to a DSL connection).

We focus on broadband access via DSL, since during the time period from 2000 to 2005, it was practically the only technology available that allowed for transfer rates with broadband speed and alternative technologies for broadband Internet access only played a negligible role in Germany by 2005 (Destatis, 2006). According to TNS Infratest (2005), in 2005 the largest competing infrastructure to DSL was broadband access via cable which posed 1.6 percent of the market for Internet access. It is moreover technically not possible to add the

[17] We use zip codes in 2000 (i.e. the pre-broadband era) to exclude the possibility that firms might relocate and follow broadband infrastructure.

[18] DSL = Digital Subscriber Line, an Internet access technology that allows for high-speed (broadband) transfer rates. It is based on the copper wires of the already existing telephone network.

coverage of different technologies – such as cable coverage – to DSL, since the overlap of the technologies is unknown. In cases of high coverage of both technologies (cable and DSL), our coverage measure would exceed 100 percent.

During the time period we consider, most firms depended on local DSL infrastructure to access the Internet. In 2005, 78 percent of firms with at least 10 employees did realize an Internet connection at all (Destatis, 2006). By end of 2004, 36 percent of Internet using firms had a broadband connection. 89 percent of these broadband users in turn use local DSL infrastructures. The remaining 11 percent of broadband users realize their broadband connection via alternative technologies, such as cable or – particularly in the case of large businesses – leased lines that are independent of the local broadband infrastructure (Destatis, 2005).

Since the Broadband Atlas was only launched in 2005, we cannot observe actual DSL availability before that time. However, the evolution of the telecommunication network infrastructure allows us to argue that DSL was basically not available before 2000 and we set DSL values in 2000 at zero.[19] In the mid-1990s, the Internet experienced a strong increase in use and popularity among business as well as private users. The existing telecommunication network, based on non-broadband dial-up modem and equally non-broadband ISDN access technologies, did not suffice to meet the demands for transfer services and DSL emerged as a new technology. End of 1999, the German telecommunication incumbent Deutsche Telekom started to roll out DSL infrastructure to eight large cities, namely to Berlin, Bonn, Cologne, Düsseldorf, Frankfurt (Main), Hamburg, Munich and Stuttgart. From 2000 onwards, DSL technology was deployed to other cities (Endres et al., 1999).

Table 3–1 shows that by 2005, broadband was at 83.1 percent coverage (simple average, unweighted by number of firms observed in the municipality, the weighted average lies at 75.98 percent) already widely available to German firms in the municipalities in our sample. But the technology did not diffuse evenly throughout the regions. Telecommunication providers are reluctant to establish their infrastructure in rural areas. Obstacles to invest in these areas are due to high costs of provision and a lack of profitability, which give rise to differences in broadband availability

3.3.3 Further Municipality-Level Data

We obtain additional municipality characteristics, namely population size, population density and the local business tax rate from the official statistics on German municipalities

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[19] This assumption of zero DSL availability in 2000 will be dealt with in sensitivity analyses when we discuss our results.

by the Federal Office of Statistics ("Statistik Lokal"). Overall, there are 12,227 municipalities in Germany as of territorial status 2008, which is the status of the broadband data. After mapping the firms to municipalities, 6,214 municipalities remain in which we observe at least one firm. Unfortunately, detailed statistics at the municipality level are only available from 2002 onwards. We thus approximate values on municipality characteristics in 2000 by their values in 2002.

The reported figures only relate to the 6,214 municipalities, in which we observe at least one firm. As shown in Table 3–1, about 83 percent of the firms are located in West-Germany. The average firm in our sample lies in a municipality with 345,000 inhabitants. This large value can be explained by the concentration of economic activity in urban and agglomeration areas. Likewise is the average firm located in an area with a high population density of about 1,093 inhabitants per km^2, which is about 4 times as high as the German average. The values of population size and density decline over time since we observe that some firms relocate between 2000 and 2005. We observe a saldo of about 100 firms moving away from Berlin, which weighs much with over 3 million inhabitants.

Local business tax rates in Germany are defined as a multiplier (in percent) of the firms' taxable trade income.[20] Business tax rates reflect the extent to which local governments try to attract businesses to their municipalities. On average the tax rate lies at 382.6 percent in 2000 and does not change much over time.

We further obtain time-invariant municipality characteristics. Table 3–1 shows the percentage of municipalities which are cities with council status. These cities are characterized by the fact that they fulfil council duties as well as municipality duties in the provision of public goods and administration. They also are of a certain population size (most of them count more than 100,000 citizens) and importance to the surrounding region. 35.4 percent of the firms are located in such a municipality. We moreover observe travel to work regions ("Raumordnungsregionen") that a firm is located in. Germany is divided in 97 travel to work regions, which are official statistical units that are used for administrative purposes and that are based on commuting structures. They range in between NUTS-2 and NUTS-3 levels in size. As Table 3–1 shows, 13.5 percent of the firms are located in travel to work regions that are classified as rural areas, 31.2 in urban and the majority at 55.2 percent in agglomeration areas.

[20] Taxable trade income in Germany is 3.5 percent of the trade income. In a municipality with a business tax rate of 400 the firm thus has a tax liability of (400% * 3.5% * trade income).

3.4 Methodology

The main question addressed in this chapter is whether broadband infrastructure affects firm performance. We measure firm performance by the number of employees and annual revenue. The identification of this effect is not trivial. A general concern in the estimation is that unobservable determinants of broadband providers' decisions to roll-out broadband infrastructure may be correlated with local firms' characteristics. While a single firm is not likely to exert direct influence on local infrastructures[21], the economic situation of the municipality a firm is located in will determine the speed of the diffusion of broadband Internet. Broadband infrastructure follows demand and was rolled out first in structurally strong regions, which at the same time are those regions in which we are more likely to observe a successful, expanding firm than in a structurally weak region. In order to account for firm- and region specific, time persistent characteristics that may affect the broadband providers' investment decisions, we employ a first-difference model where the change in the respective outcome variable over time is regressed on the change in the explanatory variables. A first-difference model is equivalent to estimating firm fixed effects in that it takes out level differences between individuals. The equation we estimate is:

$$\Delta \mathrm{Y}_{i,m} = \alpha + \beta \, \Delta DSL_{\mathrm{m}} + \Delta \mathrm{X}_{\mathrm{m}}{}' \gamma + W_{\mathrm{i}}{}' \delta + \varepsilon_{\mathrm{i}} \qquad (3.1)$$

$\Delta\mathrm{Y}_{i,m}$ is the growth in the outcome of interest between 2000 (the pre-broadband period) and 2005 (the broadband period) of firm i in municipality m. The outcomes we use to measure firm performance are the growth in the number of employees and growth in revenue.[22] DSL is our measure of broadband availability, i.e. the share of households with DSL availability in municipality m. This is equal to the value in 2005, since it is zero in 2000. In $\Delta\mathrm{X}_{\mathrm{m}}$ we control for changes in a municipality's characteristics. The roll-out of broadband infrastructure is driven by considerations on costs and expected profits by the broadband providers which in turn depend on population size respectively the population density. These considerations may change over time as regions become economically more attractive. We therefore include changes in population size as an indicator for local broadband demand and changes in the local business tax rate as an indicator for the effort that local governments might undergo in order to promote local economic activity.[23] A

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[21] Firms of a scale large enough to directly affect local broadband infrastructures are likely to have their own leased lines and thus be independent of the local network.

[22] We measure the dependent variables in logs. Taking first differences ln(Yt) – ln(Yt-1) de facto implements the growth rates as dependent variables.

[23] According to standard tax theory (see e.g. Wilson, 1999) local governments will lower tax rates to attract economic activity to their jurisdiction.

generally more active government in turn might correlate with the government's involvement in the public provision of broadband infrastructure.

We estimate a model in first differences, time-invariant – or for most firms invariant – characteristics, such as the location or the industry branch will be eliminated with first difference estimations. However, one may expect that the firms may follow specific trends within the same travel to work regions or within the same industry as they underlie common shocks. The matrix W thus contains a set of dummies for the respective travel to work region a firm is located in as well as a set of industry dummies at the 2-digit NACE level. We moreover cluster standard errors at the municipality level since the variable of interest is measured at the municipality level (Moulton, 1986).

The DSL coefficient β is the association between the spread of DSL infrastructure in a municipality and the local firms' performance. The effect of DSL is estimated consistently under the assumption that, conditional on the covariates, the change in DSL is not correlated with ε. Controlling for travel to work regions in addition to the firm fixed effects (de facto implemented by the first differences) gives us a strong case for the identification strategy: In this way we compare firms with identical trends within one travel to work region.

3.5 Estimation Results on Broadband Availability and Firm Outcomes

Results from the first difference model are reported in Table 3–2. DSL has a positive, statistically significant impact on employment. According to Column (1), an increase in local broadband availability by 10 percentage points would increase the growth rate in employment by about 1.3 percentage points during the time period from 2000 to 2005. We gradually introduce changes in municipality controls in Columns (2) to (4). Controlling for population size or population density as an alternative, as well as the local business tax rate does not change the size or significance level of our DSL coefficient, and a set of industry dummies at the NACE 2 digit level slightly decreases it. The effect declines dramatically and loses statistical significance, however, when we introduce region fixed effects. The point estimate would than imply that a 10 percentage point increase is merely associated with about 0.16 percentage point increase in employment growth over five years. The association between broadband infrastructure and revenue growth is equally statistically insignificant and very small at a point estimate of approximately 0.09 percentage point increase over a five year period.

Next, we show the robustness of our results to the exclusion of outliers in terms of employment and revenue. The sample as we defined it so far excludes the upper and lower one percent of the distribution of the change in employment and revenue, respectively. Columns (1) and (2) of Table 3–3 show results for samples from which we excluded the upper and lower five percent of the distributions of changes in employment and revenue, respectively. The point estimates decrease further in magnitude towards zero and remain statistically insignificant.

One might argue that we possibly underestimate the effect of broadband availability in a municipality, since we cannot observe the true degree of diffusion of broadband in 2000 and set its value at zero due to the low degree of diffusion and take-up of DSL at that time. As outlined earlier, the deployment of DSL infrastructure had already begun in eight large cities prior to 2000, namely in Berlin, Bonn, Cologne, Düsseldorf, Frankfurt (Main), Hamburg, Munich and Stuttgart.

In order to check the plausibility of our assumption of zero DSL in 2000, we next exclude all firms located in one of these cities. The results can be seen in columns (3) and (4) of Table 3–3. Even though the point estimates slightly increase in comparison to our baseline estimates in Table 3–2, they are comparable in size. In a next step we therefore exclude all firms located in a city with council status from the analysis. Cities with council status are of considerable importance for their surrounding region in terms of population size and economic activity. It is therefore highly likely that broadband infrastructure diffuses more quickly in there cities than in other municipalities. The estimates without these municipalities are shown in Columns (5) and (6). Even though the sample size has dropped by roughly 40 percent in the employment sample and about 35 percent in the revenue sample compared to the baseline estimations, the coefficients of interest do not change notably. This provides confidence that we do not underestimate the effect of broadband infrastructure due to unobserved higher previous diffusion rates in 2000.

3.6 Effect Heterogeneity

The results presented so far suggest that an increase in broadband availability does not generate notable benefits for the majority of firms in Germany. However, there may be certain firms for which the availability of local broadband infrastructure is more important than for others. This section explores possible heterogeneities between subgroups first by municipality and then by firm characteristics and how they react to a change in broadband availability. While previous studies that look into heterogeneous effects of broadband infrastructure are limited to geographic heterogeneities due to the nature of the data, the firm-level dataset allows us to differentiate by firm characteristics.

Table 3-2: Results from First-Difference Estimates for the Full Sample, Dependent Variables: Employment and Revenue Growth

	Employment						Revenue
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
DSL	0.126***	0.126***	0.126***	0.126***	0.103***	0.016	0.009
	(0.013)	(0.013)	(0.013)	(0.013)	(0.013)	(0.013)	(0.014)
Log population		0.008**		0.005	0.006	0.007	0.003
		(0.004)		(0.006)	(0.006)	(0.006)	(0.008)
Population density			0.002**				
			(0.000)				
Business tax rate				0.000	0.000	0.000	-0.000
				(0.000)	(0.000)	(0.000)	(0.000)
Firm fixed effects	yes	Yes	yes	yes	yes	yes	yes
NACE-2 fixed effects					yes	yes	yes
Region fixed effects						yes	yes
Number of firms	210,760	210,760	210,760	210,760	210,760	210,760	152,363
R-squared	0.001	0.001	0.001	0.001	0.013	0.019	0.017

Notes: First-difference estimations for the years 2000 and 2005. The dependent variable is employment growth between 2000 and 2005 in Columns (1) to (6) and growth in annual revenue in Column (7). The employment sample consists of firms for which we observe employment in both years. It does not contain observations in the upper and lower 1 percent of the distribution of absolute changes in employment. The sample in Column (7) consists of firms in the first sample with information on revenues in both years. It does not contain observations in the upper and lower 1 percent of the distribution of absolute changes in revenue. A constant is included, but not reported. Standard errors are clustered at the municipality level. Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1.

The first distinction we make is by firms located in West and East Germany as shown in Table 3–4. Several studies have emphasized the structural economic differences between these regions (see, e.g. Ragnitz, 2007). In addition, the structure of the telecommunication networks have evolved differently and that broadband infrastructure diffused at a lower speed in East Germany due to a technology that was prevalent in East Germany and that hindered the roll out of DSL infrastructure (see Bauernschuster et al., forthcoming).

Our findings in Table 3–4 show statistically significant differences in employment growth in reaction to broadband availability between firms located in West and those in East Germany. A 10 percentage points higher broadband availability results in a 0.41 percentage points higher growth rate in East Germany (Column (2)), whereas it shows no significant effect in the West. For revenue growth, firms located in the west exhibit a higher coefficient than the east, but both effects are not statistically different from zero. One explanation for this is that we observe a higher variation in broadband availability in East Germany, due to the slower diffusion of DSL in these regions. By 2005, the average firm in West Germany had 85.46 percent broadband availability (with standard error 13.18) and the average East German firm had 69.74 percent broadband availability (with standard error 23.92). As a result, the effect of broadband could be estimated more precisely. Another possible explanation is that East German firms actually profited more from technological progress. The east has exhibited a lower growth rate and labor productivity was low compared to the West since reunification (Sinn, 2004). This was partly due to old capital stock and infrastructure, inherited from the former GDR. The new broadband technology and the access to information and interregional exchange it enabled might therefore have had a larger impact on labor productivity and therefore demand for labor on the economy in East Germany.

Next, we divide the sample by the degree of DSL availability that the firms' municipalities have reached by 2005. Röller and Waverman (2001) e. g. find positive effects of telecommunication infrastructure at the country level only from a critical mass onwards. Their explanation for this phenomenon is that telecommunication infrastructures in general exhibit network externalities, i.e. the more infrastructure users there are, the higher are these users' benefits. At the regional level, one could think of a different mechanism. A low local diffusion rate in the own municipality relative to the others means that the firms in that municipality are "cut-off" from communication with the other, better equipped, regions and the introduction of broadband infrastructure to such a municipality could generate large effects for the local firms. Table 3–5 shows that the point estimates of subsamples for firms in municipalities with less than 50 percent coverage (in Columns (1) and (3)) are indeed larger than those for firms with a higher broadband diffusion. However, the effects are not statistically significant.

Table 3-3: Subsamples for Robustness Checks

	Percentiles 5-95		w/out Cities with DSL in 1999		w/out Council Status	
	Employment	Revenue	Employment	Revenue	Employment	Revenue
	(1)	(2)	(3)	(4)	(5)	(6)
DSL	0.008	0.002	0.019	0.013	0.019	0.016
	(0.011)	(0.013)	(0.013)	(0.014)	(0.013)	(0.015)
Log population	0.004	0.005	0.006	0.003	0.002	-0.006
	(0.005)	(0.007)	(0.006)	(0.008)	(0.006)	(0.009)
Business tax rate	0.000	-0.000	0.000	0.000	0.000	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Firm fixed effects	yes	yes	yes	yes	yes	yes
NACE-2 fixed effects	yes	yes	yes	yes	yes	yes
Region fixed effects	yes	yes	yes	yes	Yes	yes
Number of firms	192,561	140,075	178,734	130,512	136,758	100,487
R-squared	0.015	0.019	0.020	0.018	0.022	0.019

Notes: First-difference estimations for the years 2000 and 2005. The dependent variable is employment growth between 2000 and 2005 in Columns (1), (3) and (5) and growth in annual revenue in Columns (2), (4) and (6). Columns (1) and (2) do not contain the upper and lower 5 percent of the total distribution of absolute changes in employment and revenue, respectively. Columns (3) to (6) do not contain observations in the upper and lower 1 percent of the total distribution of absolute changes in employment/revenue, respectively. Columns (3) and (4) do not contain firms located in Berlin, Bonn, Cologne, Düsseldorf, Frankfurt (Main), Hamburg, Munich and Stuttgart. Columns (5) and (6) do not contain firms located in a city with council status. A constant is included, but not reported. Standard errors are clustered at the municipality level. Robust standard errors in parentheses *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

Next, we distinguish firms by the type of travel to work region they are located in, i.e. whether they are located in a rural, urban or agglomeration region. Previous research is inconclusive on whether the effect of ICT is complementary to rural or agglomeration areas and where the highest payoffs are to be expected. Forman et al. (2012) have shown the use of ICT in firms does only generate positive effects in already wealthy, well-off regions. Kolko (2012) in contrast finds that rural areas may benefit more from broadband infrastructure. Our results in Table 3–6 show that there is no difference in the benefits from broadband availability by the type of travel to work region. By tendency, agglomeration areas exhibit greater employment growth from broadband and less revenue growth. But the effects are consistently small, and, again, not statistically significant. This contrasts previous studies that find heterogeneous effects for different types of regions.

As already mentioned above, not all firms can be expected to depend equally on local broadband infrastructure in order to access the Internet. The larger a firm, the higher is the probability that it has sufficient resources to establish an own leased line, with which it becomes independent of the local infrastructures. We therefore divide the sample of firms by their employment sizes as shown in Table 3–7. Class size categories, based on the number of employees, are chosen in accordance with European Commission (2006) categories.[24] The results again show no heterogeneities between firms of different size categories. The association between broadband availability and revenue becomes relatively large at 0.6 percentage point higher growth in employment in response to a 10 percentage point increase in the explanatory variable (Column (8)). But at the same time, the standard error increases by about tenfold compared to the other estimations. This indicates that the effect of broadband infrastructure cannot be estimated precisely due to much noise in the largest firm category.

Several studies have come to the conclusion that the service sector differs in the way in which it uses ICT resources from other sectors (see, e.g. Hempell et al., 2004; Gago and Rubalcaba, 2007; OECD, 2008, Polder et al., 2009). According to an OECD study (2000), the service sector has played a leading role in the adoption of ICT. Firms in the services sectors have been investing more heavily in ICT equipment during the 1990s. Examples for ICT use in the service industries in the early 2000s are cash machines, online banking, e-commerce or web-based after-sales customer services (Hempell, 2005). All of these applications require Internet access. Broadband infrastructure is therefore likely to affect the service sector differently from other firms. We divide our sample in two parts by NACE codes to distinguish the service sector from other industries. Columns (1) and (3) of Table

[24] Further results for class sizes, in which not only the number of employees, but also revenue (i.e. the classification for small and medium Enterprises) are used as cutoff criteria, are provided in Table 3-10 in Appendix 3.9. The results are qualitatively comparable in that no significant differences between the subsamples exist.

