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The effect of broadband internet on establishments' employment growth: evidence from Germany

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Content

Abstract

This study investigates the effects of local broadband internet availability on establishment-level employment growth. The analysis uses data for Germany in the years 2005-2009, when broadband was introduced in rural regions of Western Germany and in large parts of Eastern Germany. Technical frictions in broadband rollout are exploited to obtain exogenous variation in local broadband availability. The results suggest that broadband expansion had a positive effect on employment growth in the Western German service sector and a negative effect in Western German manufacturing. This pattern of results is driven by pronounced positive effects in knowledge- and computer-intensive industries, suggesting that it is the actual use of broadband in the production process that leads to complementary hiring, respectively a slowdown of employment growth, in the respective sectors. For Eastern Germany, no significant employment growth effects are found.

Zusammenfassung

Dieser Artikel untersucht die Wirkungen der lokalen Verfügbarkeit von Breitband-Internet auf das Beschäftigungswachstum in Betrieben. Es werden Daten aus Deutschland für den Zeitraum 2005-2009 genutzt, als Breitband-Internet in den ländlichen Regionen Westdeutschlands und weiten Teilen Ostdeutschlands eingeführt wurde. Zudem werden verschiedene technische Hürden des Breitbandausbaus genutzt, um exogene Varianz in der lokalen Verfügbarkeit von Breitband-Internet zu erhalten. Die Ergebnisse legen nahe, dass der Breitband-Ausbau einen positiven Effekt auf das Beschäftigungswachstum in westdeutschen Dienstleistungsbetrieben hatte, im westdeutschen Industriesektor hingegen einen negativen Effekt. Dieses Ergebnismuster geht einher mit deutlichen positiven Effekten in wissens- und computerintensiven Branchen. Dies legt nahe, dass die genannten Effekte auf die tatsächliche Nutzung von Breitband-Internet im Produktionsprozess zurückgehen und dass Betriebe in den jeweiligen Sektoren komplementär zu Breitband Beschäftigung aufbauen, beziehungsweise den Beschäftigungsaufbau verlangsamen. Für Ostdeutschland werden keine signifikanten Effekte auf betriebliches Beschäftigungswachstum gefunden.

JEL-Klassifikation: J63, O33, R23

Keywords: Broadband internet, local labor markets, employment growth, establishments

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1 Introduction

The expansion of broadband internet is one of the most important current developments regarding the technological infrastructure in industrialized countries. Across Europe and North America, federal and regional governments are investing large sums in the expansion of broadband, notably to rural areas. Germany, the empirical focus of this paper, is no exception. According to one estimate, the German federal government's goal to provide download rates of at least 50 Mbit/s to all households in Germany by 2018 requires investments of about € 20 billion, potentially even more.[1] One of the declared goals of broadband expansion is to promote business and employment. As yet, however, there is limited empirical evidence to inform policymakers of the economic effects of broadband expansion.

Existing evidence suggests that broadband expansion may close the "digital divide" between urban and rural areas and help prevent the depopulation of the latter, but may not stimulate employment (Briglauer et al., 2016). Moreover, there is relatively little empirical evidence on employment effects at the firm level, where employment decisions are made. This lack of micro-level evidence makes it hard to assess through which channels the potential employment effects of broadband come about; for instance, broadband might affect employment not only through changes in production technologies, but also through changes in product demand. Previous research suggests, however, that service-sector employment benefits more from broadband deployment than manufacturing employment (Bertschek et al., 2016; What Works Centre for Local Economic Growth, 2015). From a policy perspective, sectoral effect heterogeneity is important also because industries are often spatially concentrated (Dauth et al., 2016). Since broadband expansion is primarily a regional policy objective, one should thus account for potential sectoral heterogeneity in broadband effects when deriving policy recommendations. I thus estimate the effects of local broadband availability on the employment growth of German firms,[2] focusing on potential complementarities in the production process and considering potential sectoral heterogeneity.

In order to identify the causal relationship between broadband availability and employment growth, I use exogenous differences in municipal broadband availability due to historically determined technical frictions. The analysis focuses on the years 2005-2009, when broadband was introduced in the rural parts of Western Germany and large parts of Eastern Germany. The results indicate that German establishments ex-

[1] See http://www.it-zoom.de/it-director/e/breitbandversorgung-in-deutschland-9341/, last accessed April 28, 2016. The federal state of Bavaria alone contributes € 1.5 bn to reach this goal within its territory (see http://www.schnelles-internet-in-bayern.de/foerderung/ueberblick.html, last accessed April 28, 2016).

[2] In fact, the empirical analysis is based on establishments rather than firms. For better legibility, I refer to firms where the distinction is conceptually irrelevant.

perienced very different employment growth effects in response to broadband expansion. For Western German establishments, I find a significant drop in employment growth rates for the manufacturing sector, but at the same time a significant increase in the service sector. Further estimations suggest the latter effect is driven by knowledge- and computer-intensive industries, which concentrate in the service sector. No significant results are found for Eastern Germany.

This paper is structured as follows. The following section discusses the technological importance of broadband and its implications for the labor market, and summarizes the current state of empirical research on the labor market effects of broadband. Section 3 presents the data on local broadband infrastructure, and section 4, the identification strategy based on these data. Section 5 presents the estimation model and briefly describes the establishment-level employment data. Section 6 provides descriptive statistics. Section 7 presents the results. Section 8 discusses limitations of the analysis and potentials for further research. Section 9 concludes.

2 Theoretical background and previous evidence

2.1 Broadband as a technology

Broadband internet has drastically reduced the cost of information and communication. A given amount of information can be delivered much faster via broadband than via basic internet service, and within a given amount of time, broadband can transfer higher-quality content than earlier technologies. In the terminology of Bresnahan and Trajtenberg (1995), broadband can be regarded as a “general purpose technology” (see also Harris, 1998 and Atkinson and McKay, 2007) which improves the conditions for innovation and productivity in a broad range of economic activities, due to complementarity with subsequent innovations in many industries. Furthermore, broadband may be regarded as an “enabling technology” which unfolds its full economic potential once it is widely available (Bresnahan and Trajtenberg, 1995). Thus, the productivity gains from ICT extend well beyond the ICT sector itself. Instead, ICT-using firms and households contribute to improvements in productivity and demand, and thus growth (OECD, 2008).

In line with these predictions, Röller and Waverman (2001) find that telecommunication infrastructure seems to be causally related to economic growth in OECD countries, suggesting that better telecommunication infrastructure facilitates market transactions. Röller and Waverman (2001) also suggest that the growth effect of telecommunication infrastructure gets strongest as the infrastructure approaches universal coverage, enabling a large share of producers and consumers to use it. Similarly, Koutroumpis (2009) and Czernich et al. (2011) find that it takes a “critical mass” of broadband users for the technology for the full economic impact of broadband to unfold, in line with the “enabluing technology” hypothesis. In a survey of empirical evidence for the US, Holt and Jamison (2009) find that ICTs generally, and broadband more specifically, seem to have positive economic effects (notably, on output and productivity growth). In a cross-country comparison, Czernich et al. (2011) find that across OECD countries, broadband availability increases GDP growth.

As a broad technological advancement, thus, broadband seems to have far-reaching consequences for production, notably a positive effect on total factor productivity. In particular, broadband should increase the efficiency of economic activities which use information that can be "digitized" and thus shared via the internet. According to standard theory, this efficiency increase implies a reduction in the relative demand for kinds of labor that broadband substitutes for, and an increase in the relative demand for complementary labor (e.g. Cahuc and Zylberberg, p. 587 sqq.). Regarding total labor demand (and hence employment), the effect of technological advancements such as broadband introduction is theoretically ambiguous for two reason. First, broadband can be either a substitute for or a complement to labor, or both (in different sectors or groups of workers, respectively). This ambiguity can be addressed by analyzing different segments of the labor market (e.g. industries and qualification groups) separately. Second, the labor market effects of technological progress depend on the elasticity of demand in the product market (e.g. Blien and Ludewig, 2016). Therefore, for an assessment of the aggregate employment effects of broadband expansion, one has to account for its product-market implications. Accounting for this latter ambiguity, however, is beyond the scope of this paper. The aim is instead to identify firm-level employment effects.