3–8, include NACE codes 01-49.[25] Columns (2) and (4) contain firms in the service sector, i.e. NACE codes 50 to 99.[26] The results show, that broadband availability is indeed positively correlated with employment and revenue growth. Both DSL coefficients are statistically significant at the 5 and 10 percent levels, respectively. This may possibly be because they were more advanced users of broadband in the early years of DSL expansion. At the same time, broadband does exhibit a slightly negative relationship with non-service sectors. But the effects are not statistically significant.

In Table 3–9, we further divide the sample of firms in the service sector by class sizes, analogous to Table 3–7. This shows that employment growth from broadband infrastructure is driven by the smallest category of firms with less than 10 employees (cf. Column (1)). Moreover, revenue gains are generated in the second smallest firm category (Column (6)). Again, we observe a very large, but statistically insignificant effect for revenue growth in the largest class size of firms above 250 employees. We argue that this coefficient cannot be estimated precisely with relatively few observations in the highest category. In addition, there is likely to be much noise in the data since these are the companies that are the least likely to depend on local broadband infrastructure.

3.7 Discussion of the Results

The results we presented so far suggest that even though broadband infrastructure is already widely available to German firms by 2005, we do not find statistically significant general effects of the new technology. However, a subset of firms, namely small firms in the service industry, reacts positively to the deployment of broadband. The overall effect we find is considerably smaller than previous studies on the effect of broadband infrastructure suggest. Kolko (2012) states that broadband deployment in a zip code area is associated with a 6.4 percentage point higher growth rate over a seven year period. Compared to that, our estimations are considerably smaller: Going from zero to full coverage in a municipality is associated with a (not from zero distinguishable) point estimate of 1.6 percentage points higher growth rates (cf. Table 3–2, Column (6)) growth in the number of employees over a time period of 5 years. Calculating the 95 percent confidence interval gives us a range of values between -0.9 and 4.2 percentage points higher growth rates. We thus argue that we do not confirm the very large positive effects of broadband availability on employment

[25] These are the sectors A-F (agriculture, fishing, mining, manufacturing, electricity, gas and water supply as well as construction).

[26] These are the sectors G-P (trade, hotels and restaurants, transport storage and communication, finance, real estate, Public administration, education, health and social work, social and personal service and private household services).

found in previous studies based on the evidence we presented here. We are not aware of any comparable studies to hold the estimated sizes for revenue growth against.

As outlined earlier, in theory the effects of broadband availability could be negative and in the presence of positive omitted variables bias we would overstate the true effects of broadband availability. Given that the identification strategy is quite strong in that trends of firms in different municipalities within the same travel to work region are compared with each other, there should not be much unobserved heterogeneity left. Still, there could be time-varying, unobserved factors left that influence the change in DSL as well as the change in the respective outcomes. We do, however, expect any possible remaining omitted variables bias (after controlling for firm, industry and regional fixed effects) to be positive. We assume that a single firm will not directly influence broadband provision. Well performing, successful firms are (on average) more likely to be located in regions of economic upswing, which would overestimate the true effect of DSL on employment irrespective of whether the true population effect of broadband availability was positive or negative.

Similarly to employment, we have no prior on the direction of the effect of DSL on firms' revenues. Broadband availability may increase the firms' geographic radius of potential sales markets, thus generating higher revenues, but at the same time, local customers may substitute away from local products due to higher market transparency and lower cost of transaction of buying products from firms that are located further away. We have no information in our dataset on the size of a firm's sales radius or export activity. If additional sales were generated only through the firm's local market – possibly due to an increase in local incomes and therefore higher demands – and at the same time broadband infrastructure was rolled out in this area, this effect would be attributed to our DSL coefficient even though it was not necessarily generated through broadband availability. In this case its effect on revenues would be overestimated due to an omitted variables bias.

Previous empirical studies with outcomes at the aggregated regional level might moreover find higher positive effects from stronger omitted variables bias by construction. A single firm, as we observe it, is not likely to attract broadband deployment in the municipality, but the region as such (i.e. the composition of many firms and households) will influence broadband providers' decisions to roll out infrastructure with certainty.

Our findings do not necessarily imply that there are no general effects of broadband availability and there are several reasons for why one might find general effects in a different setting. First, our sample captures an introduction effect since we only observe the early period after the expansion of the newly introduced broadband technology. Information technologies in general are considered one of the most important examples of a general purpose technology. Other examples are electricity or the steam engine. The latter highlight the fact that the early impacts of a general purpose technology start off rather small and that the full potential of these innovations will not be realized until several decades later.[27] It might thus well be, that larger benefits of broadband could be observed in later years, even though it diffused quickly and is already widely available by 2005.

Moreover, our data might suffer from measurement error. Measurement error in the explanatory variable might arise since data on broadband availability are based on self-reported figures from broadband providers. Under the assumption of a classical measurement error, our estimate of the coefficient of interest would be biased towards zero. In addition, the outcome variables, i.e. information on employment and revenue, might contain some measurement errors even though we deleted the upper and lower 1 percent of extreme values from our sample. We assume that potential errors in our broadband measure and the outcomes are not correlated with each other. This seems not a strong assumption since information on the firm level outcomes and the explanatory variable of interest stem from different sources and aggregation levels. Under this scenario, our estimates would be downward biased as in the case of classical measurement error (Hyslop and Imbens, 2001).

In this study, we measure the effect of broadband availability only along two dimensions with our outcome variables. Other measures of firm performance might exist, but not be captured by the number of employees or revenue. A higher quality of products or more efficient processes within the firm have been suggested as benefits of ICT in general. As outlined in Chapter 2, ICT investments are indeed linked with a higher innovative activity. Unfortunately, we have no further information on any of these firm measures.

As far as the dataset is concerned, we employ a first-difference approach, such that our sample only contains firms that already existed in 2000. We thus cannot observe the founding of new firms. In theory, broadband availability might also cause marginal firms to exit the market due to higher competitive pressure, but previous evidence suggests a positive saldo of broadband on the number of firms. Mack et al. (2011) for example find that broadband provision explains some decisions by knowledge-intensive industries to locate in U.S. metropolitan areas. Gillett et al. (2006) conclude that U.S. communities that had broadband by 1999 experienced higher growth in the number of businesses from 1998 to 2002 than other communities.

Moreover, as previously discussed, our dataset underrepresents small firms. But the smaller a firm is, the more likely it is to depend on the local broadband networks at their sole Internet access technology. This could pose another source of underestimation.

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[27] David (1990) states that the largest benefits from electricity occurred in the US around 40 years after the introduction of the first commercial generators. Similarly, Crafts (2004) finds that the lag of the steam engine lay at around 80 years.

Finally, one should note, that we explicitly measure the effect of broadband availability, not the effect of broadband use, which we cannot observe. Broadband availability proved to be the politically relevant variable for governments' involvement as it can be directly influenced, whereas changing firms' broadband use is much more difficult. But when considering the economic effect of broadband usage, our study represents a reduced form that underestimates the usage effect. As outlined in the data section, the take-up rate of broadband among German businesses was not yet very high by 2005, as only about 25 percent of firms made active use of local DSL connections. This may be an indication that political efforts towards the promotion of the use of new broadband technologies could be more effective than the provision of infrastructure.

3.8 Conclusion

Broadband infrastructure is considered an important location factor by policy makers, in that it makes firms more productive, which might generate employment effects. In addition, it may create financial benefits for local firms by opening up new markets. In consequence, a comprehensive availability and the public financing of broadband infrastructure has been recurring subject to government involvement.

While broadband infrastructure has already reached high levels of diffusion throughout German municipalities by 2005, the overall payoffs of broadband availability appear rather limited. First-difference estimations between 2000 and 2005, which account for time-invariant, firm and location-specific persistence, find no overall effect of local broadband infrastructure on firm performance. However, we do find a positive, statistically significant relationship between broadband availability and employment as well as revenue growth for small firms in service industries, possibly because they were more advanced users of broadband in early years. In addition, firms in East Germany show stronger positive employment effects to broadband.

Given that the firms in our sample already reached on average high levels of broadband availability – 83 percent in 2005 – it seems like one may not set expectations in the economic implications of a comprehensive broadband availability too high. The promotion of broadband adoption could possibly generate larger effects than mere infrastructure provision.

Table 3-4: Subsamples by West and East Germany

	Employment		Revenue	
	West Germany	East Germany	West Germany	East Germany
	(1)	(2)	(3)	(4)
DSL	-0.004	0.041**	0.022	-0.004
	(0.017)	(0.018)	(0.018)	(0.022)
Log population	0.007	0.010	0.015	-0.012
	(0.008)	(0.009)	(0.010)	(0.014)
Business tax rate	0.000	-0.000	-0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.001)
Firm fixed effects	yes	yes	yes	yes
NACE-2 fixed effects	yes	yes	yes	yes
Region fixed effects	yes	yes	yes	yes
Number of firms	174,474	36,260	126,797	25,566
R-squared	0.015	0.026	0.015	0.030

Notes: First-difference estimations for the years 2000 and 2005. The dependent variable is employment growth between 2000 and 2005 in Columns (1) and (2) and growth in annual revenue in Columns (3) and (4). All subsamples do not contain observations in the upper and lower 1 percent of the total distribution of absolute changes in employment/revenue, for the respective outcomes. Columns (1) and (3) are based on firms located in West Germany, Columns (2) and (4) on those located in East Germany. A constant is included, but not reported. Standard errors are clustered at the municipality level. Robust standard errors in parentheses *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

Table 3-5: Subsamples by DSL Availability in 2005

	DSL Availability			
	< 50%	>= 50%	< 50%	>= 50%
	Employment		Revenue	
	(1)	(2)	(3)	(4)
DSL	0.053	0.030	0.026	-0.003
	(0.039)	(0.020)	(0.047)	(0.022)
Log population	-0.031	0.011*	-0.091**	0.012
	(0.020)	(0.006)	(0.042)	(0.008)
Business tax rate	0.001**	-0.000	0.003**	-0.000
	(0.001)	(0.000)	(0.001)	(0.000)
Firm fixed effects	yes	yes	yes	yes
NACE-2 fixed effects	yes	yes	yes	yes
Region fixed effects	yes	yes	yes	yes
Number of firms	9,141	201,593	6,816	145,547
R-squared	0.045	0.018	0.053	0.016

Notes: First-difference estimations for the years 2000 and 2005. The dependent variable is employment growth between 2000 and 2005 in Columns (1) and (2) and growth in annual revenue in Columns (3) and (4). All subsamples do not contain observations in the upper and lower 1 percent of the total distribution of absolute changes in employment/revenue, for the respective outcomes. Columns (1) and (3) are based on firms located in municipalities with less than 50 percent DSL availability in 2005, Columns (2) and (4) on those with 50 percent or more DSL coverage. A constant is included, but not reported. Standard errors are clustered at the municipality level. Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1.

Table 3-6: Subsamples by Type of Region

	Type of Region					
	Rural	Urban	Agglomeration	Rural	Urban	Agglomeration
	Employment			Revenue		
	(1)	(2)	(3)	(4)	(5)	(6)
DSL	0.009	0.003	0.031	0.035	0.023	-0.035
	(0.021)	(0.020)	(0.026)	(0.025)	(0.022)	(0.027)
Log population	0.024	-0.005	0.009	0.024	-0.003	0.000
	(0.015)	(0.011)	(0.008)	(0.018)	(0.016)	(0.010)
Business tax rate	-0.000	0.000	-0.000	-0.002**	0.000	0.000
	(0.001)	(0.000)	(0.000)	(0.001)	(0.001)	(0.000)
Firm fixed Effects	yes	yes	yes	yes	yes	yes
NACE-2 fixed effects	yes	yes	yes	yes	yes	yes
Region fixed Effects	yes	yes	yes	yes	yes	yes
Number of firms	28,473	65,852	116,409	21,518	45,948	84,897
R-squared	0.029	0.022	0.016	0.026	0.024	0.014

Notes: First-difference estimations for the years 2000 and 2005. The dependent variable is employment growth between 2000 and 2005 in Columns (1) to (3) and growth in annual revenue in Columns (4) to (6). All subsamples do not contain observations in the upper and lower 1 percent of the total distribution of absolute changes in employment/revenue, for the respective outcomes. Columns (1) and (4) are based on firms located in rural regions, Columns (2) and (5) on firms located in urban regions and Columns (3) and (6) on firms located in agglomeration regions. Firm location in 2000 is relevant for the subsamples. A constant is included, but not reported. Standard errors are clustered at the municipality level. Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1.

Table 3-7: Subsamples by Firm Size Category

	Employment Size							
	0-9	10-49	50-249	≥250	0-9	10-49	50-249	≥250
	Employment				Revenue			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
DSL	0.021	0.017	-0.006	-0.012	0.007	0.011	0.032	0.063
	(0.017)	(0.020)	(0.018)	(0.019)	(0.020)	(0.020)	(0.038)	(0.213)
Log population	0.011*	0.000	0.000	-0.014*	0.009	-0.008	-0.016	-0.078*
	(0.007)	(0.012)	(0.012)	(0.008)	(0.010)	(0.013)	(0.028)	(0.045)
Business tax rate	-0.000	0.001*	-0.000	0.000	-0.000	0.001*	-0.000	0.002
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)	(0.002)
Firm fixed effects	yes	yes	yes	yes	yes	yes	yes	yes
NACE-2 fixed effects	yes	yes	yes	yes	yes	yes	yes	yes
Region fixed effects	yes	yes	yes	yes	yes	yes	yes	yes
Number of firms	135,450	61,682	12,288	1,314	88,734	51,775	10,726	1,146
R-squared	0.018	0.057	0.056	0.121	0.010	0.021	0.026	0.081

Notes: First-difference estimations for the years 2000 and 2005. The dependent variable is employment growth between 2000 and 2005 in Columns (1) to (4) and growth in annual revenue in Columns (5) to (8). The subsamples do not contain observations in the upper and lower 1 percent of the total distribution of absolute changes in employment/revenue, for the respective outcomes. Columns (1) and (5) contain firms with less than 10 employees. Columns (2) and (6) contain firms with 10 to 49 employees. Columns (3) and (7) contain firms with 50 to 249 employees. Columns (4) and (8) contain firms with more than 250 employees. The subsamples are based on firm size in 2000. A constant is included, but not reported. Standard errors are clustered at the municipality level. Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1.

Table 3-8: Subsamples by Type of Industry

	Service Industries			
	No	Yes	No	Yes
	Employment		Revenue	
	(1)	(2)	(3)	(4)
DSL	-0.014	0.034**	-0.025	0.036*
	(0.018)	(0.017)	(0.018)	(0.020)
Log population	0.006	0.008	-0.012	0.013
	(0.009)	(0.008)	(0.010)	(0.010)
Business tax rate	-0.000	0.000	0.000	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)
Firm fixed effects	yes	yes	yes	yes
NACE-2 fixed effects	yes	yes	yes	yes
Region fixed effects	yes	yes	yes	yes
Number of firms	75,210	135,524	61,225	91,138
R-squared	0.026	0.014	0.029	0.012

Notes: First-difference estimations for the years 2000 and 2005. The dependent variable is employment growth between 2000 and 2005 in Columns (1) and (2) and growth in annual revenue in Columns (3) and (4). All subsamples do not contain observations in the upper and lower 1 percent of the total distribution of absolute changes in employment/revenue, for the respective outcomes. Columns (1) and (3) are based on firms in not-knowledge intensive industries. Columns (2) and (4) are based on those in knowledge intensive industries. Subsamples are generated by 2-digit NACE codes (2003 classification). A constant is included, but not reported. Standard errors are clustered at the municipality level. Robust standard errors in parentheses *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

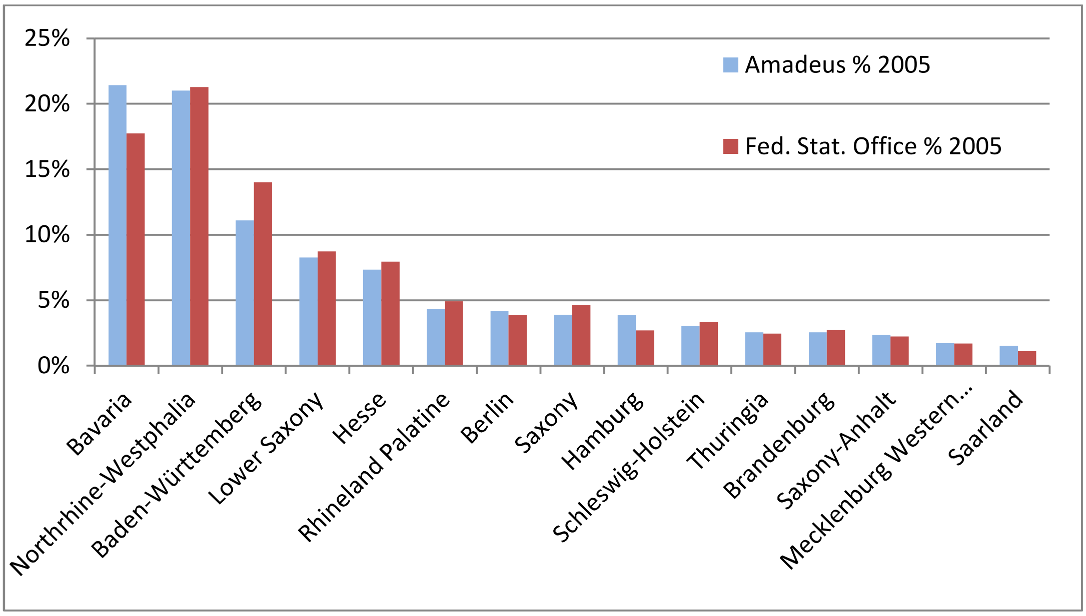
Table 3-9: Subsamples by Firm Size Category in the Service Sector

	Employment Size							
	0-9	10-49	50-250	>250	0-9	10-49	50-250	>250
	Employment				Revenue			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
DSL	0.041**	0.046	-0.040	-0.007	0.027	0.051*	-0.022	0.673
	(0.021)	(0.029)	(0.026)	(0.030)	(0.028)	(0.030)	(0.047)	(0.664)
Log population	0.018**	-0.022	-0.012	-0.002	0.020	-0.000	0.004	-0.068
	(0.008)	(0.018)	(0.014)	(0.008)	(0.013)	(0.019)	(0.030)	(0.046)
Business tax rate	-0.000	0.001*	0.001	0.000	-0.000	0.000	-0.000	0.002
	(0.000)	(0.001)	(0.001)	(0.000)	(0.000)	(0.001)	(0.001)	(0.002)
Firm fixed effects	yes	yes	yes	yes	yes	yes	yes	yes
NACE-2 fixed effects	yes	yes	yes	yes	yes	yes	yes	yes
Region fixed effects	yes	yes	yes	yes	yes	yes	yes	yes
Number of firms	91,086	37,025	6,690	723	55,285	29,618	5,637	598
R-squared	0.017	0.063	0.033	0.173	0.015	0.030	0.035	0.217

Notes: First-difference estimations for the years 2000 and 2005. The dependent variable is employment growth between 2000 and 2005 in Columns (1) to (4) and growth in annual revenue in Columns (5) to (8) in the service sector. All subsamples do not contain observations in the upper and lower 1 percent of the total distribution of absolute changes in employment/revenue, for the respective outcomes. Columns (1) and (5) contain firms with less than 10 employees. Columns (2) and (6) contain firms with 10 to 49 employees. Columns (3) and (7) contain firms with 50 to 249 employees. Columns (4) and (8) contain firms more than 250 employees. The subsamples are based on firm size in 2000. A constant is included, but not reported. Standard errors are clustered at the municipality level. Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1.