At the micro level, the realms of broadband internet effects on the labor market can be broadly distinguished as follows. On the one hand, broadband may affect labor supply and matching. In particular, fast internet facilitates job search and increases the number and quality of job offers job seekers can receive, thus potentially affecting labor supply and worker-firm matching (see Mang, 2012 and Dettling, 2013). For instance, job seekers may find jobs faster, or in contrast, raise their expectations about job characteristics, due to an increased quantity and quality of search results. On the other hand, broadband may affect firms' labor demand. To make use of the local broadband infrastructure, firms may have to adjust their labor input, and different firms (and industries) may react differently to increased broadband availability. While this paper focuses on labor demand at the firm level, most studies on broadband and the labor market consider outcomes at the region level, since broadband availability varies mainly in the spatial dimension. In the following, I therefore review relevant studies at both, the region and micro levels.

2.2 Regional labor market effects of broadband

There are large differences in broadband coverage between core and peripheral areas (the "digital divide") that attract policymakers' attention, and a substantial number of empirical studies address the economic implications of these differences. Overall, these studies tend to find positive, but not necessarily large employment and wage effects. More specifically, broadband effects vary between types of regions, industries, and groups of workers (notably by skill level), according to one survey article

(What Works Centre for Local Economic Growth, 2015). Another very comprehensive literature survey is provided by Bertschek et al. (2016), who also conclude that the overall labor market effects of broadband tend to be positive. More precisely, empirical studies tend to find unambiguously positive labor market effects of broadband adoption (that is, broadband use), and somewhat less robustly positive effects of mere broadband availability. Given the just cited surveys of empirical evidence, I narrow my own literature review to studies which focus on labor market outcomes, use data from developed countries, and critically discuss the credibility of the employed identification strategies.

Kandilov and Renkow (2010) find that a US broadband loan program targeted at rural areas had positive employment and wage effects. Also for the US, Kolko (2012) finds a positive local employment growth effect of broadband availability, which is stronger in IT-intensive industries and less densely populated areas. Using German data, Fabritz (2013) finds evidence suggestive of small positive employment effects of broadband availability at the municipality level, but not in the manufacturing sector. Thus, the effect is likely to stem from the service sector (which cannot be distinguished in the data). In contrast, Czernich (2014) studies the effect of broadband internet availability on unemployment at the municipality level in rural areas in Germany, not finding a significant effect.

Some studies investigate the effect of broadband on firm start-up, that is, employment growth at the extensive margin, as opposed to the intensive margin of employment growth at incumbent firms. Tranos and Mack (2016) investigate the relationship between broadband availability and presence of knowledge-intensive service establishments in the US. Using Granger causality tests, the paper finds evidence suggestive of a causal relationship between the presence of broadband providers in a county and of knowledge-intensive service establishments. In contrast, Atasoy (2013) addresses the intensive margin (existing firms), finding a positive relationship between employment and broadband availability, also for the US. In that study, the identification of effects relies on regression specifications including county and time fixed effects.

While studies on the effects of broadband availability dominate the literature (due to data availability), some studies at the regional level have also investigated the effects of broadband adoption, that is, the take-up of the technology by firms and households. Using propensity score matching, Whitacre et al. (2014a) find that broadband adoption has positive effects on employment and income in US rural areas. Applying a difference-in-differences approach, Whitacre et al. (2014b) add that high broadband adoption in rural areas is positively associated with the number of firms and employees, as well as with median household income. However, neither study finds robustly significant effects on labor market outcomes, and none of them claims to identify causal relationships. Yet, the studies demonstrate that, even if broadband availability cannot be shown to affect local labor markets, it might have effects on those who actually use it. In this spirit, further studies on adoption effects have been conducted at the firm and worker levels.

2.3 Firm- and worker-level effects of broadband

Similar to the region-level evidence, empirical studies at the firm level often consider various outcomes that might be affected by broadband (employment, employment growth, productivity, innovation). Even if employment effects are not addressed explicitly, however, these studies may hold lessons for the labor market implications of broadband. For instance, using a sample of firms in Germany, Bertschek et al. (2013) find that broadband use positively affects innovative activity, but not labor productivity. Canzian et al. (2015), who focus on rural areas in the Trento region (Italy), find a positive effect of a more recent broadband technology (ADSL2+) on firm productivity (sales, value added), but not employment. The paper exploits plausibly exogenous variation in broadband availability, caused by a stepwise rollout of the ADSL2+ technology.

Exploiting a similar infrastructure program in Norway which generated exogenous variation in broadband availability, Akerman et al. (2015) estimate the effect of broadband adoption in firms on wages and other person- and firm-level outcomes. Their findings suggest that broadband increases high-skilled workers' employment, productivity, and wages, but has negative effects on the low-skilled. Akerman et al. (2015) attribute their findings to the complementarity of internet use with abstract, non-routine work tasks, and its substitution for routine jobs, implying that broadband increases the productivity of workers who use ICT intensively. Ruling out alternative channels through which broadband might affect labor market outcomes, Akerman et al. (2015) thus demonstrate that production processes in firms are the main such channel. Moreover, since they find no effect on the output elasticity of capital, their findings suggest that broadband affects firms primarily through its effects on labor productivity.

Broadband adoption is observed only in few other firm-level studies. Colombo et al. (2013) estimate the impact of broadband adoption on the productivity of small and medium enterprises (SMEs) in Italy. While they find hardly any effect from basic broadband technologies, there tend to be positive productivity effects associated with more advanced technologies. De Stefano et al. (2014) exploit very detailed spatial data on firms located on both sides of a technological border in the Hull region (UK), one side served by a quasi-monopolist and the other by a small competitor who provided broadband five years earlier. The study finds no significant effect of broadband adoption on the sales, employment, labor productivity, or survival of firms. Haller and Lyons (2015) find that broadband adoption, while higher in highly productive firms, does not lead to further or accelerated productivity growth in the Irish manufacturing sector. Finally, Bertschek and Niebel (2016) find evidence of positive labor productivity effects of mobile internet use by German firms, supposedly working through increased flexibility in the organization of work.

Firm-level evidence thus points at limited and not always positive effects of broadband availability and adoption on labor market outcomes. An important difference emerges between the manufacturing and service sectors – the latter typically benefits more from broadband than the former. This pattern of results likely reflects the more intense use of ICT and, more specifically, digital technologies, in the service sector. A survey of 2,000 establishments in Germany found that the share of establishments that use modern digital technologies[3] is much larger in services sector than in manufacturing (Arntz et al., 2016). One should therefore expect relatively large effects of broadband on labor demand in services and ICT-intensive industries.

In the following, I aim to identify the effect of local broadband supply on e employment growth in a sample of German establishments. I thereby focus on the demand-side channel of the labor market effects of broadband, since broadband availability is measured at production sites (or places of work), rather than at workers' places of residence (where broadband might affect labor supply, e.g. through job search behavior). Since broadband availability is measured at the municipality level, and because the sampled municipalities are relatively small, places of work and residence are relatively unlikely to coincide. Furthermore, I choose to investigate employment growth rather than employment levels as the outcome, because first, establishment are more likely able to adjust at this margin, and second, because the data I use are largely limited to employment-related indicators, but lack indicators on capital, investment, and output, which would be important covariates in an analysis of employment (level) outcomes. Before presenting the estimation model in detail, however, I provide details on the broadband data and the identification strategy used to extract exogenous variation in broadband availability.

3 Broadband data

Nowadays, the term broadband is typically understood as an internet connection with data transfer rates of several Megabits per second (MB/s), currently up to 50 MB/s or even (rarely) 100 MB/s. This most recent state of technology is not the subject of this paper. Instead, I consider the first generation of broadband, which first became available in Germany by the year 2000. By far the most important broadband technology in Germany was and is DSL (digital subscriber line), which covers more than 90 percent of broadband subscriptions in Germany (Bundesnetzagentur, 2013). DSL allows downstream data transfer rates of at least 384 kilobits per second (kb/s). Prior technologies (dial-up, ISDN) allowed maximum download rates between 64 and 128 kb/s. Thus, while slow compared to today's broadband standard, DSL drastically improved the conditions for data- and communication-intensive economic activities, for instance organizational tasks such as file-sharing and video-conferences, marketing and sales

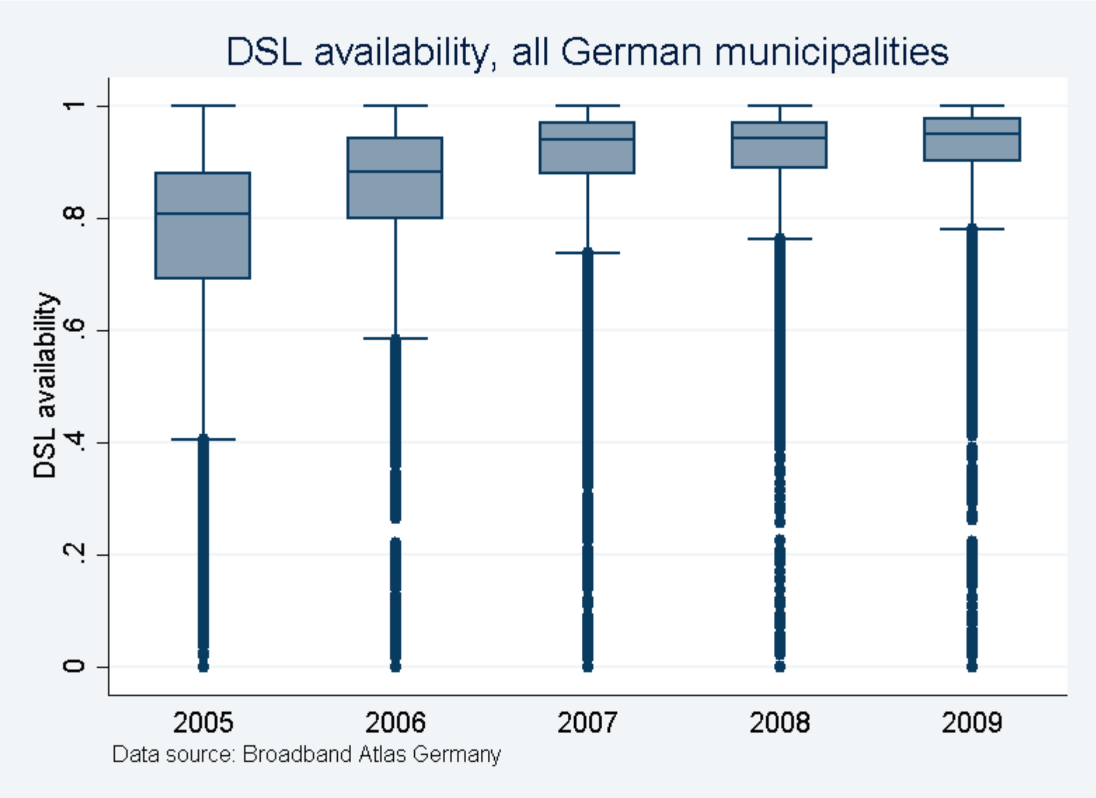
[3] E.g. cloud computing, generating and utilizing big data, or (in the case of manufacturers) cyber-physical systems and "smart factories".

via e-commerce, recruiting personnel through online portals, or other business activities.

Regarding its economic impact, an important aspect of the introduction of DSL is the fast speed at which the technology could be installed, because the necessary underlying infrastructure (the telephone network) was already in place, as explained in more detail in the following section. Furthermore, in contrast to some earlier technologies, DSL was offered from the very beginning as an “always-on” service for which users pay a flat-rate price, regardless of how intensely they use it. That is, besides increasing connection speed, DSL drastically reduced the marginal costs of internet service.

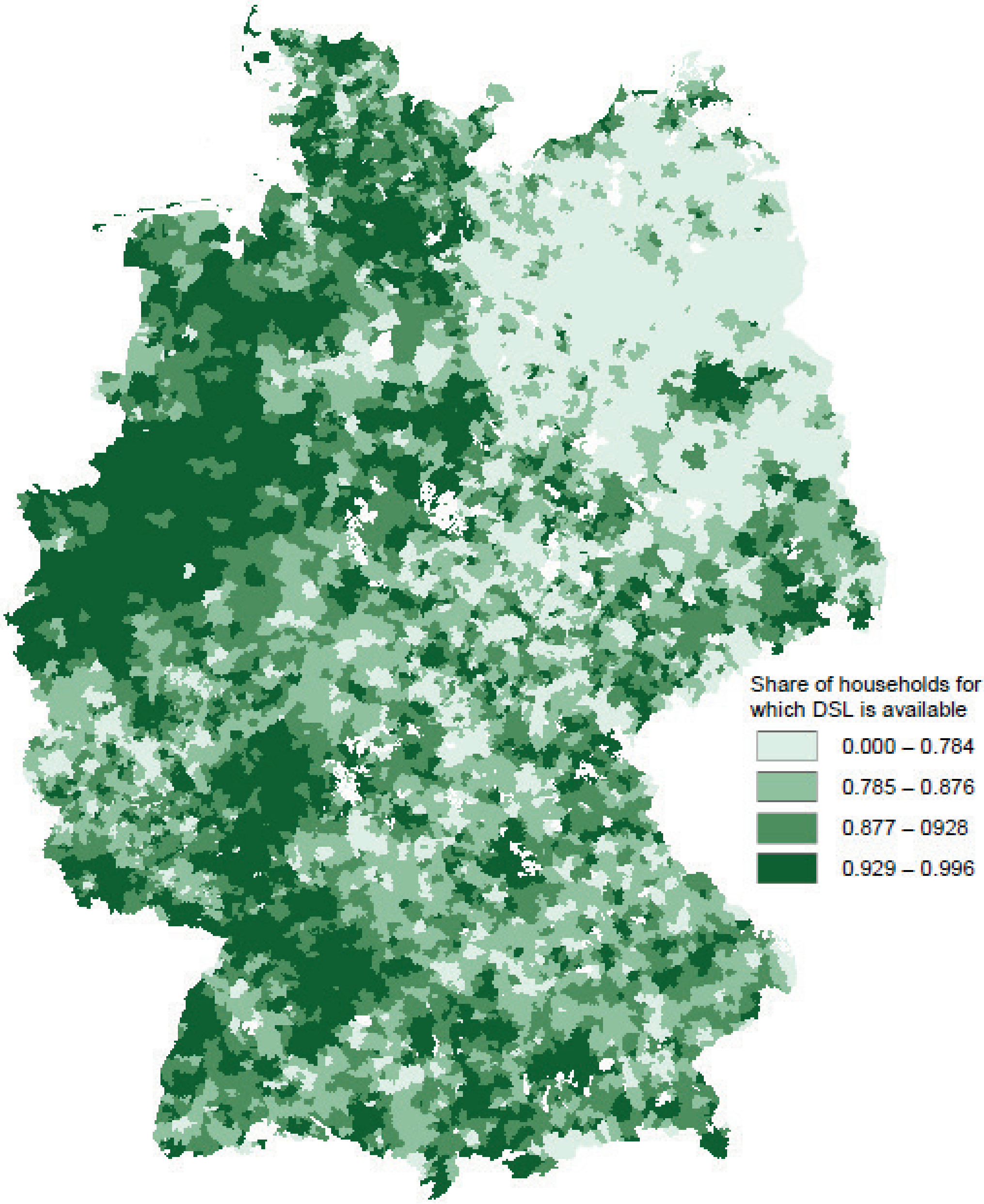
The main explanatory variable in this analysis is broadband availability, also referred to as broadband penetration. Data on broadband availability are obtained from the Broadband Atlas published by the Federal Ministry of Economics and Technology (2009). The data contain the share of households, at the municipality-year level, for which a DSL connection is available, that is, technically feasible but not necessarily adopted (used). Figure 1 illustrates that DSL availability converged to a median of about 95 percent towards the end of the observation period (2005-2009), but there was substantial variation across and within municipalities at least in the earlier years. However, the convergence to full coverage across the country could also be crucial for the identification of economic effects since, as discussed above, ICT improvements typically reach full effectiveness only when a large mass of users is reached. Regarding the sample of relatively small firms used in this study (details below), this period of widespread broadband availability thus seems particularly interesting, compared to the early stages of DSL deployment which may have affected only large and technologically advanced firms.

Figure 1
DSL availability in Germany, 2005-2009



Regarding the spatial variation of DSL availability, Figure 2 shows that availability rates in 2005-2009 were highest in densely populated regions such as Berlin, the Rhein-Ruhr area in West, the Rhein-Main (Frankfurt) region, and the major cities in the South (Munich, Stuttgart). In the following empirical analysis, however, these metropolitan areas are largely discarded (for Western Germany), as explained below. Outside the metropolitan areas, DSL availability varies visibly even between adjacent municipalities. That is, the rollout of DSL proceeded much faster in some municipalities than in others.