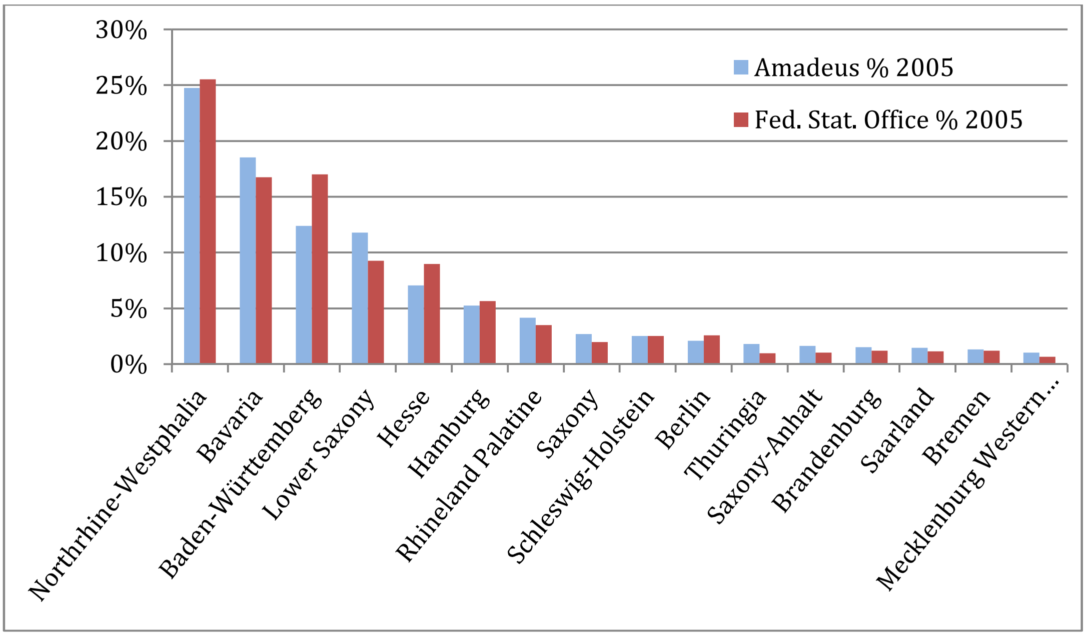
3.9 Appendix

Figure 3-2: The Distribution of Firms in Amadeus 2005, by Federal States



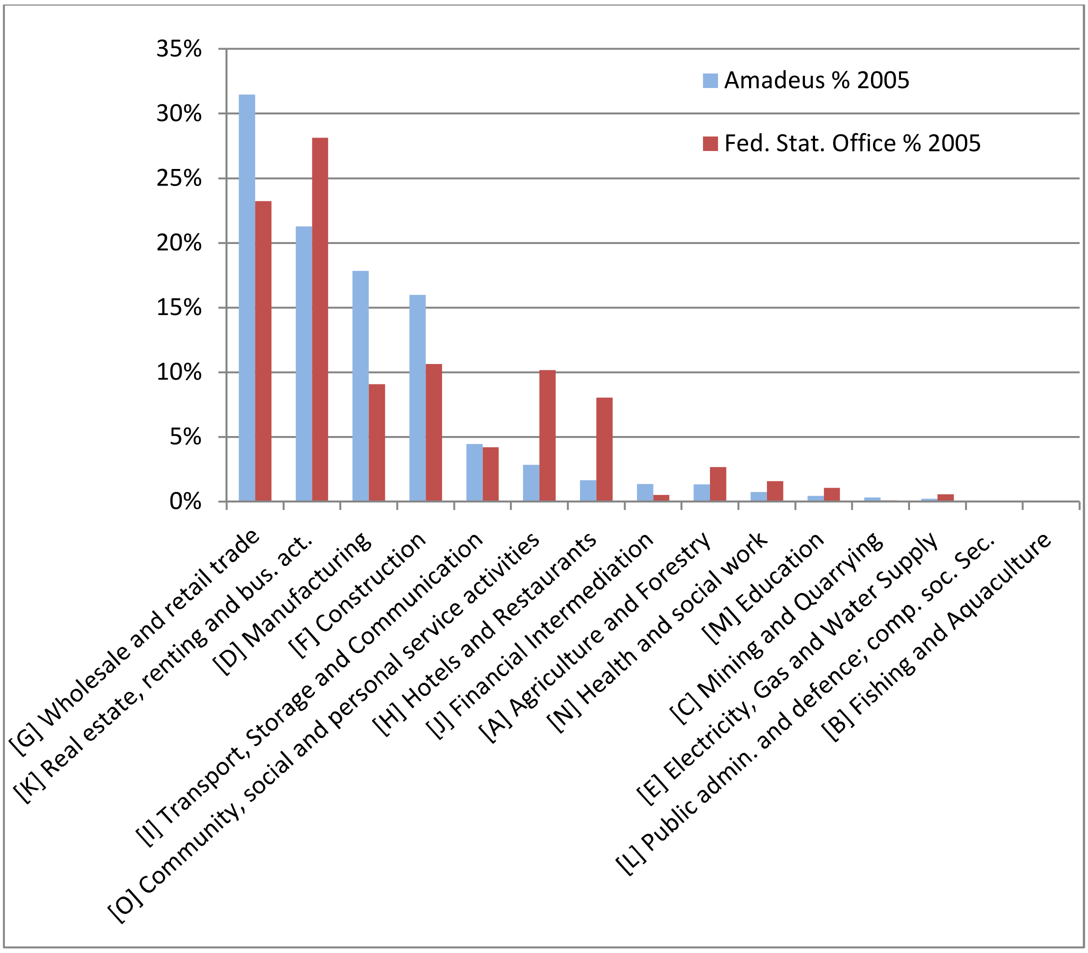
Data Source: Amadeus database (2005) and Destatis (2014b). The figure does not include NACE codes P (activities of households as employers) since the Federal Statistical Office does not provide Statistics for this branch.

Figure 3-3: The Distribution of Revenue in Amadeus 2005, by Federal States



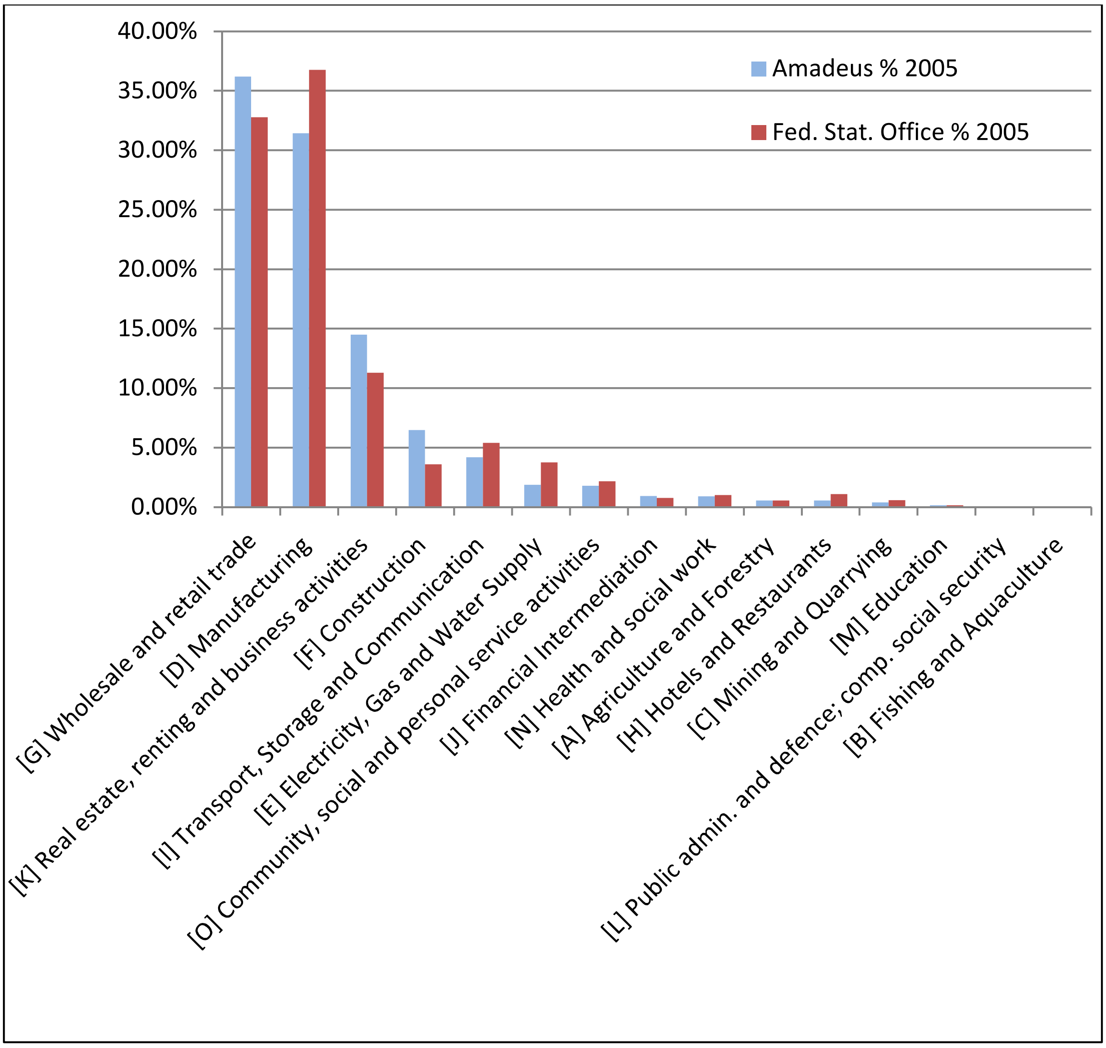
Data Source: Amadeus database (2005) and Destatis (2014c). The figure does not include NACE codes P (activities of households as employers) since the Federal Statistical Office does not provide Statistics for this branch.

Figure 3-4: The Distribution of Firms in Amadeus 2005, by NACE codes (2003)



Data Source: Amadeus database (2005) and Destatis (2014b). The figure does not include NACE codes P (activities of households as employers) since the Federal Statistical Office does not provide Statistics for this branch.

Figure 3-5: The Distribution of Revenue in Amadeus 2005, by NACE codes (2003)



Data Source: Amadeus database (2005) and Destatis (2014d). The figure does not include NACE codes P (activities of households as employers) since the Federal Statistical Office does not provide Statistics for this branch.

Table 3-10: Subsamples by Small and Medium Enterprises

	EU Firm Classification							
	Very small	Small	Medium	Large	Very small	Small	Medium	Large
	Employment				Revenue			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
DSL	0.007	0.027	-0.008	-0.047	0.013	0.009	0.010	-0.106
	(0.019)	(0.019)	(0.024)	(0.071)	(0.022)	(0.019)	(0.033)	(0.430)
Log population	0.012*	-0.004	-0.022	0.000	0.011	-0.006	-0.018	
	(0.007)	(0.011)	(0.021)	(0.010)	(0.011)	(0.012)	(0.021)	
Business tax rate	-0.000	0.001**	0.001	0.001***	-0.000	0.000	0.001	
	(0.000)	(0.000)	(0.001)	(0.000)	(0.000)	(0.000)	(0.001)	
Firm fixed effects	yes	yes	yes	yes	yes	yes	yes	yes
NACE-2 fixed effects	yes	yes	yes	yes	yes	yes	yes	yes
Region fixed effects	yes	yes	yes	yes	yes	yes	yes	yes
Number of firms	96,621	74,013	18,132	171	74,272	62,010	14,826	88
R-squared	0.020	0.038	0.024	0.451	0.012	0.018	0.020	0.847

Notes: First-difference estimations for the years 2000 and 2005. The dependent variable is employment growth between 2000 and 2005 in Columns (1) to (4) and growth in annual revenue in Columns (5) to (8). All subsamples do not contain observations in the upper and lower 1 percent of the total distribution of absolute changes in employment/revenue, for the respective outcomes. Columns (1) and (5) contain firms with less than 10 employees and up to 2 million € annual revenue. Columns (2) and (6) contain firms with less than 50 employees and up to 50 million € annual revenue. Columns (3) and (7) contain firms with less than 249 employees and up to 50 million € annual revenue. Columns (4) and (8) contain firms more than 250 employees and more than 50 million € annual revenue. The subsamples do not overlap and are based on values in 2000. A constant is included, but not reported. Standard errors are clustered at the municipality level. Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

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4 The Impact of Broadband on Economic Activity in Rural Areas: Evidence from German Municipalities[28]

4.1 Introduction

Today, most OECD countries are engaged in expanding ICT infrastructure to their so-called white spots, which are predominantly rural municipalities that have so far remained largely unprovided by the market without government intervention. For example, between 2008 and 2013, in an effort to promote broadband Internet as a source of growth in Germany, a total of €454 million from European, national, and federal state funding has been made available to German municipalities to close white spots, which chiefly occur in rural areas. In its Broadband Strategy, the German Federal Ministry of Economics and Technology (2009) identified broadband Internet as a crucial location factor in securing jobs and even creating workplaces by attracting businesses to rural areas. In addition, local decision makers, especially in smaller communities, seem to have high hopes in regard to the effects of broadband infrastructure and actively engage in its expansion. According to a recent survey in Germany, local politicians expect to keep businesses from relocating, and to attract new businesses, if the municipality can offer broadband infrastructure (Muecke und Sturm, 2010).

Even though it appears to be widely believed that broadband infrastructure will boost local economies and labor markets, theory and empirical evidence on the effect of ICT in rural areas is far less certain. The positive effects of broadband Internet from a macroeconomic perspective have been confirmed in several studies, however, it is less clear how these benefits are distributed within an economy on a regional or even local level. Two widely accepted hypotheses make diverging predictions on the extent to which rural regions profit from broadband Internet. On the one hand, broadband infrastructure considerably lowers the transport costs for large batches of information and therefore allows for interplay between physically separated economic agents, even over large distances. Indeed, it is even claimed

[28] This chapter is available as Ifo Working Paper No. 166, 2013, “The Impact of Broadband on Economic Activity in Rural Areas: Evidence from German Municipalities”.

that broadband Internet, and the applications it enables, will be the “death of distance” (Cairncross, 1997) and over-proportionately foster economic growth in rural areas. On the other hand, it is argued that ICT, in general, complement certain factors prevailing in larger cities, such as a highly qualified workforce (Autor et al., 2003). According to this argument, rural areas might receive only limited benefits from broadband infrastructure.

This study contributes to the existing literature in that we estimate a model with municipality fixed effects, which account for time invariant municipality characteristics that may be correlated with broadband deployment as well as regional development. Moreover, we concentrate on the economic benefits that broadband infrastructure confers on rural areas.

We analyze the impact of comprehensive broadband infrastructure at the municipality level on local economic development as measured by local employment patterns. We combine municipality-level employment data from the Regional Database of the German Federal Office of Statistics with detailed information from the German *Broadband Atlas* on broadband access rates at the municipality level, our variable of interest. We consider infrastructure availability as the most relevant variable, policy-wise, instead of broadband usage (even if the latter generates the benefits), since it can be influenced by policymakers and local politicians. Our study covers the years 2005 to 2009 and our sample consists of a balanced panel of 8,321 West German municipalities.

There are several challenges in identifying the effect of broadband on local employment, which are mostly due to possible endogeneity of infrastructure provision. Even after controlling for the main determinants of the supply of broadband infrastructure, there could be municipality characteristics that influence the provision of broadband infrastructure as well as the local labor market. To solve for time-invariant municipality characteristics that might bias our results, we make use of the panel structure of our dataset and control for municipality fixed effects.

Our estimates suggest that broadband infrastructure does have a positive but, in terms of economic size, rather limited effect on the local employment rates in the sample that includes all municipalities. A 10 percentage point increase in local broadband availability increases the local employment rate by 0.04 percentage points. This effect is – depending on the definition of rural areas – at least two times higher in rural areas. In addition, we find no effects in the manufacturing sector, suggesting the effect occurs in the service sector. Our results are robust to the inclusion of various control variables. We chose controls in order to reflect local demand for broadband services and to control for the fact that some local governments might actively engage in attracting business, which may be correlated with the employment rate as well as municipal broadband programs.

The chapter proceeds as follows: in Section 4.2 we provide a short overview of the literature on how broadband infrastructure influences growth and employment. Sections 0 and 4.4 introduce the data and the identification strategy, respectively. Section 4.5 presents our results and Section 4.6 concludes.

4.2 Related Literature

4.2.1 Broadband Infrastructure and Local Labor Markets

Several studies have confirmed a positive impact of broadband infrastructure on economic growth at the macroeconomic and regional levels. In a cross-country study covering the years 1996 to 2007, Czernich et al. (2011) for example employ a technology diffusion model to confirm a causal, positive impact of broadband infrastructure on growth in GDP per capita. According to their estimates, a 10 percentage point increase in broadband penetration leads to a 0.9–1.5 percentage point increase in annual per-capita growth. Furthermore, Crandall et al. (2007) find a positive association between broadband deployment and private-sector nonfarm employment at the U.S.-state level. These effects are strongest for certain service industries such as finance, education, and healthcare.

At a less aggregate level, the effect of ICT on local markets has been subject to several empirical analyses. Various studies confirm a positive association between broadband deployment and economic activity at the local level (see, e.g., Bertschek et al., 2013; Kolko, 2012).[29] However, Czernich (2011) investigates how local unemployment rates are affected by local broadband availability in German municipalities. Using a value added model, she instruments broadband availability in the municipality with distance to the closest interconnection point (which determines broadband speed to a certain extent) and finds no effect of broadband on unemployment.

In theory, there are multiple channels through which ICT can affect local labor demand. For example, ICT may affect the labor demand of already established firms. Fast Internet is the sort of technology shock that should increase these firms' productivity through an increased flow of information, or easier ways of communication with customers and business partners, or even the facilitated collaboration with research partners. However, how increased labor productivity affects firm's demand for labor is not clear. On the one hand, an income effect would increase labor demand. On the other hand, however, ICT might have a negative effect on employment since the new technology facilitates process innovations that allow for the

[29] Further studies that look into the effects of broadband at a regional level are Gillett et al. (2006) and Koellinger (2006).

use of less labor at constant production output (OECD, 2008). The overall employment effect would thus depend on which dominates – labor substitution or the income effect.