Figure 2
Map of DSL availability across German municipalities, 2005-2009 (mean of annual availability rates)



Note: White spots are areas not belonging to any municipality (gemeindefreie Gebiete; e.g., forests, lakes, mountains, and military territories) or municipalities for which boundaries could not be harmonized over time. Data source: Broadband Atlas Germany.

These sharp differences in DSL availability offer an opportunity to identify causal relationships between local broadband availability and labor market outcomes. The main empirical challenge involved is to find an exogenous source of variation in broadband availability between municipalities and intertemporal changes therein. Such a setting is unlikely to exist if broadband is provided by private firms, which have an obvious incentive to provide better access where firms and households are more likely to subscribe, which itself is more likely to occur where firms expect greater profits from using broadband. To tackle this challenge, I employ an IV approach developed and used by Czernich et al. (2011) and others,[4] which I briefly describe in the following.

4 Instrumental variables approach

Concerning Western Germany, the proposed identification strategy exploits technical properties of the public-switched telephone network (PSTN) built in the 1960s. During the observation period of this study, DSL was supplied using “fiber-to-the-node” (FTTN) technology, meaning that the more central part of the telephone network was already equipped with “fast” optical fiber connections, while the “last mile” between the most decentral nodes (main distribution frames or MDFs) was served via copper wires. Unlike telephone service, DSL service decays in quality as the distance between the MDF and the end user increases. The main supplier of DSL (Deutsche Telekom) defined the maximum acceptable amount of quality loss due to distance decay at a signal strength of 55 dB, which translates into a distance of approximately 4.2 km. Thus, beyond 4.2 km from the MDF, DSL service was not provided until, years later, at least part of the last-mile copper wires became replaced by fiber wires. That is, DSL did eventually become available even to users more than 4.2 km distant from their MDF, but only with a substantial time lag, not least because telecommunication wires are installed subsurface in Germany.

When the PSTN and hence the MDFs were installed in the 1960s, the state-monopolist telecommunication provider (the German federal postal services) aimed to provide universal telephone service, even in remote areas. Therefore, the circa 8,000 MDFs were allocated relatively densely and evenly across the country (see Figure A1 in the Appendix). The precise locations of MDFs were determined, notably, by the availability of lots or buildings were the MDF, which is the size of a small hut, could be placed.[5] The distance between an MDF and its users, in contrast, was irrelevant for the location decision. As argued extensively by Falck et al. (2014), the location of MDFs can thus be assumed to be exogenous with regard to local economic outcomes some 40 years later. Therefore, the (“fuzzy”) distance threshold of 4.2 km can be used as an instrument for the local availability of DSL.

A caveat of the proposed IV approach is that it only applies to rural areas, for the following reasons. Reflecting the number of connected users (and thus the required capacity of telephone service), there are more MDFs in cities than in rural areas. Cities usually have at least one own MDF, and hardly any users in urban municipalities are more than 4.2 km distant from the MDF they are connected to. Even for smaller towns

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4 Czernich (2012; 2014), Fabritz (2013), and Falck et al. (2014).

5 The Data on MDF locations used in this study were originally provided by Deutsche Telekom (Germany’s largest telecommunication provider) and further processed (aggregated to the municipality-year level and merged with other municipality-level data) by Falck et al. (2014).

and villages which host at least one MDF within their boundaries, the distance between MDF and users rarely exceeds 4.2 km, since the average German municipality is the size of a circle with 3.2 km radius.[6] Furthermore, only for very few municipalities, the entire territory is more than 4.2 km distant from the MDF, emphasizing the quasi-randomness of MDF locations across the country.

Yet, a substantial number of rural municipalities do not host an MDF, meaning that the distance between any point in the municipality and the MDF is positive. Using the municipality centroid as a proxy for the location of the municipality, one can thus measure the distance between the municipality and the MDF. Thus, the distance-based IV applies to Western German municipalities without an own MDF, resulting in a sample of rather rural municipalities. For a descriptive comparison of sample municipalities to all other municipalities, see Figure A4.

As in Falck et al. (2014), thus, the IV is a dummy variable that classifies municipalities as being above or below the 4.2 km threshold as follows:

$$IV_m^{West} = \begin{cases} 1 \; if \; municipality \; centroid > 4200m \; from \; assigned \; MDF \\ 0 \; otherwise. \end{cases}$$

As argued by Falck et al. (2014), this dummy is a more credible IV than would be the linear distance between the municipality center and the MDF. In particular, the exact distance to the MDF might violate the exclusion restriction, i.e. it might have an effect on the outcome (employment growth) other than through DSL availability. This is because municipalities particularly far from the MDF are likely also very remote locations in other respects, such as access to transport infrastructure, that have a direct impact on the labor market.

The discussion so far focused only on the MDF the municipality was originally (in the 1960s) assigned to for telephone service. However, the assigned MDF is not necessarily the closest one. In fact, some municipalities above the 4.2 km threshold (with respect to the assigned MDF) are less than 4.2 kms distant from the nearest MDF, which has two important implications: First, this possibility is further evidence that the distance between MDF and users was indeed irrelevant for the original location of MDFs, respectively the assignment of municipalities to MDFs. Second, municipalities with an *assigned* MDF above the threshold but a *nearest* MDF below the threshold

[6] As of Dec. 31, 2015, Germany had 11,092 municipalities (https://de.statista.com/statistik/daten/studie/1254/umfrage/anzahl-der-gemeinden-in-deutschland-nach-gemeindegroessenklassen/, last accessed Feb. 10, 2017) and it has a land area of 357,386 square km (http://www.statistik-portal.de/Statistik-Portal/de_jb01_jahrtab1.asp, last accessed Feb. 10, 2017). Average municipality size is thus roughly 32 square km, equivalent to a circle with 3.2 km radius.

did, after all, obtain DSL by getting connected to the latter. I drop the (few) municipalities where this is the case from the estimation sample.[7] All three possible situations of municipalities without an own MDF are illustrated for a concrete example in Figure A2 in the Appendix. Figure A3 presents a map of all German municipalities without an own MDF, indicating whether they are above or below the distance threshold. The map shows that even adjacent (and therefore otherwise similar) municipalities differ with respect to their distance from the MDF. Being above or below the threshold thus is probably the most important reason for the sharp differences in DSL availability even between similarly located municipalities seen in Figure 2.

For Eastern Germany (the former German Democratic Republic), one cannot construct the same distance-based IV, but it is possible to exploit a historic "accident" that also exogenously caused some municipalities to receive DSL service later than others (see also Falck et al., 2014). When the Eastern German telephone network was modernized after the German Reunification in the early 1990s, the government and private providers anticipated a growing need for high data transfer rates. In a number of pilot projects and subsequently at a larger scale, a technology called OPAL (*Optische Anschlussleitung*) was therefore installed in 213 Eastern German catchment areas (i.e. areas served by one MDF). OPAL is a predecessor of modern fiber-wire technology, which at the time was regarded as capable of providing high-speed internet service. Unfortunately, the data transfer rates that were eventually required (for DSL) where strongly underestimated. Therefore, having the OPAL technology installed turned out to be a disadvantage for DSL rollout. In order to supply DSL, the local OPAL networks had to be either replaced altogether or substantially technically updated, both of which were time-consuming and costly enterprises. Being located in an OPAL area thus negatively affected DSL availability throughout the decade 2000-2009. An OPAL area dummy can therefore be used as an instrument for DSL availability in Eastern German municipalities:

$$IV_m^{East} = \begin{cases} 1 \; if \; OPAL \; area \\ 0 \; otherwise. \end{cases}$$

Although OPAL areas are relatively urban municipalities (or parts thereof), the value of the OPAL dummy can be reasonably regarded as quasi-random (see Figure A1). To ensure the relevance of this IV for DSL availability, the estimation sample includes only municipalities whose geographic centroid is less than 4.2 km distant from the nearest MDF. In these municipalities, as in Western German municipalities below the distance threshold, DSL was easily available – except for OPAL areas. Restricting the

[7] Alternatively, one could retain these municipalities and set the value of the IV to zero. I choose not to do so because an important robustness check (using the share of a municipality's land area above the distance threshold as an alternative IV) is only possible with respect to the assigned MDF (given the available data).