Another possible channel of how broadband availability affects local labor demand is the settlement of firms in an area. Broadband infrastructure might affect their location decisions ex ante, which would increase demand for labor in a region. In theory, these may be newly founded enterprises, new branches of already existing firms, or even relocating firms. The founding of new firms would be an aggregate positive effect. However, a mere relocation effect would not generate positive effects in the aggregate level. It is not clear which areas benefit from the relocation of businesses. A study by Mack et al. (2011) finds that broadband provision explains some decisions by knowledge-intensive industries to locate in U.S. metropolitan areas. Gillett et al. (2006) conclude that U.S. communities that had broadband by 1999 experienced higher growth in employment and in the number of businesses from 1998 to 2002 than other communities.

As to how broadband Internet impacts labor *supply*, note that not only firms, but also households may make decisions based on its availability. In general, ICT advancement is assumed to increase telecommuting (see, e.g., Autor, 2001) and this may be especially relevant for rural areas. People who live in remote areas and who previously may have faced prohibitively high commuting costs might choose to enter the labor market when they have access to broadband Internet because it allows them to work from home. However, broadband availability does not necessarily induce growth in total (nationwide) employment since employees who previously commuted to work might also choose to work from home. Thus, enhanced broadband provision might simply shift labor from metropolitan areas into more rural areas, not actually increase total employment. However, to date, these possibilities have not been empirically confirmed. Indeed, based on data from a U.S. household survey, Kolko (2012) finds no evidence of a positive relationship between broadband provision and telecommuting.

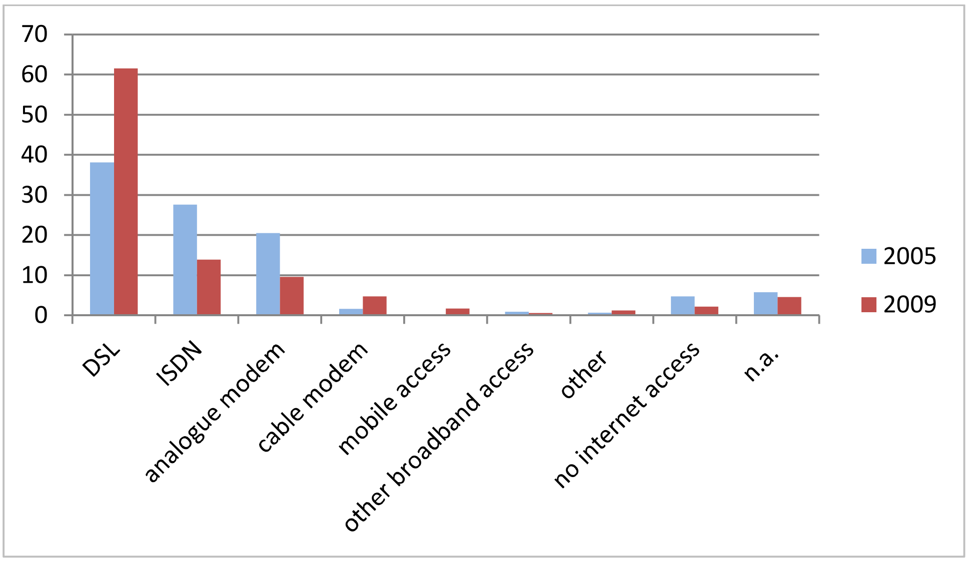
Additionally, it is suggested that broadband might improve job matching between employees and firms in that it reduces asymmetries and lowers the costs of job search (see, e.g., Autor, 2001; Stevenson, 2009). One empirical study by Mang (2012) states that individuals who found their workplaces via the Internet have higher job satisfaction than individuals who found work via other means such as newspapers. Mang suggests that this finding is due to the Internet providing better job matching quality. Still, in the context of rural areas, the overall effect of better job matching on economic activity in municipalities is ambiguous. Since an individual's job search radius is likely to become larger as he or she gains access to broadband Internet, the individual may move to other municipalities, or even find work abroad. Structurally weak municipalities thus might lose workers since it is easier for them to find jobs elsewhere, whereas economically booming municipalities might benefit. This again suggests that rural areas may benefit differently from the provision of broadband than urban areas.

4.2.2 Evidence on the Impact of Broadband in Rural Areas

Although there is a steadily increasing amount of literature on how broadband affects the labor market, very few studies consider heterogeneity in the effects of ICT by types of municipality. In general, broadband effects can be expected to be heterogeneous for urban and rural municipalities. The economic literature offers two seemingly contradictory hypotheses as to how broadband availability and usage will impact rural areas.

First, according to the "death of distance" argument (see, e.g., Cairncross, 1997), small municipalities should benefit over-proportionately from broadband usage. Broadband technology considerably reduces transport costs for the exchange of information, thus reducing the importance of agglomeration advantages for firms and citizens. In addition, broadband Internet offers a new channel of distribution. Firms that formerly only operated in local markets may now serve a wider customer base via the Internet and exploit more distant markets. Indeed, there is some empirical evidence that supports the death of distance argument. Ioannides et al. (2008) find robust evidence that an increase in the number of local telephone lines per capita leads to a more concentrated distribution of U.S. city populations. The authors conclude that this leads to more dispersion in the spatial distribution of economic activity, which takes the form of a shift of economic activity away from large cities and toward less urban areas. In a recent study, Kolko (2012) discovers a positive relationship between broadband expansion and employment growth. The effect is stronger for less densely populated areas, thus confirming the theory of spatial dispersion.

Figure 4-1: The development of Internet access technologies in Germany



Data Source: (N)Onliner Atlas by TNS Infratest (2005 and 2009)

The second strand of literature on how broadband will impact rural communities (see, e.g., Autor et al., 2003; Michaels et al., 2014) concludes that ICT-related technologies actually over-proportionately benefit urban areas. Broadband Internet facilitates the exchange of information and therefore enables a more efficient production of knowledge. ICT usage is therefore complementary to human capital. Given that high-skilled labor is concentrated in large cities, it may well be that broadband technology has only a small, or even no, impact in remote areas. For example, Forman et al. (2012) relate the use of advanced Internet technology to significant employment growth in US counties, but only in the upper 6 percent of counties that already had a large and highly skilled population, high income, and IT usage before the expansion of broadband. This indicates that rural areas may benefit less from broadband infrastructure than urban regions.

4.3 Data

The sample under investigation includes the 8,321 West German municipalities that could be followed over time in the dataset, that is, those that did not amalgamate during the period from 2005 to 2009. East German municipalities were excluded from the analysis due to an extremely high degree of amalgamations during the observation period.

4.3.1 Broadband Measure

Our municipality-level broadband data are from the Broadband Atlas, an annual survey by the Federal Ministry of Economics and Technology that was launched in 2005.[30] The data are comprehensive and provide detailed information at the municipality level. They also form the basis of the German government's broadband strategy and policies. The information is based on reports by the largest Internet providers in a municipality.

Our broadband measure is defined as the share of households per municipality that could access broadband service. We restrict the analysis to DSL[31] technology since it is by far the most common broadband technology in Germany (see Figure 4-1) during the time period considered. According to a survey conducted by TNS Infratest in 2005, 96.3 percent of responding Internet users have either DSL or the non-broadband ISDN or the equally non-broadband analogue modem (TNS, 2005). These three technologies still account for 91.2 percent in 2009 (TNS, 2009). While the share of broadband Internet access increases over time at the cost of the non-broadband technologies ISDN and analogue modem, DSL emerges by far as the dominant access technology. Alternative technologies for broadband Internet access were practically nonexistent in 2005, the largest being cable modem at 1.6 percent. In 2009, cable modems were used to access the Internet by 4.7 percent of Internet users.

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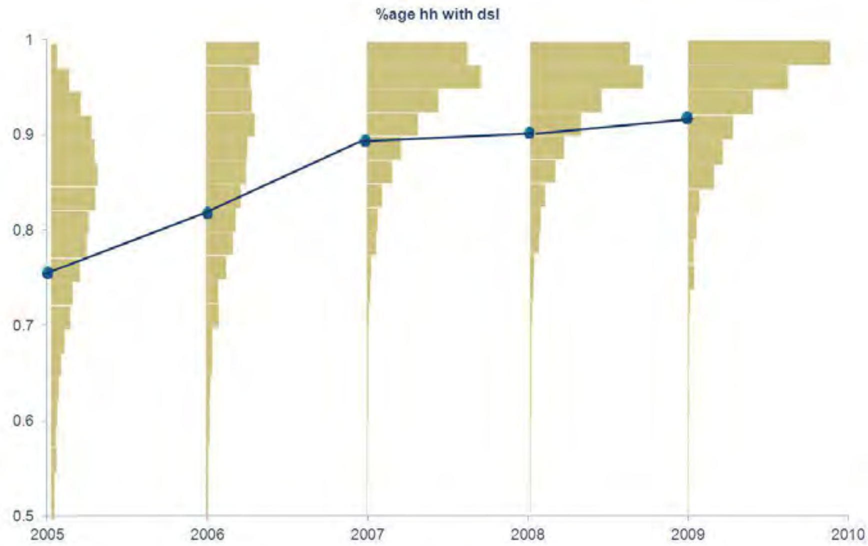
[30] Broadband data are the limiting factor in the time period used in this analysis. They are available for this study for the years 2005 to 2009.

[31] DSL = Digital Subscriber Line.

A household is considered to have broadband access if there was a downstream transfer rate of at least 384 kbit/s at the time the service was activated (i.e., the household had chosen to subscribe to DSL). The data in Table 4–1 show that in 2005, broadband was already widely available in German municipalities. Still, there is considerable variation in the broadband variable in the cross-section as well as over time. In each period, its values range from 0 to 100% coverage of households. Figure 4-2 illustrates the mean distribution of broadband availability in the municipalities during the observed time period. In 2005, the mean availability per jurisdiction was at 76 percent; in 2009 it was 92 percent.

Figure 4-2: The distribution of municipal broadband availability, by year



Source: Own calculations based on Breitbandatlas Deutschland (2005-2009)

We cannot observe actual broadband use in our data. Even though it is the take-up and use of technology, rather than the mere availability of it, that generates economic effects, we consider our broadband measure as the more policy relevant variable since it can be actively influenced by politicians. Moreover, residential broadband coverage directly affects the DSL availability for firms. As of 2010, 82 percent of Internet using firms in Germany depend on local DSL networks as Internet access (Destatis, 2010); only large firms can afford their own private access to the Internet. We therefore conclude that our broadband measure not only reflects residential, but also (at least small) firms', access to broadband Internet.

4.3.2 Socioeconomic Data

We combine the information on broadband availability with employment data from Statistik Lokal, the official statistics on German municipalities by the Federal Office of Statistics (2005-2009). Employment is defined as the number of employees in a municipality who are subject to social insurance contributions. This includes all workers, employees, and trainees whose monthly earnings exceed 400 Euros on average. Not included in the variable are the self-employed, family members working on a voluntary basis, civil servants, and the short-

Table 4-1: Descriptive statistics

		2005		2009	
All municipalities	Obs	Mean	Std. Dev.	Mean	Std. Dev.
Employment rate (in %)	8321	28.50	(26.65)	30.49	(28.87)
Share of households with DSL	8321	0.76	(0.21)	0.92	(0.13)
Population size (in 1,000)	8321	7.82	(36.56)	7.79	(37.10)
Area (in km2)	8321	29.09	(34.22)	29.12	(34.23)
Population density (per km2)	8321	211.71	(293.36)	210.10	(294.35)
Tax rate (in%)	8321	338.81	(31.24)	341.80	(31.48)
Industrial area (m2 per capita)	8321	31.43	(48.99)	34.87	(55.25)
Distance to reg.center (in km)	8321	24.20	(12.63)	24.20	(12.63)
Municipalities without DSL in 2005	Obs	Mean	Std. Dev.	Mean	Std. Dev.
Employment rate (in %)	357	16.57	(26.40)	18.02	(30.18)
Share of households with DSL	357	0	(0)	0.55	(0.44)
Population size (in 1,000)	357	0.65	(0.64)	0.63	(0.63)
Area (in km2)	357	11.93	(12.84)	11.94	(12.84)
Population density (per km2)	357	71.34	(77.51)	69.67	(78.75)
Tax rate (in%)	357	337.13	(27.76)	339.56	(26.51)
Industrial area (m2 per capita)	357	28.14	(67.92)	30.21	(73.06)
Distance to reg. center (in km)	357	33.07	(12.86)	33.07	(12.86)

Notes: The first panel presents descriptive statistics for all municipalities contained in the full sample. The second panel shows descriptive statistics for municipalities with zero broadband coverage in 2005.

term employed. Employees are counted based on where they work, not where they live, and thus the variable reflects the economic activity of local firms.

To remove scale dependency, the variable is reported in relation to the potential workforce, defined as the working-age population in a municipality, that is, those between 20 and 65 years. The dependent variable is therefore measured in percentages. It will be zero if no employees are registered to work in the respective municipality. In our sample, this is the case for 113 municipalities on average. The variable can take values greater than 100 percent if more people work in a municipality than are registered to live there (aged 20 to 65), that is, a large share of the working population commutes to the municipality. This is the case for an average of 169 municipalities during the time period observed. As shown in Table 4–1, the simple average of our measure of local employment share varies between 28.5 percent in 2005 and 30.49 percent in 2009.[32] The aggregated population average in Germany is around 32 percent. These smaller local values are due to the concentration of economic activity in some (urban) areas, such that many municipalities have net out-commuters, whereas relatively few have net in-commuters. The Federal Statistical Offices in Germany report employment counts in municipalities as missing if the value is 1 or 2 such that no conclusions on individuals' identities can be drawn. During the five years of our analysis, this is the case for 2,120 observations (424 municipalities on average). We impute these missing values with the expected value of 1.5.

Other variables that reflect local heterogeneity, such as population size, municipality area[33], business tax rates, and the industrial area are also provided by the Federal Office of Statistics. Based on tax competition theory, we include local business tax rates and the size of the industrial area since local governments may use these measures to actively attract business and promote economic activity. For ease of exposition, industrial area is expressed in terms of population size. The local business tax rate, a multiplier of the tax base, is scaled in percent (Table 4–1; cf. also Chapter 3.3.3 for a more detailed explanation).

In addition, Table 4–1 reports the municipality's distance to the next regional metropolis, which serves as an indicator for how remote or rural a municipality is. The term "regional metropolis" describes a city with a high degree of centrality that is of special importance for its surrounding region in terms of facilities and infrastructure. The classification is made by the regional planning offices of the Federal States; common criteria are the existence of specialized hospitals, academic institutions, or museums. The variable is calculated as the

[32] The values are smaller than conventional employment rates, which include the self-employed, family members working on a voluntary basis, civil servants, and the short-term employed, as well as so-called "mini-jobs".

[33] The average municipality area slightly increases over time (cf. Table 4-1). This is because over time, some municipalities "swallow" another municipality or district – without changing their id number.

linear distance between a municipality center, which is defined as the geographic location with the highest population density within each jurisdiction, and the center of its closest regional metropolis. The variable takes the value zero if the municipality is a regional metropolis itself. The distribution of distance to the next regional metropolis is shown in Figure 4-3 in the Appendix.

4.4 Estimation Approach

We make use of the dataset's panel structure and employ a model with time and municipality fixed effects. The equation we estimate is

$$e_{i,t} = \alpha + \beta dsl_{i,t} + X_{i,t}\gamma' + u_i + c_t + \varepsilon_{i,t} \qquad (4.1.)$$

where $e_{i,t}$ denotes the percentage of the working-age population registered to work in a municipality *i* in time period *t*. $dsl_{i,t}$ denotes the share of households with broadband access as defined in Section 4.3.1.0. $X_{i,t}$ is a vector of controls at the municipality level, u_i and c_t are municipality- and time fixed effects, respectively. $\varepsilon_{i,t}$ is an error term.

We are interested in the causal effect of broadband infrastructure on local employment. The municipality fixed effects account for time-invariant unobserved heterogeneity. One example of this would be the geographic conditions in which a municipality is located and that may influence the roll out of infrastructure as well as economic conditions, such as slope of terrain (cf. Kolko, 2012). However, the estimates may still be biased by the presence of unobserved time-varying variables if such are related to the change in broadband coverage as well as the outcome. In what follows, we discuss how endogenous local broadband coverage may affect the results.

In general, we expect to overestimate the effect of broadband infrastructure on employment due to reverse causality (see, e.g., Kolko, 2012). The spread of broadband infrastructure is largely market based, that is, its provision is based on profit-maximizing considerations of the providers. Spatial differences in broadband availability arise from expected local demand as well as the costs of supplying it. Regions with low per capita fixed costs and high expected demand have the highest broadband penetration rates. Excavation work is the most expensive part of providing broadband infrastructure and it is a fixed cost. Therefore, the more people who can be served, and the shorter the cable lengths needed (i.e., the higher the population density), the lower the per-capita costs. To account for this market force in our analysis, we include population density as a strong indicator of broadband supply.

Another reason as to why the effect of broadband infrastructure might be overestimated relates to time-varying unobserved heterogeneity in local policies, maybe induced by a change in the local government. A steadily increasing number of municipalities build their own local broadband infrastructure. Such local governments are likely to engage in other public infrastructure projects, as well as work to actively attract business, thereby directly influencing demand for labor in the region. We therefore include in our regression the local business tax rates and the industrial area as proxies for local government involvement. The local business tax rates reflect the extent to which a local government engages in tax competition to attract business to the region (see, e.g., Wilson, 1999). Allotting area to industry is another means that local governments can use to attract business and stimulate the local economy.

This chapter is concerned with the benefits to rural municipalities from broadband Internet. We therefore provide estimates for subsamples of municipalities with increasing degrees of rurality. In accordance with the death of distance theory, we sort municipalities by their distance to the geographically next regional metropolis. The interest in sorting municipalities by their distance to the next regional center is twofold. First, it captures the physical distance between a municipality and the next large city and therefore the extent of agglomeration benefits the municipality may enjoy. Second, it acts as a proxy for local human capital, since regional centers are defined as such by the presence of universities and technical colleges. The subsamples are constructed based on quartiles of the distance distribution.

Another way a municipality's rurality can be reflected is by its population density. To support our estimates based on subsamples sorted by distance to the next regional metropolis, we additionally provide estimates in which municipalities are sorted according to population density.

We expect broadband Internet to generate most benefits in terms of employment for the service sector. Several studies confirmed the importance of ICT in general to the service sector (Hempell et al., 2004; Gago and Rubalcaba, 2007; Polder et al., 2009). Broadband facilitates the globalization of many services, which allows producers and consumers of services to be in different geographical locations. In addition, the service industries are frequent users of applications such as cash machines, online banking, e-commerce or web-based after-sales customer services (Hempell, 2005), all of which require Internet access. To gain further insight into how the benefits of broadband are absorbed in the economy, we would like to be able to distinguish between effects by industrial sector. Unfortunately, the employment data are not available by industrial sectors. However, since the official statistics do report employment in the manufacturing sector in addition to total employment, we can provide estimates for employment in the manufacturing sector.

4.5 Estimation Results

This section presents empirical results on the association between broadband infrastructure and local employment. We show results for the full sample of West German municipalities as a benchmark and then present results for municipalities with increasing degrees of rurality based on distance to the next metropolis and population density. Robustness tests of the estimates are also provided.

4.5.1 Baseline Results

Baseline results for the effect of broadband on the employment rate in the full sample are shown in Table 4–2, Columns (1) and (2) report pooled OLS estimates as a benchmark for the fixed effects (FE) estimations in Columns (3) to (6). In the bivariate regression in Column (1), a 10 percentage point increase in local broadband availability is associated with a 1.4 percentage point increase in our measure of local employment rate. Introducing time fixed effects does not change the coefficient. The coefficient in Column (3) is considerably reduced if we control for municipality fixed effects. This confirms that local broadband penetration is positively correlated with time-invariant municipality characteristics, which would lead to a considerable overestimation of the effect of dsl if not controlled for. The coefficient in Columns (3) to (6) is positive and significant at least at the 10 percent significance level. A 10 percentage point increase in households' broadband availability is associated with a 0.041 percentage point increase in the employment rate according to Column (3). This result is robust to the inclusion of population density, the local business tax rate, and the industrial area per capita; none of these change the coefficient of dsl significantly. All these control variables are highly significant and have the expected signs: Population density is negatively correlated with our measure of the employment rate, since in most municipalities people on average are net out-commuters. With the FE estimations we use within variation of municipalities and find that if, over time, one more person moves to the municipality but does not work there (as is the case for most municipalities), he or she will lower the dependent variable. The tax rate is negatively correlated with local economic activity, which is in accordance with standard tax competition theory. The size of the industrial area has a positive association with employment since more businesses can settle in the municipality if the industrial area increases.

4.5.2 Heterogeneous Effects

Table 4–3 shows the effect of broadband on subsamples of municipalities sorted by population density. We find a negative, albeit not statistically significant relationship between the employment rate and broadband availability for municipalities in the first quartile of the distribution of population density (Column (1)). However, for municipalities in the second to fourth quartiles, that is, those with a population density of 225.37 and more, the relationship becomes positive and statistically significant (Columns (2) and (3)). For municipalities of the second and third quartiles (Column (2)), a 10 percentage point increase in dsl increases the local employment rate by 0.05 percentage points, an effect that is statistically significant at 10 percent. The fourth quartile (Column (3)) seems to exhibit the strongest reaction to the provision of dsl.

Table 4-2: The Effect of Broadband Availability on Local Employment

	OLS		Fixed Effects Model			
	(1)	(2)	(3)	(4)	(5)	(6)
Dsl	14.447***	14.657***	0.405*	0.404*	0.428**	0.425**
	(0.761)	(0.806)	(0.207)	(0.207)	(0.207)	(0.206)
Density				-0.024***	-0.024***	-0.024***
				(0.005)	(0.005)	(0.005)
Tax rate					-0.017***	-0.017***
					(0.003)	(0.003)
Industrial area (p.c.)						177.309***
						(20.452)
Year FE	no	yes	yes	yes	yes	yesy
Municipality FE	no	no	yes	yes	yes	yesy
Constant	18.597***	18.732***	28.493***	33.617***	39.353***	38.639***
	(0.672)	(0.689)	(0.164)	(0.975)	(1.528)	(1.529)
Observations	41,605	41,605	41,605	41,605	41,605	41,605
# municipalities	8,321	8,321	8,321	8,321	8,321	8,321
R-squared (within)	0.061	0.061	0.073	0.074	0.075	0.077

Notes: Estimations are based on the full sample of the 8,321 West German municipalities that we observe from 2005 to 2009 and that do not amalgamate. The dependent variable is the local employment rate. Columns (1) and (2) show OLS results. Columns (3) to (6) show contain municipality fixed effects. All specifications contain 2,120 imputed observations for missing values of local employment as well as a dummy variable for imputation and an interaction effect of imputed and dsl. * $p < 0.10$; ** $p < 0.05$; *** $p < 0.01$.

At 0.08 percentage points, the effect is larger than that for the other subsamples and twice the magnitude of the effect in the full sample.[34]

The pattern is less striking but nevertheless existent when regarding our second measure of rurality, namely, distance to the next regional center, as can be seen in Columns (4) to (6) of Table 4–3. While we find a weakly positive relationship of broadband in the first to third quartiles of the density distribution, and a weakly negative association for observations in the middle, municipalities above the fourth quartile again exhibit a strong response to dsl. They show an increase in the employment rate of about 0.17 percentage points in response to a 10 percentage point increase in broadband availability.

These results seem to support the death of distance theory, since they indicate that remote municipalities over-proportionately benefit from broadband Internet whereas municipalities with high degrees of human capital – approximated by the presence of academic institutions – do not or at least they seem to respond less to a change in broadband internet.

In order to exclude that the results are driven by few influential observations, we calculate Cook's Distance and again estimate the effect of dsl for the subsamples as presented in Table 4–3 but without influential observations.[35] Results for a conventional cutoff value of Cook's Distance smaller 1 are presented in Table 4–5 in the Appendix. With this criterion, few observations are identified as influential in the population density subsamples and subsequently dropped from the regression. The results are very similar to those in Table 4–3. In the subsamples by distance to the closest regional metropolis, no observation is dropped. Table 4–6 reports results without influential observations with a relatively strict cutoff value for Cook's Distance. In these specifications, observations with a value greater (4/number of observations) are dropped. Taken together, about 3 percent of observations are dropped in Columns (1) to (3). While the dsl coefficients remain within the same order of magnitude for the first three quartiles (Columns (1) and (2)), the effect significantly drops for the fourth quartile (Column (3)). However, in the second panel of Table 4–6, while the coefficients in Columns (4) and (5) are no longer statistically significant, the dsl coefficient in Column (6) remains significant at the 5 percent level.

One can think of reasons for why we might actually underestimate the effect of broadband availability in urban areas. For example, it is possible that there is simply not enough variation in dsl in the concerned areas to identify the effect. In 2005, our first year of observation, broadband had already reached considerably high levels such that there was not

[34] This pattern holds when we divide the full sample by subsamples of population size (not shown). Results are available on request.

[35] As cut-off value we choose the common criterion of 4/n, where n is the number of observations.

much room for further spread in urban areas. In addition, the effect of dsl might be nonlinear, meaning that an increase in broadband might have a larger effect between 0 and 10 percentage points than between 90 and 100 percentage points. Moreover, we cannot observe actual broadband use in our data, even though it is the take-up and use of technologies rather than their mere availability that generates the economic effects. The results presented here, therefore, might represent a lower boundary on the effect of broadband on local employment. Nevertheless, we consider this variable most relevant for policy advice since residential broadband availability is a variable of direct political concern and can be actively influenced by the government.

Arguably, the effect of broadband observed in rural areas might be confounded with the temporary employment impact of actually building the infrastructure, for example, the necessary excavation work. If this were the case, it would lead to an overestimation of our dsl coefficient. We rule out this possibility since firms that provide the DSL infrastructure are specialized firms that typically bring their own workers with them to do the excavation work and thus are unlikely to generate employment in the concerned municipality. Towards the end of the observation period – in 2008 – the federal government launched an initiative to provide matching grants to municipalities that were as yet without broadband access. Since this program coincided with an economy-wide economic stimulus package, it could be argued that the effect of broadband might actually be underestimated, since the eligible municipalities are predominantly in rural, less densely populated areas with presumably lower demands for broadband services. This can be seen in the second panel of Table 4–1, where descriptive statistics for municipalities without broadband in 2005, the so-called white spots, are provided. However, for the time period considered in this study, the effects of broadband should not be confounded with these infrastructure programs. Even though the program was announced in 2008, the take-up of funding and the actual public provision of broadband infrastructure did not actually occur for quite some time. In 2012, the German Federal Ministry of Economics and Technology stated that municipalities had been reluctant to take advantage of federal funding for providing broadband due to high administrative barriers. We thus conclude that the government program should not affect our data.

To more specifically determine where the positive effects occur, it would be preferable to distinguish employment effects in specific industrial sectors; however, the official statistics only report the number of employees in the manufacturing sector. We therefore choose the local employment rate in the manufacturing sector as an alternative dependent variable. Table 4–4 provides findings for subsamples in the manufacturing sector. In none of the specifications – apart from Column (3) – does dsl have an effect on the manufacturing sector in rural areas. This matches our expectations, since the effects we find in the total employment rate are thus most likely to stem from the service sector.

Table 4-3: The Effect of Broadband Availability on Local Employment, by Subsamples (based on Quartiles)

	Population Density (per km^2)			Distance to reg. Metropolis (in km)		
	[> 225.37]	[225.37; 64.11]	[<64.11]	[< 14.68]	[14.68; 31.80]	[> 31.80]
	Q1	Q2-Q3	Q4	Q1	Q2/Q3	Q4
	(1)	(2)	(3)	(4)	(5)	(6)
Dsl	-0.175	0.531*	0.806**	0.699*	-0.475*	1.705***
	(0.436)	(0.318)	(0.382)	(0.377)	(0.265)	(0.475)
Density	-0.018***	-0.054***	-0.323***	-0.022***	-0.023***	-0.036***
	(0.004)	(0.014)	(0.056)	(0.005)	(0.007)	(0.014)
Tax rate	-0.034***	-0.022***	0.001	-0.040***	-0.007	-0.011
	(0.005)	(0.006)	(0.007)	(0.005)	(0.005)	(0.008)
Industr. area (p.c.)	533.292***	254.079***	128.617***	219.568***	298.590***	101.911***
	(73.579)	(37.968)	(31.133)	(53.556)	(30.790)	(37.086)
Municipality FE	yes	yes	yes	yes	yes	yes
Year FE	yes	yes	yes	yes	yes	yes
Constant	63.024***	40.397***	30.524***	52.219***	34.403***	32.767***
	(2.794)	(2.614)	(3.305)	(2.518)	(2.055)	(3.248)
Observations	10,401	20,803	10,401	10,405	20,800	10,400
# municipalities	2,119	4,273	2,154	2,081	4,160	2,080
R-squared (within)	0.161	0.083	0.057	0.138	0.095	0.048

Notes: The dependent variable is the local employment rate (%). Subsamples in columns (1) to (3) are based on population density and in columns (4) to (6) on the distance to the next regional metropolis. Subsamples by population density are based on the density distribution in 2005. Columns (1) and (4) show results for the first quartiles (Q1). Columns (2) and (5) show results for the second and third quartiles (Q2-Q3). Columns (3) and (6) show results for the fourth quartiles (Q4). All specifications contain 2,120 imputed observations for missing values of local employment as well as a dummy variable for imputation and an interaction effect of imputed and Dsl. * $p < 0.10$; ** $p < 0.05$; *** $p < 0.01$.

4.6 Discussion and Summary

In contrast to the extant literature on broadband infrastructure, we find no overall economically meaningful effects of broadband availability on local economic activity for the full sample of municipalities. A 10 percentage point increase in broadband availability is associated with a 0.04 percentage point increase in the employment rate. Compared to an average employment rate of about 30 percentage points (see Table 4–1), this puts the economic benefits into perspective.

However, when distinguishing by the degree of a municipality’s rurality, we find evidence that remote and less densely populated areas benefit most from broadband infrastructure. The effect is considerably larger compared to that found in more urban areas. A 10 percentage point increase in broadband availability in rural areas is associated with a 0.08 to 0.17 percentage point increase in the local employment rate. This may well be especially the case for rural areas, as broadband facilitates the opening up of larger markets for local firms. The impact of a larger potential customer base may be more important for rural areas. Moreover, we find no employment effects in the manufacturing sector, indicating that the positive effects of broadband should mostly manifest in the service sector.

Many of the studies that find a larger impact of broadband on economic activity use data from the early expansion phase of DSL. It may well be that the effect of broadband infrastructure was higher during that phase and that by 2005 broadband was already a widely available commodity in most municipalities. If the intensive margin becomes very small close to the saturation point, the relationship between broadband infrastructure and economic benefits would be non-linear. Another reason for our results being different from those of previous studies could involve the panel structure of the data, which allows including municipality fixed effects. As discussed above, these estimations considerably lower the effect of broadband infrastructure.

Table 4-4: Subsamples by Quartiles in the Manufacturing Sector

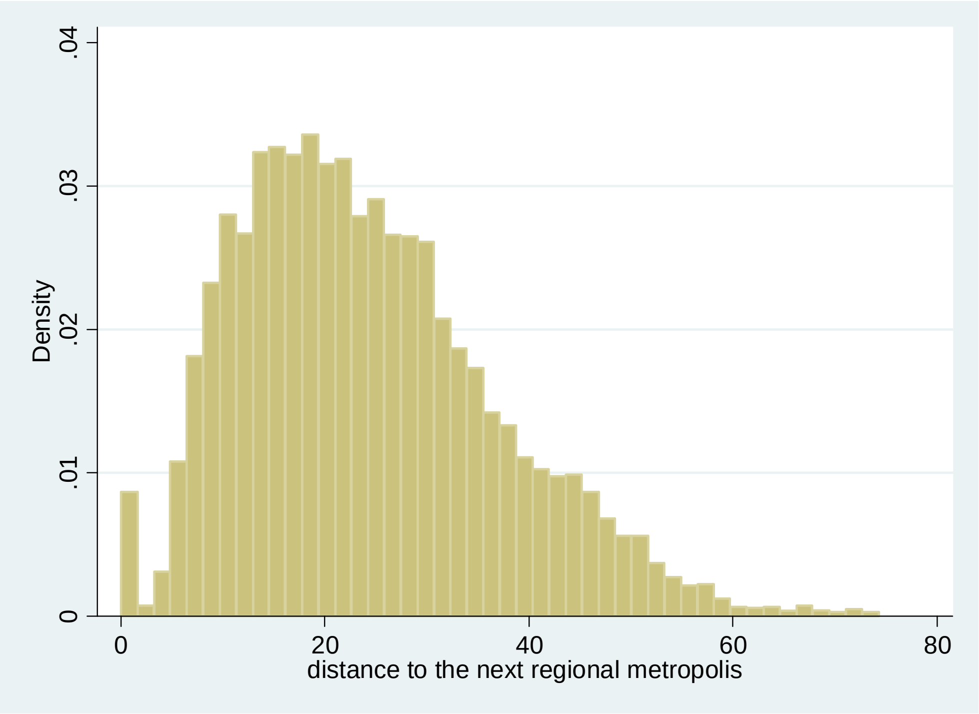
	Population Density (per km^2)			Distance to reg. Metropolis (in km)		
	[> 225.37]	[225.37; 4.11]	[<64.11]	[< 14.68]	[14.68; 1.80]	[> 31.80]
	Q1	Q2-Q3	Q4	Q1	Q2/Q3	Q4
	(1)	(2)	(3)	(4)	(5)	(6)
Dsl	0.396	0.313**	0.029	0.059	0.183	0.095
	(0.253)	(0.132)	(0.051)	(0.206)	(0.113)	(0.091)
Density	-0.009***	0.012**	0.001	-0.010***	0.000	-0.009***
	(0.002)	(0.006)	(0.007)	(0.002)	(0.003)	(0.002)
Tax rate	-0.007**	-0.005**	-0.001	-0.003	-0.005**	-0.003**
	(0.003)	(0.002)	(0.001)	(0.003)	(0.002)	(0.002)
Industrial area (p.c.)	158.179***	115.188***	8.187**	241.758***	54.547***	13.198**
	(43.369)	(17.267)	(3.951)	(33.156)	(14.011)	(6.697)
Municipality FE	yes	yes	yes	yes	yes	yes
Year FE	Yes	yes	yes	yes	yes	yes
Constant	19.354***	6.082***	1.096***	12.519***	8.047***	6.166***
	(1.655)	(1.088)	(0.414)	(1.392)	(0.904)	(0.602)
Observations	7,510	14,234	8,266	7,276	14,844	7,890
# municipalities	1,690	3,199	1,783	1,622	3,225	1,674
R-squared (within)	0.083	0.048	0.008	0.065	0.040	0.030

Notes: The dependent variable is the local employment rate in the manufacturing sector (%). Subsamples in columns (1) to (3) are based on population density and in columns (4) to (6) on the distance to the next regional metropolis. Subsamples by population density are based on the density distribution in 2005. Columns (1) and (4) show results for the first quartiles (Q1). Columns (2) and (5) show results for the second and third quartiles (Q2-Q3). Columns (3) and (6) show results for the fourth quartiles (Q4). All specifications contain 2,120 imputed observations for missing values of local employment as well as a dummy variable for imputation and an interaction effect of imputed and dsl. * $p < 0.10$; ** $p < 0.05$; *** $p < 0.01$.

This study provides some insight into the benefits of broadband infrastructure in rural areas, but several important questions remain: Since large businesses are able to buy or rent customized infrastructure, our broadband measure likely does not capture ICT use in large companies. In addition, broadband infrastructure may affect economic activity and the labor market in dimensions other than employment rate, for example, it could have an impact on home-based work and telecommuting. Also the presented results are short- to mid-term effects. Local infrastructure might also have longer-term effects. Unfortunately, we cannot provide answers to these important questions with the available data and must leave them for future research.

4.7 Appendix

Figure 4-3: The distribution of distance to the next regional metropolis



Notes: Own calculations based on distances between municipality centers as of 2008. Municipality centers are points with the highest population density within a municipality.

Table 4-5: The Effect of Broadband Availability on Local Employment, by Subsamples (based on Quartiles) without Influential Observations (1)

	Population density			Distance to regional metropolis		
	Q1	Q2 and Q3	Q4	Q1	Q2 and Q3	Q4
	(1)	(2)	(3)	(4)	(5)	(6)
Dsl	-0.175	0.536*	0.788**	0.699*	-0.475*	1.705***
	(0.436)	(0.318)	(0.382)	(0.377)	(0.265)	(0.475)
Density	-0.018***	-0.055***	-0.315***	-0.022***	-0.023***	-0.036***
	(0.004)	(0.014)	(0.056)	(0.005)	(0.007)	(0.014)
Tax rate	-0.034***	-0.022***	0.001	-0.040***	-0.007	-0.011
	(0.005)	(0.006)	(0.007)	(0.005)	(0.005)	(0.008)
Industrial area (p.c.)	533.292***	257.850***	213.702***	219.568***	298.590***	101.911***
	(73.579)	(38.312)	(39.960)	(53.556)	(30.790)	(37.086)
Year fixed effects	yes	yes	yes	yes	yes	yes
Municipality fixed effects	yes	yes	yes	yes	yes	yes
Constant	63.024***	40.396***	29.932***	52.219***	34.403***	32.767***
	(2.794)	(2.615)	(3.308)	(2.518)	(2.055)	(3.248)
Observations	10,401	20,800	10,399	10,405	20,800	10,400
# municipalities	2,119	4,273	2,154	2,081	4,160	2,080
R-squared (within)	0.161	0.083	0.058	0.138	0.095	0.048

Notes: The dependent variable is the local employment rate (%). Subsamples without influential observations, defined as cook's distance < 1. Cook's distance is calculated for each subsample separately. Subsamples in columns (1) to (3) are based on population density and in columns (4) to (6) on the distance to the next regional metropolis. Subsamples by population density are based on the density distribution in 2005. Columns (1) and (4) show results for the first quartiles (Q1). Columns (2) and (5) show results for the second and third quartiles (Q2-Q3). Columns (3) and (6) show results for the fourth quartiles (Q4). All specifications contain 2,120 imputed observations for missing values of local employment as well as a dummy variable for imputation and an interaction effect of imputed and Dsl. * $p < 0.10$; ** $p < 0.05$; *** $p < 0.01$.