Eastern sample to these municipalities results in a relatively urban sample (see Figure A5 for a comparison of sampled and non-sampled municipalities).

5 Employment data and estimation model

The empirical specification I estimate can be written as a two-stage model, with establishment-level employment growth as the main outcome. Establishment-level data are obtained from the Establishment History Panel (BHP) of the Institute for Employment Research (IAB), a annual panel (at the reference date June 30) that contains employment aggregates and other characteristics of all establishments in Germany with at least one employee liable to social security.[8] The data are based on the administrative records of the German Federal Employment Agency, which contain all private and public sector employees liable to social security. I use a ten percent random sample of establishments observed in the BHP in the period 2005-2009. The sample is cleared of establishments observed for the first time in 2005 or later, since these are likely newly founded establishments which might have been attracted by broadband expansion, rather than experiencing broadband rollout as an exogenous technological shock. Further sample cleaning steps are documented in Appendix section “Sample restrictions”.[9]

Regarding the estimation model, the main (second-stage) equation is:

$$\ln\left(\frac{L_{it+1}}{L_{it}}\right) = \beta_0 + \beta_1 \widehat{DSL}_{mt} + \boldsymbol{\beta_2 X_{it}} + \boldsymbol{\beta_3 X'_{mt}} + \theta_c + \vartheta_j + \mu_t + \varepsilon_{it}. \qquad (1)$$

The dependent variable is the log growth rate of establishment i’s employment between years t+1 and t (with t = 2005, …, 2009). L_{it} is the total number of employees at establishment i in year t. The explanatory variable of interest is the (instrumented) availability of broadband in municipality m and year t (DSL_{mt}), measured as the share of households for which DSL is available.[10] Control variables at the establishment level (X_{it}) are the log number of full-time employees, the share of high-skilled employ-

8 For a detailed description of the BHP, see Gruhl et al. (2012).

9 The municipality-level sample restrictions implied by the identification strategy are independent of these establishment-level restrictions. That is, only a regional subset of the ten percent random sample of establishments enter the analysis.

10 Municipality codes refer to territorial boundaries as of Dec. 31, 2008.

ees, the log median daily wage for full-time workers, and three dummies for establishment age.[11] Unfortunately, the BHP does not contain data on capital, investment, output, or profitability.[12] Municipality-level controls (X'_{mt}) include the log number of full-time employees and its growth rate (between t-1 and t), log employment density, the share of high-skilled employees, as well as the log mean wage of full-time workers. Municipality-level controls are computed using the entire population of establishments in the BHP (ca. 2 million establishments). The mean wage is computed as the municipality-year mean of establishment-level median wages. The municipality-level controls furthermore include the share of high-skilled employees. Finally, I include fixed effects for districts (c), three-digit industries (j), and years (t). Municipality fixed effects are not an option because the time-invariant instrument would drop out of the first-stage estimation equation.

At the first stage, broadband availability is instrumented using either of the IVs presented above, both of which vary between municipalities but not over time. Control variables, indices, and fixed effects are the same as in the second-stage equation. The first stage thus is:

$$DSL_{mt} = \alpha_0 + \alpha_1 IV_m + \alpha_2 \boldsymbol{X_{it}} + \alpha_3 \boldsymbol{X'_{mt}} + \pi_c + \rho_j + \sigma_t + u_{mt}. \qquad (2)$$

Since large establishments are rare but employ a major share of the national workforce, I weight all estimations by the establishment's number of full-time employees. Thus, the obtained estimates should be more meaningful regarding the overall employment growth effect of broadband. Furthermore, standard errors are clustered at the municipality level, since this is the level at which the instruments vary. Finally, to account for the sectoral heterogeneity in broadband effects, I estimate the model not only for all sampled establishments, but also separately for different sectors.

Besides the rather obvious problem of potential endogeneity (the main motivation for the proposed IV approach), another rationale for employing IV regression is to address measurement error in the explanatory variable, see Angrist and Pischke (2009, p. 127 sqq.) and Hausman (2001). By using spurious variation in the explanatory variable, measurement error tends to bias OLS estimates towards zero. In the current

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[11] High-skilled employees are defined by their occupation rather than education, because the latter variable has a large number of missing values. Occupations considered as high-skilled are: engineers, managers, professionals (e.g. lawyers, architects), semi-professionals (service-sector workers with an advanced qualification), and technicians (manufacturing-sector workers with an advanced qualification).

[12] The survey-based IAB Establishment Panel, which can be linked to the BHP, does contain some of this information. However, using only establishments surveyed in the Establishment Panel (ca. 16,000 observations/year) would result in a much too small estimation sample, considering that the IV strategy is applicable only to a subset of municipalities (in the case of Western Germany, these are rural municipalities which host only a small fraction of all establishments and employees).

context, the most obvious source of measurement error is that DSL availability is observed only at the municipality level, while employment growth is observed at the establishment level. Therefore, DSL availability is necessarily measured with error for some establishments. Regarding the Western German sample in particular, such mismeasurement is likely if the municipality is classified as being above the distance threshold, while the establishment location is in fact below the threshold, or vice versa. This particular source of error is further addressed in a robustness check. Another minor source of measurement error may be that DSL availability is measured with regard to households and not establishments. For the Western German sample, for which the precise distance to the MDF is crucial, DSL availability might thus differ between households and establishments, inasmuch as these are located differently across the municipality. The IV approach is intended to alleviate the estimation bias due to these measurement errors.

Regarding the interpretation of the estimates, under standard assumptions,[13] the IV estimator identifies the local average treatment effect (LATE) for "compliers," i.e. establishments in municipalities which have lower (higher) broadband availability if the technical friction used as an IV is (not) in place (Imbens and Angrist, 1994). Obviously, this consideration involves a counterfactual and therefore cannot be assessed empirically. However, considering the massive negative associations between the IVs and broadband availability (documented below), this does not appear to be a major limitation. That is, municipalities had no choice but to comply, that is, to have lower (higher) local broadband availability if (not) being subject to one of the technical frictions. At the establishment level, at which the outcome is measured, a potential problem of non-compliance does arise: Establishments could obtain broadband service independently of the general local DSL rollout via private leased lines. However, at the time considered, these were affordable only to large firms.[14] Given the average size of our sample establishments (about ten full-time employees in both the Western and Eastern samples), thus, the identified LATE should be a fair approximation of the average treatment effect.

A related caveat to the interpretation of the estimated coefficient is that only broadband availability, but not broadband adoption by the establishments is observed. In potential outcomes terminology, this means the identified coefficient represents an intention-to-treat (ITT) effect. As discussed by Czernich (2014), the ITT effect is necessarily closer to zero than the effect of adopting and using broadband. Therefore, the estimated effect of DSL availability should understate the effect of DSL use on

[13] Validity of the exclusion restriction (the instrument affects employment growth only through DSL availability); relevance of the instrument; monotonicity of the instrument's effect on DSL availability (either positive or negative, including the possibility of a neutral effect for some units of analysis); see Angrist and Pischke, 2009, pp. 154 sq.).

[14] According to Fabritz (2013), 82 percent of German firms use the local DSL infrastructure.

employment growth. At the same time, however, note that the observation period captures a relatively late stage of DSL rollout, when DSL was already an established and affordable technology. Firms that use the internet intensely therefore likely adopted DSL as soon as it became available to them. Thus, the difference between the ITT effect and the average treatment effect should be limited.

A final issue regarding the interpretation of the results is external validity, due to the geographic bias of the sample municipalities (relatively rural for Western Germany, relatively urban for Eastern Germany). The estimated effects may not extend to establishments in urban Western German or rural Eastern Germany municipalities.

6 Descriptive analysis

Pursuing the above-discussed identification strategy, I obtain two separate estimation samples for Western and Eastern Germany. Table 1 summarizes the number of municipalities, establishments, and observations for both samples and both possible values of the respective IV. For the Western German sample, broadband availability is exogenously determined by the MDF-distance threshold. The relevance of the instrument can thus be displayed as a relationship between a municipality's DSL availability and the distance to its assigned MDF. Figure 3 plots DSL availability against the distance between municipality threshold and MDF; municipality-year observations are grouped into bins (each containing 100 observations) ordered by the same distance. As the graph shows, DSL availability decreases sharply at the 4.2 km threshold.[15] Figure 4 illustrates the relevance of the respective IV for both, the Western and Eastern German samples – in both cases, DSL availability is highly significantly correlated with the instrument – the technical frictions represented by the instruments indeed seem to inhibit DSL availability.