Table 4-6: The Effect of Broadband Availability on Local Employment, by Subsamples (based on Quartiles) without Influential Observations (2)

	Population density			Distance to regional metropolis		
	Q1	Q2 and Q3	Q4	Q1	Q2 and Q3	Q4
	(1)	(2)	(3)	(4)	(5)	(6)
Dsl	-0.044	0.365	0.080	0.451	-0.225	0.750**
	(0.434)	(0.229)	(0.228)	(0.307)	(0.213)	(0.294)
Density	-0.011***	-0.022**	-0.128***	-0.013***	-0.004	-0.023**
	(0.003)	(0.010)	(0.034)	(0.005)	(0.006)	(0.009)
Tax rate	-0.022***	-0.005	0.000	-0.004	-0.006*	-0.007
	(0.005)	(0.004)	(0.004)	(0.004)	(0.004)	(0.005)
Industrial area (p.c.)	646.409***	540.176***	176.311***	508.202***	511.426***	318.520***
	(74.570)	(37.578)	(35.368)	(57.366)	(36.884)	(41.506)
Year fixed effects	yes	yes	yes	yes	yes	yes
Municipality fixed effects	yes	yes	yes	yes	yes	yes
Constant	51.872***	27.925***	20.288***	33.575***	27.832***	27.284***
	(2.508)	(1.905)	(2.004)	(2.252)	(1.656)	(2.006)
Observations	9,944	20,323	10,085	9,985	19,998	10,097
# municipalities	0.171	0.122	0.090	0.160	0.119	0.073
R-squared (within)	2,049	4,201	2,109	2,015	4,036	2,036

Notes: The dependent variable is the local employment rate (%). Subsamples without influential observations, defined as cook's distance < (4/no. of observations). Cook's distance is calculated for each subsample separately. Subsamples in columns (1) to (3) are based on population density and in columns (4) to (6) on the distance to the next regional metropolis. Subsamples by population density are based on the density distribution in 2005. Columns (1) and (4) show results for the first quartiles (Q1). Columns (2) and (5) show results for the second and third quartiles (Q2-Q3). Columns (3) and (6) show results for the fourth quartiles (Q4). All specifications contain 2,120 imputed observations for missing values of local employment as well as a dummy variable for imputation and an interaction effect of imputed and Dsl. * $p < 0.10$; ** $p < 0.05$; *** $p < 0.01$.

5 The Effect of Local Deregulation on Investment in Broadband Infrastructure[36]

5.1 Introduction

Traditionally, it was considered necessary to regulate the telecommunication sector so as to foster competition by opening former incumbents' network infrastructure (ITU, 2000). Years, and in some countries decades, after market liberalization, telecommunication markets have done well and incumbents in many countries face increasing infrastructure-based competition. In this context, regulatory authorities and policymakers are now concerned with designing appropriate incentives that will ensure this positive development continues and that will encourage future investment and innovation in network infrastructure.

Within countries, infrastructure-based competition has developed unequally, with some regions enjoying more competitive markets than others. Many observers therefore argue that national regulators should focus their attention on areas in which competitive markets cannot be sustained (EC, 2008a; Weizsäcker, 2008). As a result, in recent years, a number of European countries have debated – and in some cases introduced – geographically differentiated regulation schemes in the wholesale broadband access (WBA) market.[37] These schemes allow for deregulation in areas with sufficient infrastructure-based competition. It remains unresolved, both from a theoretical as well as from an empirical perspective, how deregulation of areas with well-developed infrastructure-based competition affects future competitive development (see Stumpf, 2010). Policymakers have thus been reluctant to institute deregulation (see, e.g., Bundesnetzagentur, 2010; EC, 2008c). The UK was the first country to actually implement a local deregulation at the local level, which we use for a detailed analysis of this new type of regulation.

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[36] This chapter was coauthored by Oliver Falck (LMU München and Cesifo). It is available as CESifo Working Paper No. 4277, "Investment in Broadband Infrastructure under Local Deregulation: Evidence from the U.K. Broadband Market".

[37] For an overview, see Table 5-6 in the Appendix.

To date, there are no clear predictions on future price developments and the ultimate effects on the competitive environment are unknown. The incumbent faces a tradeoff in deregulated areas: On the one hand, it has an incentive to raise wholesale prices or to deny access to competitors in order to maximize profits. On the other hand, it does not want to create too strong incentives for the competitors to invest in their own networks. For the incumbent, the deregulation of competitive areas generates incentives to invest in new networks that allow for faster broadband. Investing in new networks is more profitable in a deregulated environment, since the incumbent may expect to reap the profits from its investment. Competitors without own infrastructure will in any case face a higher insecurity in deregulated WBA markets since prices charged by the incumbent are subject to negotiation and competitors are no longer guaranteed network access. This should create an incentive for them to invest in own network infrastructure.

So far, to the best of our knowledge, there exists no empirical work that investigates the effects of geographically differentiated regulation schemes. In a theoretical study, Bourreau et al. (2012) conclude that depending on the wholesale market equilibrium, the local deregulation of competitive areas may lead to higher investments in fiber networks and be socially optimal. Previous empirical studies typically use variation across countries to investigate the effects of regulation on infrastructure investment. They largely confirm that deregulation encourages infrastructure investments in the telecommunication sector. Waverman et al. (2008) for example investigate the effects of access regulation in an unbalanced panel of 27 European countries for the time period 2002 to 2006. They find that a lower regulated access price for the copper network causes a notable substitution away from alternative broadband infrastructures, indicating that stricter regulation discourages intra-platform competition since competitors prefer to use the old networks. Friederiszick et al. (2008) provide further cross-country evidence that stricter regulation of the incumbent in fixed lines discourages infrastructure investments of market entrants. These find it worthwhile to use the relatively cheaper copper network instead of investing in own infrastructure. Wallsten (2006) separately investigates the effect of mandated wholesale broadband access (bitstream) in 30 OECD countries in a panel regression from 1999 to 2003. It has no effect on broadband penetration or download speeds.

In this study, we provide a first empirical evaluation of the effects of local deregulation in the WBA market on infrastructure investment by the incumbent telecommunication carrier and its competitors. To this end, we make use of a change in the regulatory scheme in the United Kingdom WBA market. In 2008, the U.K. regulator, Ofcom, divided the WBA market into three types of competition areas. In areas with sufficient infrastructure-based competition, the incumbent (British Telecom) was released from regulation in that specific market. Ofcom applied a set of rules that determine the deregulation of local exchange areas, inter alia, based on the number of principal operators (POs), which are large operators with extensive coverage in the British WBA market, and the size of the local retail market.

Our data are from the Internet platform Samknows (Samknows, 2007, 2012). Samknows is a not-for-profit website that provides information on broadband availability in the United Kingdom. It furthermore reports detailed information at the exchange level on key characteristics such as exchange location, regulatory status, the names of local loop unbundling (LLU) operators present in an exchange, actual and prospective fiber-to-the-curb (FTTC) status, the number of premises served by an exchange, and broadband availability via cable. We merge these exchange-level data with ward-level sociodemographic characteristics.

We measure broadband providers' investment incentives in response to local deregulation on two dimensions. First, we investigate the number of LLU operators in an exchange to capture the extent of infrastructure-based competition the incumbent faces in local markets. LLU operators made large investments in installing and maintaining their own infrastructure. Second, we analyze the incumbent's infrastructure investments by its roll out of FTTC technology, which enables higher transfer rates and allows the incumbent to differentiate itself from the competitors. We concentrate on these measures, since increasing infrastructure-based competition is the preferred goal of regulatory authorities. It is favored over service-based competition since it is sustainable and increases consumer choice while lowering consumer prices in the long run (Bourreau and Dogan, 2004; Woroch, 2002).

Identifying the effect of local deregulation on infrastructure investments is not trivial. A simple comparison of regulated and deregulated exchanges is likely to obtain biased results. Exchanges with already high levels of competition will be deregulated. We therefore quantity the effects of deregulation with a first-difference approach in which we compare the development of regulated and deregulated areas between 2007 and 2012. In this way, we account for exchange specific, time invariant characteristics that are correlated with deregulation and infrastructure investment. Since deregulation decisions are based on the competitive situation in an exchange area, regulated and deregulated areas must differ in their initial (i.e., prior to the reform) competitive situation and other local characteristics. We therefore additionally control for the initial competitive situation and other local characteristics. In a next step, we propose propensity score matching on local characteristics, which allows us to impose a common support in the sample. With common support, only exchange areas with similar propensity scores, i.e., with similar probabilities of deregulation, are compared with each other.

One concern is that our basic specification might capture a "self-fulfilling prophecy," which arises due to the fact that Ofcom's deregulation decision depends not only on actual, observed investment, but also on its forecast for local investments by POs. Therefore, our basic specification might not only capture investment due to deregulation, but also investment that would have occurred in any case (and, in fact, led to the deregulation). We cannot observe Ofcom's forecasts, but a change in the deregulation rules between the first review in 2008 and the second review in 2010 allows us to identify exchange areas that are very similar to each other, but that differ in their forecasts.

We find positive, economically important effects of deregulation on infrastructure-based competition. The number of LLU operators increases more in deregulated exchange areas than in regulated areas between 2007 and 2012. We also quantify the part of these investments that cannot stem from Ofcom forecasts and therefore capture the pure deregulation effect. According to the point estimates, upon being deregulated, an exchange area gains 0.22 additional LLU operators. Furthermore, deregulation increased the incumbent's investment in FTTC infrastructure: in deregulated areas, it is 16 percentage points more likely to roll out FFTC.

The remainder of the chapter is organized as follows. Section 5.2 describes in more detail the WBA market and the deregulation process in the United Kingdom. Section 5.3 introduces our data. Section 5.4 presents our estimation strategy and Section 5.50 shows basic results and various robustness specifications. Section 5.6 concludes.

5.2 Institutional Setting

5.2.1 Wholesale Broadband Access

WBA refers to a wholesale broadband market in which an entrant with limited own infrastructure buys transmission services from the incumbent with access to the end-users' premises. These entrants' own infrastructure only reaches certain points of presence (PoP) in the backbone network. At the PoP, entrants hand over data transmission to the incumbent. In the beginning, mandated wholesale broadband access was considered necessary to create competition in the broadband market since market entrants could then offer products on the retail market without owning infrastructure that actually connects to end-users. Over the last several years, however, market entrants have increasingly begun to invest in their own infrastructure. Their own networks typically expand down to the exchange where they connect to the copper-based local loops that link every premise to the exchange, a process known as local loop unbundling (LLU). The local loops are owned by the incumbent, who is required to grant access on regulated conditions. The infrastructure-based competitors thus can offer not only services to end-users, but also wholesale broadband access. Figure 5-1 displays the structure of the WBA market. Copper-based local loops are viewed as an essential facility and the regulation of access to them is not under debate. Deregulation of the WBA market, in contrast, is widely discussed throughout Europe, at least for areas with increasing infrastructure-based competition (OECD, 2010b; Kiesewetter, 2011).

5.2.2 The Process of Local Deregulation in the United Kingdom

In the United Kingdom, the WBA market traditionally has been regulated on a national basis, but in 2008, geographically differentiated regulation of the WBA market came into effect. The European Commission supported Ofcom's decision since ex ante regulation should be relaxed when infrastructure-based competition becomes sufficiently developed (EC, 2007).

British Telecom's local exchange areas were chosen as the relevant geographical unit. Broadband service providers make their supply and infrastructure investment decisions at the exchange level, since each exchange covers a certain geographical area and therefore defines the local customer base. Ofcom grouped all exchange areas into three categories based on their competitive situation.[38] Categories 1 and 2 remain regulated, but the incumbent British Telecom was released from regulation in Category 3 areas.

Category 1 is comprised of exchange areas where British Telecom is the only operator. Category 2 contains exchange areas in which some competition has developed. These are exchange areas with two or three principal operators (POs) actually present or forecast to be so. Also in Category 2 are exchange areas with four POs, which includes one forecast PO (i.e., three are actually present), but that serve less than 10,000 premises. Besides British Telecom and Virgin Media (the cable operator), six LLUs with a coverage of more than 45 percent of U.K. premises were considered to be POs.[39] Exchange areas with four or more POs and exchange areas with three POs and at least one more forecast, but that serve more than 10,000 premises, form Category 3. Table 5–7 in the Appendix summarizes the criteria underlying the deregulation decision in 2008.

In its 2010 revision of WBA market regulation, Ofcom considered the 10,000 premises rule redundant and introduced a new criterion for deregulation. In addition to the number of POs, British Telecom's market share had to be lower than 50 percent, the standard threshold at which significant market power can be assumed according to Commission guidelines (Ofcom, 2010). Table 5–8 in the Appendix summarizes the criteria underlying the 2010 market definitions. Figure 5-2 shows the geographical distribution of deregulated exchange areas in the United Kingdom as of 2010, mapping exchange areas that were deregulated in 2008 and 2010.

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[38] In addition, a fourth market was defined in the Hull area, where KCOM, a local provider, was the only operator. This area contains 14 exchange servers and covers 0.7 percent of U.K. premises. Due to data limitations, exchanges owned by KCOM are excluded from this analysis.

[39] These are Sky, O2, Orange, Cable&Wireless, Tiscali, and the TalkTalk group. Virgin Media counts as a PO if its coverage of premises in the respective market is at least 65 percent.

5.3 Exchange-Level Data and Regional Characteristics

Our data are from the Internet platform Samknows, a not-for-profit website that was originally founded to provide broadband speed tests to the general public. The website provides comprehensive information on the local competitive environment, such as the LLU operators present in an exchange, the enabled technologies that determine the broadband speed, and the number of premises served by an exchange. The website is continuously updated and we observe cross-sections or “snapshots” of all 5,598 exchange areas at two points in time, December 2007 and November 2012.

We obtain our main explanatory variable – the WBA deregulation status – from Samknows.[40] Each exchange is assigned to one of the three regulatory markets. In 2008, 1,193 out of 5,598 exchange areas were deregulated. After Ofcom’s 2010 revision, another 348 exchange servers were deregulated, while seven were reregulated. Overall, 28 percent of exchange areas were deregulated in 2012, which corresponds to 78.2 percent of U.K. premises.

Our measure for infrastructure investment by the incumbent’s competitors is the number of LLU operators present in an exchange. Table 5–9 in the Appendix lists the LLU operators along with their national coverage in both years. The list of LLU operators in the U.K. market is not fully congruent over time due to the highly dynamic nature of the broadband market. The six largest firms in terms of infrastructure coverage were considered POs in 2007 and are relevant for the deregulation process. In 2012, there were in effect only four operators. In 2010, PO Orange handed its LLU network back to BT. In the same year, POs Tiscali and TalkTalk merged. Despite this fact, Samknows still reports the two firms separately and so we observe five POs rather than four.[41]

Our measure for the incumbent’s infrastructure investment is a binary indicator that takes the value 1 when FTTC has been enabled by the incumbent British Telecom or will be enabled in the exchange by 2013. As Table 5–1 shows, in 2007 none of the exchange areas had FTTC, since the technology had not yet been introduced to the broadband market. By 2012, 25 percent of exchange areas had this infrastructure or had it installed in the near future. Table 5–1 further reveals that the number of LLU operators present in an exchange area increased considerably from, on average, 1.24 LLU operators in 2007 to 1.80 LLU operators in 2012. The incumbent BT and the cable operator Virgin Media count as POs,

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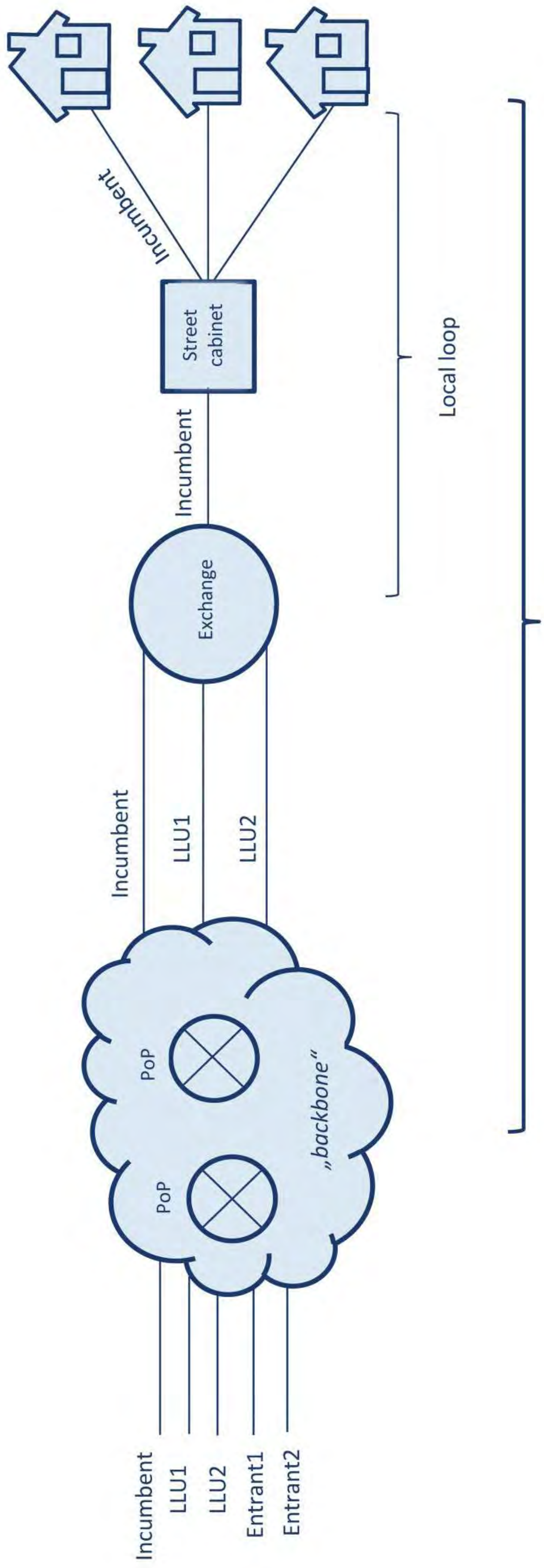
[40] Since we base our estimates on data from Samknows and not from Ofcom directly, small deviations from the figures published in Ofcom (2008, 2010) occur.