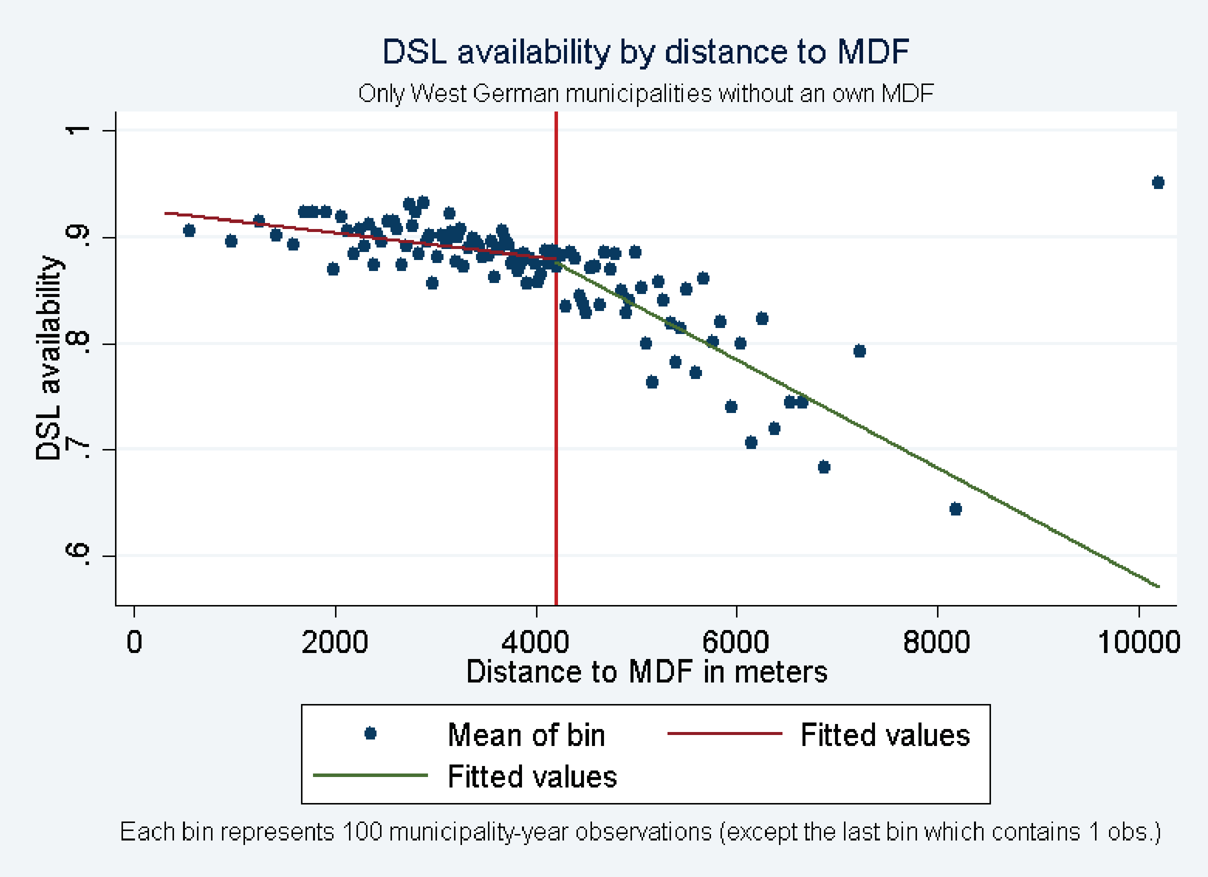
Table 1
Sample sizes

	West		East	
	IV=0	IV=1	IV=0	IV=1
Municipality observations	6,820	4,081	6,497	716
Municipalities	1,482	893	1,389	151
Establishment observations	21,708	11,765	55,766	14,989
Establishments	5,324	2,901	14,034	3,804

Data source: IAB Establishment History Panel (BHP) 7510 v1, Nuremberg 2012

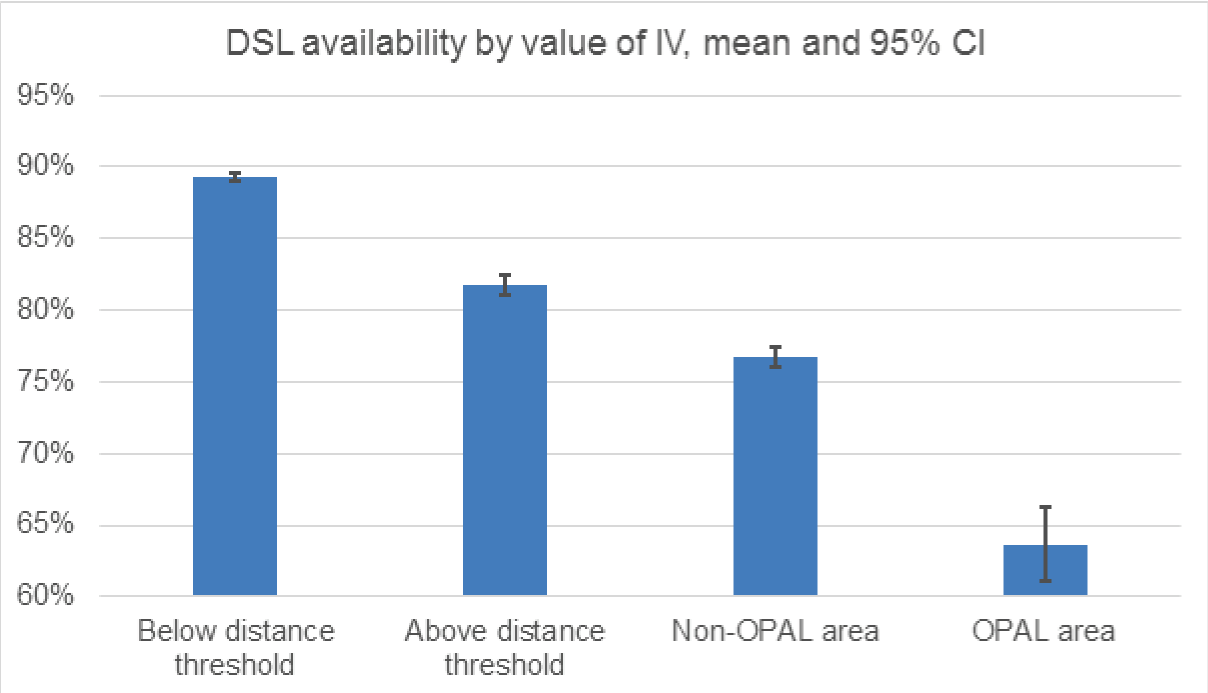
[15] The last bin, representing a municipality observation more than 10 km from the assigned MDF, can be considered an outlier.

Figure 3
DSL availability by distance between municipality centroid and MDF



Data source: Broadband Atlas Germany, Deutsche Telekom

Figure 4
DSL availability by value of the IV



Data source: Broadband Atlas Germany, Deutsche Telekom

The main issue concerning the validity of the identification strategy is whether the technical frictions on which the IVs are based can be regarded as exogenous, i.e. unrelated to the outcome of interest (except through their effect on DSL availability) and to unobserved determinants of the outcome. This question can be addressed to some extent by comparing group means of relevant covariates for either value of the binary IVs. Table 2 summarizes several municipality-level variables for both, the Western and Eastern German samples. The data refer to 1999, the year before DSL became available, so DSL use cannot possibly have affected these variables. The table reports raw group means at the municipality level and p-values from a t-test on equality of means cleared of district fixed effects (which are also used in the estimations).

Table 2
Balance of municipality-level covariates

	West			East		
	IV=1	IV=0	p-value°	IV=1	IV=0	p-value°
Log FT empl. growth rate	0.043	0.041	0.729	0.019	0.003	0.026**
Log full-time employment	5.091	5.203	0.077*	6.565	6.175	0.006***
Log mean wage	4.370	4.384	0.448	4.112	4.093	0.307
Share high-skilled (occ.)	0.102	0.111	0.182	0.148	0.141	0.797
Share high-qual. (educ.)	0.027	0.031	0.584	0.066	0.061	0.351

*p<0.1, **p<0.05, ***p<0.01. °Net of district fixed effects.

Data source: Broadband Atlas Germany, Deutsche Telekom, BHP7510 v1

In the Western German sample, municipalities above the distance threshold have lower employment levels than municipalities below the threshold. At first sight, this casts doubt on the exogeneity of the threshold instrument. However, there is a simple and plausible explanation for this observed difference that does not invalidate the underlying logic of the instrument: Municipalities above the threshold are expected to be even more remote than those below the threshold, simply because MDFs need some kind of physical infrastructure, and therefore must be near buildings or roads, which means they must be marginally closer also to workplaces. Hence, it is no surprise to find that municipalities more distant from their MDF have somewhat lower employment levels. In contrast, there are no significant differences in important employment structure variables such as the share of high-qualified workers and the wage level, showing that the two kinds of municipalities do not differ markedly in terms of labor market outcomes.

In the Eastern sample, OPAL areas are larger (in terms of employment) than other municipalities. Again, this finding is no surprise, because the few OPAL areas include some of Eastern Germany's largest cities, e.g. Dresden and Leipzig.[16] Furthermore,

[16] Note that Berlin is not contained in the Eastern German estimation sample (see section on sample restrictions in the Appendix).

the technologically disadvantaged OPAL areas had disproportionately high (!) employment growth rates in 1999. Although I control for municipality-level employment growth in the regressions, this finding calls for a somewhat more cautious interpretation of the findings for Eastern Germany.

All things considered, both IV approaches fall short of a perfect randomization of municipalities. However, the imbalances are small, take on expected signs, and can be accounted for by controlling for the respective covariates. Note, furthermore, that all variables in Table 2 are measured at the municipality level, while the employment growth analysis is conducted at the establishment level. Conditional on the municipality-level and establishment-level controls, the found imbalances thus should not severely impair the identification of establishment-level effects.

7 Results

7.1 Main results

In the following, estimation results are represented mainly for four subsamples. The first sample split is between Western and Eastern Germany, due to the different identification strategies and the systematic geographic difference between both subsamples (rural for Western Germany, urban for Eastern Germany). The second split is between the manufacturing and service sectors, for which heterogeneous effects have been found in most previous studies.

To begin with, I run OLS regressions as a baseline against which the IV regressions can be interpreted. Table 3 reports estimates for the Western German manufacturing sector. The employment growth coefficient of DSL availability is negative but only marginally significant, unless year fixed effects are controlled for. The year dummies (omitted for brevity) plausibly indicate that employment growth rates were significantly lower between 2008 and 2010 than between 2005 and 2008. Most other control variables also take on plausible signs. In particular, establishments with relatively high wages and high shares of high-skilled employees grow at faster rates. Furthermore, establishments in municipalities with relatively high employment density grow significantly slower (remember, however, that even these are rather rural municipalities, and that district fixed effects are controlled for). For the Western German service sector, the OLS estimates in Table 4 also indicate that DSL expansion had no effect on employment growth. Again, however, including year dummies changes the DSL coefficient substantially, and though insignificant at standard confidence levels, it indicates a positive relationship.

Table 3
OLS, West, manufacturing

Log employment growth rate	(1)	(2)	(3)	(4)	(5)	(6)
DSL availability	-0.026	-0.039*	-0.028	-0.000	0.002	0.004
	(-1.292)	(-1.928)	(-1.373)	(-0.002)	(0.125)	(0.177)
Log full-time empl. (estab.)		0.004*	0.005**	0.005**	0.001	-0.004
		(1.690)	(2.042)	(2.192)	(0.231)	(-1.597)
Log median wage (estab.)		0.008	0.008	0.008	0.022	0.051***
		(0.551)	(0.647)	(0.620)	(1.574)	(4.469)
Young estab.		-0.002	0.004	-0.003	-0.003	-0.010
		(-0.161)	(0.352)	(-0.294)	(-0.289)	(-0.997)
Mid-age estab.		-0.000	0.002	0.001	-0.003	-0.006
		(-0.016)	(0.215)	(0.158)	(-0.403)	(-0.946)
Share high-skilled (occ.)		0.040	0.060**	0.061**	0.056*	0.074***
		(1.384)	(2.024)	(2.025)	(1.845)	(2.681)
Log FT empl., municip.			0.003	0.003	0.003	0.004
			(0.989)	(0.911)	(0.773)	(1.165)
Log FT empl. dens., municip.			-0.009**	-0.008**	-0.008**	-0.011***
			(-2.407)	(-2.302)	(-2.186)	(-2.598)
Log mean wage (FT), municip.			0.016	0.003	-0.007	0.013
			(0.643)	(0.107)	(-0.356)	(0.637)
Log full-time empl. growth rate, municip.			0.036	0.031	0.009	-0.013
			(1.273)	(1.053)	(0.361)	(-0.540)
Share high-skilled (occ.), municip.			-0.067	-0.043	-0.036	0.017
			(-1.470)	(-0.937)	(-0.825)	(0.433)
Year FE				Yes	Yes	Yes
Industry FE (3-digit)					Yes	Yes
District FE						Yes
Observations	14823	14823	14823	14823	14823	14823
Adjusted R^2	0.000	0.006	0.008	0.017	0.043	0.065

t statistics in parentheses. * p<0.10, ** p<0.05, *** p<0.01. Constant omitted from output. Standard errors clustered at the municipality level.

Data source: Broadband Atlas Germany, BHP7510 v1

Table 4
OLS, West, services

Log employment growth rate	(1)	(2)	(3)	(4)	(5)	(6)
DSL availability	-0.020	-0.021	0.009	0.043	0.048*	0.045
	(-0.630)	(-0.690)	(0.342)	(1.530)	(1.679)	(1.613)
Log full-time empl. (estab.)		-0.002	0.001	0.001	0.001	-0.001
		(-0.409)	(0.434)	(0.448)	(0.392)	(-0.595)
Log median wage (estab.)		0.018	0.012	0.014	0.012*	0.015**
		(1.426)	(1.487)	(1.645)	(1.656)	(2.569)
Young estab.		0.033***	0.035***	0.022**	0.026**	0.023*
		(4.165)	(4.271)	(2.416)	(2.377)	(1.932)
Mid-age estab.		0.015*	0.014**	0.014**	0.011*	0.007
		(1.956)	(1.987)	(2.031)	(1.799)	(1.344)
Share high-skilled (occ.)		0.011	0.017	0.017	0.014	0.014
		(0.758)	(1.278)	(1.225)	(1.069)	(1.115)
Log FT empl., municip.			0.000	0.000	-0.001	-0.004
			(0.038)	(0.067)	(-0.365)	(-1.018)
Log FT empl. dens., municip.			-0.017***	-0.016***	-0.012***	-0.008**
			(-3.175)	(-3.192)	(-3.046)	(-2.004)
Log mean wage (FT), municip.			0.083*	0.068	0.067*	0.097**
			(1.699)	(1.538)	(1.749)	(2.241)
Log full-time empl. growth rate, municip.			0.016	0.030	0.019	0.009
			(0.221)	(0.395)	(0.247)	(0.120)
Share high-skilled (occ.), municip.			-0.038	-0.021	-0.007	-0.014
			(-0.592)	(-0.344)	(-0.144)	(-0.357)
Year FE				Yes	Yes	Yes
Industry FE (3-digit)					Yes	Yes
District FE						Yes
Observations	18650	18650	18650	18650	18650	18650
Adjusted R^2	0.000	0.004	0.011	0.025	0.042	0.056

t statistics in parentheses. * p<0.10, ** p<0.05, *** p<0.01. Constant omitted from output. Standard errors clustered at the municipality level.