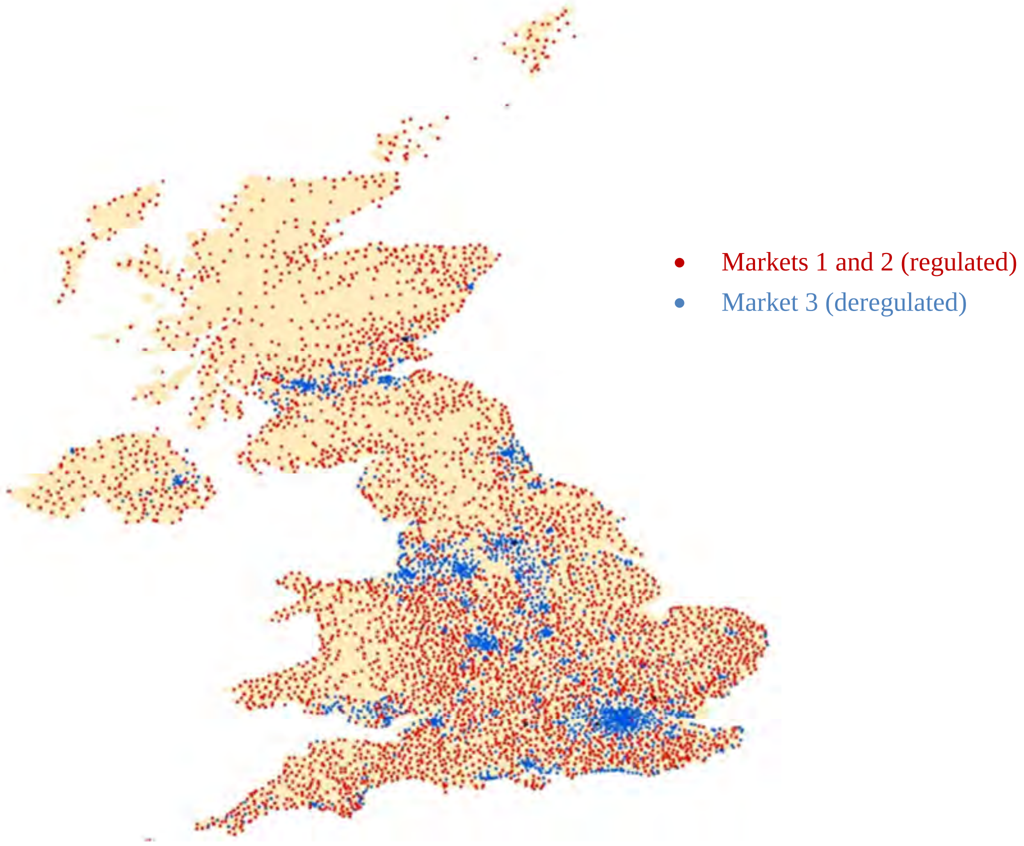
[41] Orange’s exit as an LLU and the merger of Tiscali and TalkTalk do not affect the regulatory decision since these events took place after Ofcom’s revision in 2010.

Figure 5-1: The Structure of the WBA Market



Notes: WBA = wholesale broadband access; LLU = local loop unbundling operator; PoP = point of presence.

Figure 5-2: Geographic Distribution of Deregulated Exchange Areas in the United Kingdom



Data Source: Own representation based on Samknows data

but they are not considered as LLU operators and consequently are not included in these numbers.

Our competition measures are only available at the exchange level, we cannot derive conclusions on the amounts of households a LLU serves in an exchange area, or the amount covered with FTTC.

We derive cable operator presence in the exchange area from Samknows in order to account for composition of the local infrastructure competition. Even though cable operators do not offer WBA services during the period of analysis, they exert indirect competitive pressure via the retail market. Broadband connections realized via cable infrastructure are in direct competition with FTTC lines since they offer similar broadband speeds. Lastly, we obtain from Samknows the size of the local market an exchange serves, reported as the number of premises connected to the exchange. The number of premises comprises all residential as well as commercial premises connected to an exchange.

Samknows reports the exchange areas' geographic locations via their postcodes. With this information we are able to geo-code the exchange areas and assign them to wards. We thus merge the exchange-level data with regional characteristics at the ward level. The information on ward boundaries in Great Britain is from Edina (2012); ward boundaries for

Northern Ireland are made available from the Northern Ireland Statistics and Research Agency (2012a).

Table 5-1: Descriptive statistics of exchange- and ward-level characteristics, by year

	2007		2012	
	mean	std. dev.	mean	std. dev.
Exchange-level characteristics				
# of exchange areas	5,598		5,598	
# LLU operators	1.24	(2.27)	1.80	(2.57)
FTTC enabled	0	(0)	0.25	(0.44)
Deregulated	0	(0)	0.28	(0.45)
# of premises	4,852.03	(6,984.94)	4,852.03	(6,984.94)
Broadband via cable available	0.24	(0.42)	0.24	(0.42)
Ward-level characteristics				
Population share working age	0.60	(0.05)	0.62	(0.05)
Population density (per km²)	956.10	(1,997.30)	984.99	(2,064.33)
Claimant count share (working age)	0.02	(0.01)	0.03	(0.02)

Notes: Standard deviations (std. dev.) in parentheses.

As of 2011, the United Kingdom had 9,523 electoral wards with an average population of 5,500. The working-age population and the claimant count serve as proxies for demand for broadband and local income, respectively. Population density is a measure for supply since it indicates the unit costs of providing broadband. In densely populated areas, a provider can reach a larger customer base with the same amount of infrastructure investment than it can in a sparsely populated area. The working-age population is defined as the population share of the male inhabitants aged 16–64 and the female inhabitants aged 16–59. Population density is calculated as ward inhabitants per km². The population data are obtained from the U.K. national statistical offices: the Office for National Statistics (2012), which covers England and Wales, the Scottish Neighbourhood Statistics (2012), and the Northern Ireland Statistics and Research Agency (2012b). The claimant count is obtained from NOMIS (2012), the Office for National Statistics' database on U.K.-wide labor market statistics. This measure is available at the ward-level and counts the unemployed people claiming Jobseeker's Allowances in a particular month. We construct the annual average, which is expressed as the share of claimant count in the working-age population. Descriptive statistics for these variables are reported in Table 5–1.

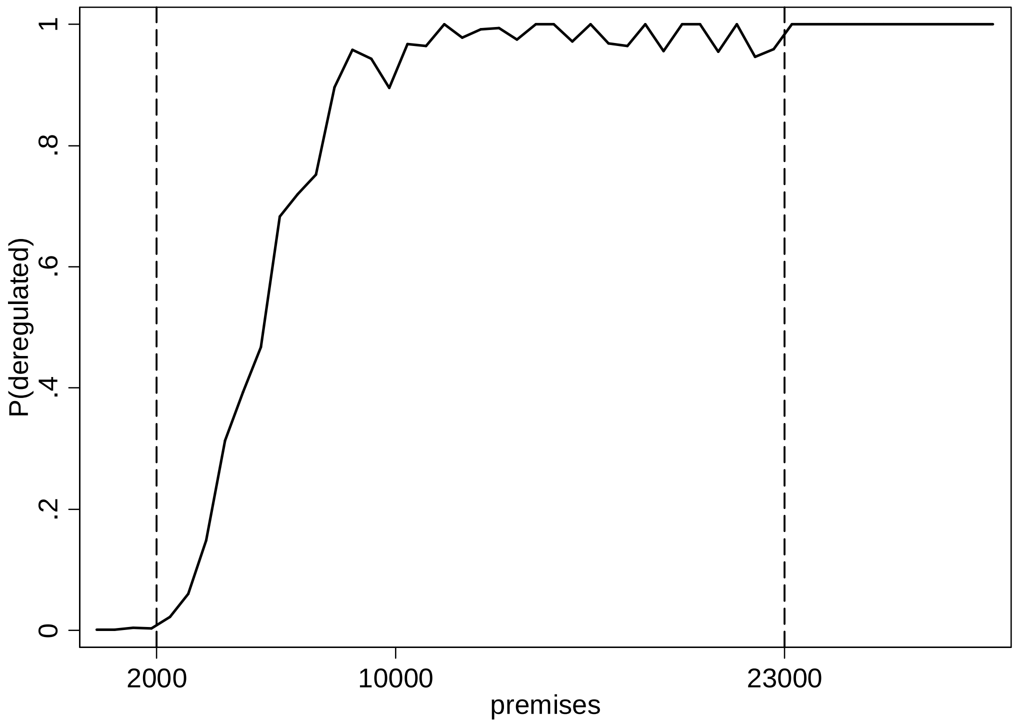
5.4 Estimation Strategy and Sample Restriction

We estimate the effect of local deregulation of the British WBA market on the investment behavior of both the incumbent and its competitors in a first-difference model conditional on initial exchange and ward characteristics:

$$\Delta Y_{i,2007-12} = \alpha + \beta D_{i,2008/10} + \delta LLU_{i,2007} + X_{i,2007}\gamma' + \Delta X_{i,2007-12}\kappa' + \varepsilon_i \quad (5.1)$$

ΔY is the change in the outcome of interest between 2007 (i.e., before deregulation) and 2012 (i.e., after deregulation). Our outcomes of interest are the development of the number of LLU operators in the exchange *i* and the incumbent's FTTC status, both of which serve as indicators of the intensity of infrastructure-based competition in the respective exchange areas.[42] D is a dummy variable that equals unity if the exchange is no longer regulated in 2008 or 2010. We control for initial values in 2007 to account for the fact that regulated and deregulated exchange areas were already different before deregulation and thus might exhibit differing trends even if deregulation had not taken place. For example, with the unbundling of the local loop in the United Kingdom in 2001, all exchange areas started without LLUs. By 2007, some areas had achieved a considerable level of competition and therefore were deregulated, whereas other areas experienced no competition. Therefore, note that the right hand side also contains LLU, the "number of LLU operators in 2007". X is a matrix of exchange characteristics (number of premises, and cable presence) and local characteristics at the ward-level (working-age population share, population density, claimant count population share, dummies for England, Wales, Scotland, and Northern Ireland) in 2007. ΔX is a matrix of all local characteristics at the ward level expressed in changes between 2007 and 2012. ε is an error term.

Figure 5-3: The Probability of Deregulation by Premises



[42] We measure the extensive margins, since we cannot observe actual market shares of LLUs or the number of premises covered with FTTC.

β is the coefficient of interest. It gives us the association between local deregulation and either the number of LLU operators present in the exchange or the FTTC status of the incumbent, conditional on initial values of exchange and (changes in) ward characteristics. The effect of local deregulation is estimated consistently under the assumption that investments at regulated and deregulated exchange areas would have developed in parallel in the absence of deregulation given the initial structural differences. To ensure comparability between regulated and deregulated areas regarding their characteristics in 2007, we also estimate our model for subgroups of exchange areas that are very similar in their initial conditions.

Figure 5-3 shows the probability of an exchange being deregulated based on number of premises served. The figure indicates that if the exchange has less than 2,000 premises, its probability of being deregulated is practically zero, whereas if it serves more than 23,000 premises, the probability is unity. In contrast, we find strong variation in the probability of local deregulation of the WBA market for exchange areas having a number of premises served that falls between these two values. We thus restrict our analysis to those 2,276 exchange areas that serve between 2,000 and 23,000 premises.

Table 5-2: Descriptive statistics in 2007, by regulatory status

	Regulated	Deregulated	|Difference|
Exchange-level characteristics			
No. of exchange areas	928	1,348	
No. of LLU operators	0.09	4.26	4.17***
No. of principal operators	1.13	5.29	4.16***
FTTC enabled	0	0	
No. of premises	3,832.80	11,790.90	7,958.1***
Cable via broadband	0.16	0.70	0.54***
Ward-level characteristics			
Population share working age	0.59	0.62	0.03***
Population density (per km²)	58.77	270.45	211.77***
Claimant count share (working age)	0.015	0.024	0.009***

Notes: Descriptive statistics for exchange areas with 2,000 to 23,000 premises. *** p<0.01.

Table 5–2 shows descriptive statistics for the exchange areas included in our analysis. Descriptive statistics are reported before deregulation took place in 2007, and by regulatory status in 2008/2010. Out of the 2,276 exchange areas, 928 (41 percent) are deregulated by 2008/2010. The table reveals that regulated and deregulated exchange areas are not directly comparable due to large structural differences between them that already existed before deregulation. Deregulated exchange areas serve on average about 8,000 premises more than regulated exchange areas. Initial competition is more pronounced in deregulated exchange areas than in regulated exchange areas as deregulated exchange areas initially have, on average, 4.16 LLU operators more than regulated areas and they are located in denser wards than are regulated exchange areas.

5.5 The Effect of Local Deregulation on Investment

5.5.1 Baseline Results

Table 5–3 shows the results for our first-difference specification.[43] The first column reports results for changes in the number of LLU operators and the second column for the FTTC status of British Telecom. Both regressions include the initial number of LLU operators, the number of premises served by the exchange, and cable presence. This information is from the year 2007. We also include ward characteristics for the year 2007 and changes in ward characteristics from 2007 to 2012. Robust standard errors are reported in parentheses. The results suggest that, on average, deregulated exchange areas have 1.1 (rounded) LLU operators more than regulated ones. FTTC rollout is on average 26.2 percentage points more likely in deregulated exchange areas.

The control variables have the expected signs and magnitudes. The initial value of LLU operators is negative in Column (1), which might indicate a saturation effect: with an increasing amount of initial infrastructure-based competition, it is less profitable for additional competitors to become LLUs. In contrast, the effect is positive in Column (2), which denotes the incumbent's reaction: in regions with a priori well-developed infrastructure competition, BT is more likely to invest in FTTC. This infrastructure upgrade might be a reaction to increased competition from the LLUs since BT can use FTTC to differentiate itself from its competitors by offering a higher quality product (in terms of bandwidth). As expected, the cable variable is negative in both estimations. In areas where broadband is available via cable, LLUs and the incumbent find it less economically worthwhile to invest. In a sense, the cable variable could be interpreted as reflecting the cable operator's first-mover advantage. Finally, the premises variable clearly reveals that broadband provider investment is driven by potential local demand, as they are more likely to invest in larger markets.

To this point, we have imposed a linear relationship between the outcome of interest and the initial level of LLU operators. This assumption becomes especially hazardous when we estimate the effect on the change in the number of LLU operators and additionally control for the number of LLU operators in 2007. Our specification implies that an increase in the initial number of LLU operators from, e.g., one to two operators will have the same effect

[43] Descriptive statistics by year for this subsample of 2,276 exchanges are provided in Table 5–10 in the Appendix.

on changes in the number of LLU operators as would an increase from four to five initial LLU operators. To see whether this may affect our results, we next relax the assumption of a linear relationship between the outcome of interest and the initial exchange characteristics.

Table 5-3: Basic results

	Baseline		LLU dummies	
	ΔLLU	ΔFTTC	ΔLLU	ΔFTTC
	(1)	(2)	(3)	(4)
Deregulated (in 2008 or 2010)	1.055***	0.262***	1.199***	0.199***
	(0.072)	(0.028)	(0.096)	(0.035)
# LLU (in 2007)	-0.476***	0.041***		
	(-0.023)	(0.007)		
LLU dummies (in 2007)			yes	yes
Broadband via cable (in 2007)	-0.168***	-0.117***	-0.191***	-0.102***
	(-0.051)	(-0.021)	(-0.053)	(-0.022)
Premises (in 1,000s)	0.079***	0.023***	0.079***	0.023***
	(0.009)	(0.003)	(0.009)	(0.003)
ΔRegional characteristics	yes	yes	yes	yes
Regional characteristics in 2007	yes	yes	yes	yes
Country dummies	yes	yes	yes	yes
# of exchanges	2,276	2,276	2,276	2,276
R-squared	0.333	0.394	0.348	0.4

Notes: First-differences estimations on the exchange level. Exchange areas with 2,000 to 23,000 premises are included in the regressions. Columns (3) and (4) include a full set of dummies for every starting value of LLU operators. Descriptive statistics by year for this sample of exchanges are provided in Table 5-10 in the Appendix. Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

We do this by replacing the initial number of LLU operators in our basic regressions with a full set of dummies for every starting value of LLU operators. The results are shown in Columns (3) and (4) of Table 5–3. Deregulated exchange areas, on average, now have 1.2 LLU operators more than regulated exchange areas. FTTC rollout is on average 19.9 percentage points more likely in deregulated exchange areas. The estimated effects of local deregulation are comparable to the effects found in the first specification, indicating that the functional form of the first specification does not compromise the validity of our results.[44]

[44] In addition, we allow for a more flexible form of the number of premises and include a dummy variable that takes the value unity if the exchange serves more than 10,000 premises in specifications (1) and (2) of Table 5–3. The results are equally comparable to the baseline results. Estimates are available on request.

5.5.2 Ensuring Comparability Between Regulated and Deregulated Exchange Areas

To better compare regulated and deregulated areas regarding their initial situations, we now create different subsamples in which regulated and deregulated exchange areas have very similar initial conditions. Our first subsample consists of regulated and deregulated exchange areas that are "statistical twins" in terms of their ward characteristics. Statistical twins are matched, using the propensity score matching method, on working-age population share, population density, and claimant count population share. As a nonparametric estimation technique, propensity score matching allows us to impose a common support in the sample. With common support, only exchange areas with similar propensity scores, i.e., with similar probabilities of deregulation, are compared with each other. Figure 5-4 in the Appendix shows the distributions of the propensity scores for treated and non-treated exchanges. The results are shown in Table 5-4 and suggest that deregulated exchange areas have, on average, between 0.84 and 0.95 LLU operators more than regulated exchange areas, depending on the matching algorithm. FTTC rollout is on average between 14.3 and 23.3 percentage points more likely in deregulated exchange areas. Overall, the matching only slightly decreases the magnitude of the deregulation effects presented in Table 5–3, suggesting that differences in initial ward characteristics, which are the basis of our matching approach, do not distort our results.

Our second subsample approach concentrates on the 451 exchange areas with three or four POs present in 2007. These exchange areas are comparable in terms of their initial competitive situation but differ in the probability of being deregulated according to Ofcom's rules. Note that in 2008, Ofcom deregulated only those exchange areas with four POs or exchange areas with three POs if at least one more PO was forecast and the number of premises served by the exchange is greater than 10,000. The results of this subsample estimation are shown in Columns (1) and (2) of Table 5-5. On average, deregulated exchange areas have 0.61 LLU operators more than regulated exchange areas. FTTC rollout is on average 17.1 percentage points more likely in deregulated exchange areas.

Even though in the subsample of exchanges with three or four POs in 2007 deregulated and non-deregulated exchanges are comparable in terms of initial competitive situation, they might still differ in terms of market size. Deregulated exchange areas serve on average larger markets. Therefore, in a next step, we restrict the sample of exchanges with three or four POs in 2007 to exchange areas serving fewer than 10,000 premises so as to achieve better comparability between regulated and deregulated exchange areas.[45] The results are shown in Columns (3) and (4) of Table 5-5. Again, deregulation shows a positive effect, and

[45] Descriptive statistics by year for the two subsamples of 450 and 340 exchanges respectively are provided in Table 5–10 in the Appendix.

the coefficients are significant at the 5 and 10 percent level for the number of LLU operators and FTTC deployment, respectively. The effect on the number of LLU operators decreases to 0.42, while the effect on FTTC deployment remains relatively stable and decreases only slightly to 16.1 percentage points.

The results in Table 5-5 imply that controlling for the initial competitive situation in an exchange area is not sufficient to guarantee the validity of the common trend assumption when considering the effect on BT's competitors. Restricting the subsample to ex ante more similar exchange areas thus provides more credible estimates of the deregulation effect.

5.5.3 Removing Principal Operator Forecasts

The last subsample is interesting from another perspective, too: in its deregulation decisions, Ofcom considers unobserved forecasts of principal operators' future investments. Thus, our estimation results of the effect of deregulation on the number of LLU operators might simply reflect, to some extent, Ofcom's forecasts as a self-fulfilling prophecy: that is, an exchange area is expected to have a positive development in the future and is consequently deregulated. If the expected investments occur in the future, they will be attributed to deregulation in the results presented in the previous section, even though they would also have occurred in the absence of deregulation, giving rise to endogeneity bias of the deregulation coefficient.

To distinguish between the effect of deregulation and these forecast effects, we use the fact that Ofcom incorporated the criterion that exchange areas had to exceed 10,000 premises for deregulation in 2008, but then dispensed with this requirement in 2010. Until 2010, an exchange area with up to 10,000 premises could only be deregulated if it had 4 POs (no forecasts were considered). From 2010 on, the same areas only needed three POs actually present plus one PO forecast. [46]Therefore, in our subsample of exchanges areas with three or four POs and less than 10,000 premises, 120 premises were deregulated in 2008 because they had four POs. Out of the remaining 221 exchange areas that were not deregulated by 2008, 179 were deregulated in 2010. Since the 10,000 premises criterion was dropped, these areas could be deregulated in 2010 if they initially had three POs and at least one additional PO forecast. The remaining 42 exchange areas were not deregulated. These areas had three POs present and no PO forecast. To disentangle the forecast effect from the deregulation effect, we estimate separate effects for exchanges that were deregulated in 2008 and those deregulated in 2010. The binary variable for deregulation in 2008 captures the pure

[46] Instead, the incumbent's market share was introduced as additional criterion. Unfortunately we cannot make use of this additional deregulation criterion, since we have no information on BT's local market shares.

deregulation effect, whereas the indicator for deregulation in 2010 captures both effects. The difference between the two estimators is thus the forecast effect.

The estimates are shown in Column (5) of Table 5-5 and imply, as expected, that the pure deregulation effect from 2008 is smaller than the estimate from 2010 that captures both effects. According to our point estimates, upon being deregulated, an exchange area gains 0.22 additional LLU operators, whereas the forecast effect is about 0.24 LLU operators, the difference between the two coefficients. At 340 observations, the sample is unfortunately small and therefore the point estimates of the deregulation effect as well as the forecast effect – even though economically important – are not statistically significant on conventional levels.

5.6 Conclusion and Outlook

This study provides first empirical evidence on the relationship between local deregulation and subsequent competitive development in the WBA market. Although to date theoretical predictions about competition-related developments in deregulated local markets have been unclear, our findings shed some light on this “black box.” Our estimates imply that local deregulation of the U.K. WBA market has a positive effect on infrastructure-based investment by both the incumbent and its competitors. Upon being deregulated, every exchange gains at least 0.22 additional LLU operators. Moreover, after deregulation, the probability that the incumbent rolls out FTTC infrastructure increases by at least 16.1 percentage points.

We cannot observe counterfactual outcomes, i.e., we do not know with certainty how deregulated markets would have developed in the absence of deregulation. But given that our first-difference approach accounts for time-invariant exchange area characteristics, and that we also control for initial pretreatment conditions in 2007, we are confident that our results reflect the counterfactual effect very well. This is corroborated by the fact that we find positive effects of deregulation in all subsamples and for all alternative specifications. In addition, our LLU operator estimates are not confounded with forecast effects that would bias our results.

These findings have important policy implications. The data reveal no negative effects on infrastructure-based competition in response to deregulation of competitive areas. On the contrary, our study shows that deregulated areas exhibit even higher levels of competition after deregulation. This finding should mitigate, at least to some degree, regulator concerns that competition will weaken when competitive exchange areas are deregulated.

Debate over the pros and cons of local deregulation of the WBA market is a recent development. We study the effects of local deregulation of the British WBA market because the United Kingdom was the first country to take this step. This allows us to study the medium-term effects on the investment behavior of the incumbent and its competitors. It is beyond the scope of our analysis to study longer-term effects such as how increased infrastructure-based competition will affect consumer prices and choice. Studying these effects provides a fruitful avenue of further research.

Table 5-4: Propensity score matching

	1-to-1 w/out replacement		1-to-1 with replacement		5-n-n with replacement		Kernel (Epanechnikov)	
	ΔLLU (1)	ΔFTTC (2)	ΔLLU (3)	ΔFTTC (4)	ΔLLU (5)	ΔFTTC (6)	ΔLLU (7)	ΔFTTC (8)
Deregulated (in 2008 or 2010)	0.949***	0.233***	0.877***	0.154***	0.875***	0.143***	0.841***	0.144***
	(0.065)	(0.027)	(0.077)	(0.033)	(0.07)	(0.029)	(0.066)	(0.028)
# LLU (in 2007)	-0.466***	0.051***	-0.458***	0.051***	-0.439***	0.054***	-0.431***	0.050***
	(-0.017)	(0.007)	(-0.018)	(0.008)	(-0.016)	(0.007)	(-0.016)	(0.007)
Broadband via cable (in 2007)	-0.172***	-0.114***	-0.172***	-0.065**	-0.159***	-0.072***	-0.125**	-0.081***
	(-0.052)	(-0.022)	(-0.06)	(-0.025)	(-0.054)	(-0.023)	(-0.052)	(-0.022)
Premises (in 1,000s)	0.093***	0.017***	0.075***	0.012***	0.071***	0.012***	0.069***	0.013***
	(0.008)	(0.003)	(0.007)	(0.003)	(0.006)	(0.003)	(0.006)	(0.003)
ΔRegional characteristics	yes	yes	yes	yes	yes	yes	yes	yes
Regional characteristics (in 2007)	yes	yes	yes	yes	yes	yes	yes	yes
Country dummies	yes	yes	yes	yes	yes	yes	yes	yes
# of exchanges	1,854	1,854	1,581	1,581	1,932	1,932	2,148	2,148
R-squared	0.294	0.408	0.31	0.304	0.294	0.317	0.275	0.305

Notes: First-differences estimations at the exchange level. Columns (1) and (2) report results for one-to-one nearest neighbor matching without replacement. Columns (3) and (4) report results for one-to-one nearest neighbor matching with replacement. Columns (5) and (6) report results for five-nearest neighbor matching with replacement. Columns (7) and (8) report results for kernel matching with Epanechnikov kernel. Propensity score matching is based on ward characteristics in 2007. Only exchange areas with 2,000 to 23,000 premises are included in the regressions. Robust standard errors in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0$.

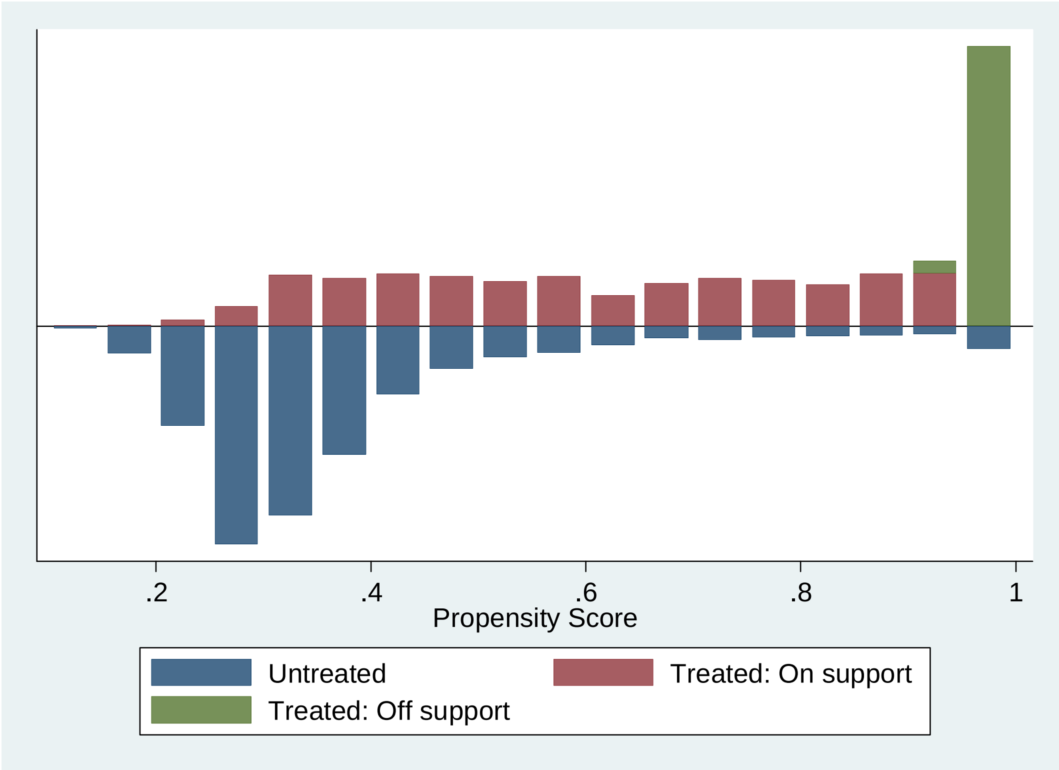
Table 5-5: Subsamples based on deregulation rule

	3 and 4 POs in 2007		3 and 4 POs in 2007 & premises < 10,000		
	ΔLLU (1)	ΔFTTC (2)	ΔLLU (3)	ΔFTTC (4)	ΔLLU (5)
Deregulated (in 2008 or 2010)	0.610***	0.171**	0.415**	0.161*	
	(0.191)	(0.077)	(0.196)	(0.084)	
Deregulated (in 2008)					0.216
					(0.253)
Deregulated (in 2010)					0.456**
					(0.193)
# LLU (in 2007)	-0.463***	0.059**	-0.386***	0.077**	-0.318***
	(-0.086)	(0.03)	(-0.085)	(0.037)	(-0.109)
Broadband via cable (in 2007)	-0.183	-0.156**	-0.122	-0.121*	-0.054
	(-0.169)	(-0.064)	(-0.181)	(-0.073)	(-0.19)
Premises (in 1,000s)	0.127***	0.027***	0.265***	0.029	0.273***
	(0.022)	(0.005)	(0.045)	(0.018)	(0.045)
ΔRegional characteristics	yes	yes	yes	yes	yes
Regional characteristics (in 2007)	yes	yes	yes	yes	yes
Country dummies	yes	yes	yes	yes	yes
# of exchanges	451	451	340	340	340
R-squared	0.248	0.222	0.264	0.195	0.211

Notes: First-differences estimations at the exchange level. Columns (1) and (2) report results for the subsample of exchanges with three or four principal operators in 2007. Columns (3) to (5) report results for the subsample of exchanges with three or four principal operators in 2007 and less than 10,000 premises. Descriptive statistics by year for the two samples of exchanges are provided in Table 5-10 in the Appendix. Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

5.7 Appendix

Figure 5-4: The distribution of propensity scores for deregulated and regulated exchanges



Notes: The graph shows the distribution of the probabilities of exchanges to be deregulated, by their respective treatment status. The algorithm used in obtaining the graph is nearest neighbor matching (without replacement). Deregulated exchanges are the treatment group, regulated exchanges the untreated.

Table 5-6: National Regulatory Agencies' requests for geographic differentiation of the Wholesale Broadband Access market

Criteria for deregulation	UK	PT	DE	AT	ES
Unit of (de)regulation	exchange areas	exchange areas	exchange areas	exchange areas	exchange areas
Market size (premises)	≥ 10,000 (in 2008 only)	-	> 4,000 households	> 2,500	≥ 10,000 households
Market share incumbent	≤ 50% (2010)	≤ 50%	< 50%	< 50%	≤ 50%
No. of relevant operators*	≥ 4	≥ 3 (min. 1 LLU, 1 cable)	> 4	≥ 4	≥ 4 (2 LLU + 1 cable or 3 LLU)
Cable	≥ 65 % cov.	≥ 60 % cov.	No	yes	≥ 60 % cov.
EC (or NRA) notification					
Status	approved (Feb. 2008)	approved (Jan. 2009)	rejected by NRA (2009)	rejected by Admin. Court (Dez. 2008)	rejected by EC "serious doubts" (Nov. 2008)
Reasons for rejection			national scope of market removal of exchanges (future development unknown)	national scope of market	national scope of market WBA < 30 Mbit LLUs' usage of own WBA is counted

Notes: Apart from Germany and Austria, all countries' NRAs filed notifications for geographic segmentation with the EC, which were rejected or approved by the Commission. NRA= National Regulatory Authority; UK = United Kingdom, PT = Portugal, DE = Germany, AT = Austria, ES = Spain, FI = Finland, PL = Poland, RO = Romania, CZ = Czech Republic. Sources: Bundesnetzagentur (2010); EC (2008b, 2008c, 2008d); Ofcom (2008, 2010). * relevant operators include the incumbent.

Table 5-6: National Regulatory Agencies' requests for geographic differentiation of the Wholesale Broadband Access Market, continued

Criteria for deregulation	FI	PL	RO	CZ
Unit of (de)regulation	exchange areas	Municipalities		municipalities
Market size (premises)	-	-		-
Market share incumbent	< 50%	≤ 40%	market traditionally unregulated	≤ 40%
No. of relevant operators*	≥ 3 (or 2 +1 BWA)	≥ 3 (retail level)		≥ 3 (competing infrastructures)
Cable	yes	no		yes
EC (or NRA) notification				
Status	rejected by EC: "serious doubts" (Jan. 2009)	rejected by EC: "serious doubts" (Apr. 2012)	acknowledged by EU in 2010	rejected by EC: "serious doubts" (Aug. 2012)
Reasons for rejection	national scope of market	national scope of market		municipalities do not reflect local markets
	"structural" indicators	"structural" indicators no cost orientation for FTTC		differing infrastructures not sufficient for competition

Notes: Apart from Romania, all countries' NRAs filed notifications for geographic segmentation with the EC, which were rejected or approved by the Commission. NRA= National Regulatory Authority; UK = United Kingdom, PT = Portugal, DE = Germany, AT = Austria, ES = Spain, FI = Finland, PL = Poland, RO = Romania, CZ = Czech Republic. Sources: EC (2008e, 2010b, 2012a, 2012b). * relevant operators include the incumbent.

Table 5-7: Summary of the WBA market definitions by Ofcom in 2008

Market	Description	Exchanges		Coverage
		No.	%	as % of premises
Market 1	those geographic areas covered by exchange areas where BT is the only operator	3,658	65.3%	16.4%
Market 2	those geographic areas covered by exchange areas where there are 2 or 3 principal operators present (actual or forecast) AND exchange areas where there are forecast to be 4 or more principal operators but where the exchange serves less than 10,000 premises	747	13.3%	16.8%
Market 3	those geographic areas covered by exchange areas where there are currently 4 or more principal operators present AND exchange areas where there are forecast to be 4 or more principal operators but where the exchange serves 10,000 or more premises	1,193	21.3%	66.8%

Source: Ofcom (2008, p. 29); own calculations based on Samknows data.

Table 5-8: Summary of the WBA market definitions by Ofcom in 2010

Market	Description	Exchanges		Coverage
		No.	%	as % of premises
Market 1	exchange areas where only BT is present or forecast to be present	3,396	60.7%	11.2%
Market 2	exchange areas where two principal operators are present or forecast AND exchange areas where three principal operators are present or forecast but where BT's share is greater than or equal to 50 percent	661	11.8%	9.9%
Market 3	exchange areas where four or more principal operators are present or forecast but where BT's share is less than 50 percent	1,541	27.5%	78.9%

Source: Ofcom (2010, p. 14); own calculations based on Samknows data

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Table 5-9: Development of Local Loop Unbundlers between 2007 and 2012

2007	exchanges enabled		premises covered		2012	exchanges enabled		premises covered	
	#	%	(in 1,000s)	%		#	%	(in 1,000s)	%
Orange	940	16.8	15,115	55.8	(Orange no longer LLU)	n.a		n.a	
TalkTalk	1,515	27.1	19,913	73.5	TalkTalk	2,537	45.3	24,759	91.4
Sky	1,146	20.5	17,683	65.3	Sky	1,952	34.9	22,869	84.4
AOL	1,036	18.5	16,490	60.8	AOL	1,252	22.4	18,802	69.4
O2	819	14.6	13,374	49.4	O2	1,265	22.6	18,283	67.5
Tiscali	569	10.2	9,793	36.1	Tiscali	947	16.9	15,459	57.0
C&W	793	14.2	13,911	51.3	C&W	942	16.8	16,080	59.3
Pipex	99	1.8	2,113	7.8	Pipex	132	2.4	2,627	9.7
Edge Telecom	1	0.0	1	0.0	Edge	38	0.7	526	1.9
n.a.					Digitalregion	36	0.6	504	1.9
n.a.					Entanet	20	0.4	306	1.1
Newnet	3	0.1	88	0.3	Newnet	11	0.2	301	1.1
n.a.					Lumison	5	0.1	56	0.2
n.a.					Rutland	5	0.1	23	0.1
Node4	4	0.1	79	0.3	Node4	4	0.1	79	0.3
Zen	4	0.1	120	0.4	Zen	4	0.1	146	0.5
Smallworld	3	0.1	45	0.2	Smallworld	3	0.1	45	0.2
n.a.					Kingston	2	0.0	8	0.0
WBI	1	0.0	23	0.1	WB	1	0.0	23	0.1

Notes: LLU = local loop unbundler; PO = principal operator. Source: Own calculations based on Samknows data. Premises covered describes the maximum potential number of premises a LLU operator could serve given the market size of the local exchanges where the LLU operator is present (it does not say about actual subscriber rates). % premises covered refers to a total of 27.1 million premises. n.a. refers to Operators that were not present in 2007.

Table 5-10: Descriptive statistics of exchange- and ward-level characteristics for subsamples in Table 5–3 and Table 5-5, by year

	sample 1 (Table 5–3)		sample 2 (Table 5-5)		sample 3 (Table 5-5)	
	2007	2012	2007	2012	2007	2012
Exchange-level characteristics						
# of exchange areas	2,276	2,276	450	450	340	340
# LLU operators	2.51	3.77	2.38	3.88	2.22	3.67
	(2.58)	(2.39)	(1.07)	(1.42)	(1.01)	(1.37)
FTTC enabled	0	0.48	0	0.64	0	0.57
	(0)	(0.50)	(0)	(0.48)	(0)	(0.50)
Deregulated	0	0.59	0	0.89	0	0.87
	(0)	(0.49)	(0)	(0.31)	(0)	(0.34)
# of premises	8.55	8.55	8.50	8.50	6.76	6.76
	(5.74)	(5.74)	(3.71)	(3.71)	(1.67)	(1.67)
Broadband via cable available	0.48	0.48	0.49	0.49	0.53	0.53
	(0.50)	(0.50)	(0.50)	(0.50)	(0.50)	(0.50)
Ward-level characteristics						
Population share working age	0.61	0.63	0.60	0.63	0.60	0.62
	(0.06)	(0.05)	(0.05)	(0.05)	(0.04)	(0.04)
Population density (per km²)	184.19	189.46	160.74	164.21	137.95	140.84
	(241.41)	(249.53)	(146.61)	(150.24)	(131.58)	(135.12)
Claimant count share (working age)	0.02	0.03	0.02	0.04	0.02	0.03
	(0.01)	(0.02)	(0.02)	(0.02)	(0.01)	(0.02)

Notes: Standard deviations (std. dev.) in parentheses below means. Sample 1 refers to exchanges with 2,000 to 23,000 premises (Table 5–3), Sample 2 refers to exchanges with 2,000 to 23,000 premises and 3 or 4 Principal Operators in 2007 (Columns (1) and (2) of Table 5-5). Sample 3 refers to exchanges with 2,000 to 10,000 premises and 3 or 4 Principal Operators in 2007 (Columns (3) and (4) of Table 5-5).

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