Data source: Broadband Atlas Germany, BHP7510 v1

Table 5
OLS, East, manufacturing

Log employment growth rate	(1)	(2)	(3)	(4)	(5)	(6)
DSL availability	0.008	0.002	-0.001	0.013	0.012	0.021
	(0.576)	(0.143)	(-0.089)	(0.898)	(0.997)	(1.562)
Log full-time empl. (estab.)		0.005***	0.005***	0.005***	0.001	-0.000
		(3.050)	(2.760)	(2.592)	(0.361)	(-0.211)
Log median wage (estab.)		0.000	-0.003	-0.003	0.004	0.007
		(0.034)	(-0.388)	(-0.348)	(0.452)	(0.796)
Young estab.		0.014	0.014	-0.002	-0.003	-0.003
		(1.351)	(1.285)	(-0.162)	(-0.274)	(-0.257)
Mid-age estab.		0.002	0.002	-0.008	-0.009*	-0.010*
		(0.368)	(0.386)	(-1.469)	(-1.689)	(-1.825)
Share high-skilled (occ.)		0.027***	0.030***	0.031***	0.028*	0.023
		(2.817)	(3.281)	(3.332)	(1.853)	(1.524)
Log FT empl., municip.			-0.003	-0.002	0.002	-0.002
			(-1.079)	(-0.691)	(0.806)	(-0.517)
Log FT empl. dens., municip.			0.001	0.000	-0.003	-0.001
			(0.347)	(0.063)	(-0.954)	(-0.204)
Log mean wage (FT), municip.			0.032	0.023	-0.002	0.018
			(1.413)	(0.986)	(-0.112)	(0.789)
Log full-time empl. growth rate, municip.			0.056	0.070*	0.059*	0.049
			(1.626)	(1.871)	(1.667)	(1.371)
Share high-skilled (occ.), municip.			-0.007	-0.013	-0.008	0.009
			(-0.144)	(-0.267)	(-0.194)	(0.220)
Year FE				Yes	Yes	Yes
Industry FE (3-digit)					Yes	Yes
District FE						Yes
Observations	24138	24138	24138	24138	24138	24138
Adjusted R^2	0.000	0.005	0.005	0.012	0.026	0.032

t statistics in parentheses. * p<0.10, ** p<0.05, *** p<0.01. Constant omitted from output. Standard errors clustered at the municipality level.

Data source: Broadband Atlas Germany, BHP7510 v1

Table 6
OLS, East, services

Log employment growth rate	(1)	(2)	(3)	(4)	(5)	(6)
DSL availability	-0.004	-0.006	-0.002	0.009	0.010	0.012
	(-0.527)	(-0.704)	(-0.271)	(1.104)	(1.250)	(1.437)
Log full-time empl. (estab.)		-0.000	0.000	0.001	0.001	0.001
		(-0.023)	(0.083)	(0.337)	(0.688)	(0.558)
Log median wage (estab.)		0.009*	0.009*	0.007	0.011	0.010
		(1.728)	(1.666)	(1.412)	(1.596)	(1.469)
Young estab.		-0.012	-0.012	-0.026***	-0.019**	-0.017**
		(-1.421)	(-1.442)	(-2.995)	(-2.264)	(-1.977)
Mid-age estab.		-0.001	-0.002	-0.009	-0.009*	-0.010*
		(-0.321)	(-0.372)	(-1.625)	(-1.696)	(-1.803)
Share high-skilled (occ.)		-0.001	-0.002	-0.001	-0.006	-0.006
		(-0.151)	(-0.176)	(-0.099)	(-0.357)	(-0.385)
Log FT empl., municip.			-0.001	0.000	0.002	0.003
			(-0.325)	(0.170)	(0.774)	(1.011)
Log FT empl. dens., municip.			-0.004	-0.004	-0.005*	-0.004
			(-1.318)	(-1.394)	(-1.669)	(-1.487)
Log mean wage (FT), municip.			0.033	0.013	0.006	0.003
			(1.435)	(0.564)	(0.296)	(0.140)
Log full-time empl. growth rate, municip.			-0.004	0.054*	0.047	0.030
			(-0.167)	(1.820)	(1.630)	(1.109)
Share high-skilled (occ.), municip.			0.028	0.027	0.040	0.006
			(0.639)	(0.605)	(1.068)	(0.182)
Year FE				Yes	Yes	Yes
Industry FE (3-digit)					Yes	Yes
District FE						Yes
Observations	48753	48753	48753	48753	48753	48753
Adjusted R^2	-0.000	0.000	0.001	0.009	0.015	0.019

t statistics in parentheses. * p<0.10, ** p<0.05, *** p<0.01. Constant omitted from output. Standard errors clustered at the municipality level.

Data source: Broadband Atlas Germany, BHP7510 v1

For Eastern German establishments, there is no clear indication of a significant effect of DSL on employment growth; moreover, the DSL coefficient does not differ noticeably between manufacturing (Table 5) and services (Table 6). Using the most comprehensive specification (column 6) and considering services in particular, I unexpectedly find negative employment growth coefficients for medium-aged (5-10 years) and even for young (<5 years) establishments, as opposed to older establishments. This finding might be due to reduced opportunities for business expansion in the course of the financial crisis of 2008-2009. However, model fit is rather poor for the Eastern sample. A potential reason for this pattern might be the more urban geographic structure of the Eastern sample, meaning that this sample contains a greater diversity of establishments and hence, a larger variation of employment growth, some of which may be explained by unobserved factors. Overall, thus, the estimated specification appears more appropriate and plausible for the Western German sample.

The small and insignificant results obtained with OLS may indicate that there is no relationship between DSL availability and establishment-level employment growth. However, the OLS estimates may also be biased towards zero due to measurement error in the explanatory variable, as discussed above. Therefore, I turn to the IV estimates in the following. For the Western sample, I find a significantly negative (positive) employment growth effect of DSL for manufacturing (service) establishments, see Table 7 and Table 8. That is, the IV estimates broadly point in the same direction as the corresponding OLS estimates, but are larger (in absolute terms) and more precisely estimated, potentially due to measurement error in the DSL variable. The estimated coefficients imply that a 10 percentage point increase in DSL availability decreases the average employment growth rate of manufacturers by 2.4 percent, and increases that of service firms by 3.3 percent. The first-stage estimates indicate that the instrument is strong, with F statistics always above the threshold value of ten proposed by Stock et al., (2002). Furthermore, a modified version of the Durbin-Wu-Hausman test of regressor exogeneity[17] suggests that the DSL variable is indeed endogenous and hence, OLS estimates are biased.

For the Eastern sample, I find no significant effects of DSL availability on employment growth (see Table 9 and Table 10). Furthermore, the OPAL instrument is less strong, surpassing the conventional threshold of ten only in the more comprehensive specifications. Finally, the test of exogeneity yields insignificant results, suggesting that DSL availability can be considered as exogenous (given that the OPAL dummy is a valid IV). In any case, the findings indicate that there is no significant employment growth effect of DSL in Eastern German establishments. I therefore disregard the Eastern sample for the remainder of the analysis.

[17] Due to the clustering of the variance-covariance matrix, a robust score test by Wooldridge (1995) is performed by the software used for estimation (Stata).

Table 7
IV, West, manufacturing

Log employment growth rate	(1)	(2)	(3)	(4)	(5)	(6)
Second stage						
DSL availability	-0.157*	-0.187**	-0.125	-0.134	-0.162*	-0.237**
	(-1.69)	(-2.20)	(-1.36)	(-1.49)	(-1.87)	(-2.30)
Establishment controls		Yes	Yes	Yes	Yes	Yes
Municipality controls			Yes	Yes	Yes	Yes
Year FE				Yes	Yes	Yes
Industry FE (3-digit)					Yes	Yes
District FE						Yes
Observations	14823	14823	14823	14823	14823	14823
Adjusted R^2	.[a]	.[a]	0.002	0.007	0.030	0.044
First stage						
Adj. R-sq.	0.070	0.090	0.115	0.263	0.342	0.456
Robust F stat.	27.587	31.751	19.221	21.021	42.273	54.294
Prob>F	0.000	0.000	0.000	0.000	0.000	0.000
Test of endogeneity p-value	0.113	0.052	0.254	0.082	0.044	0.012

t statistics in parentheses. * p<0.10, ** p<0.05, *** p<0.01. Constant omitted from output. Standard errors clustered at the municipality level. [a]Not reported because model sum of squares is negative, a problem often arising in 2SLS estimation.

Data source: Broadband Atlas Germany, Deutsche Telekom, BHP7510 v1

Table 8
IV, West, services

Log employment growth rate	(1)	(2)	(3)	(4)	(5)	(6)
Second stage						
DSL availability	-0.028	-0.049	0.284**	0.259**	0.306***	0.325***
	(-0.27)	(-0.45)	(2.36)	(2.30)	(2.64)	(3.14)
Establishment controls		Yes	Yes	Yes	Yes	Yes
Municipality controls			Yes	Yes	Yes	Yes
Year FE				Yes	Yes	Yes
Industry FE (3-digit)					Yes	Yes
District FE						Yes
Observations	18650	18650	18650	18650	18650	18650
Adjusted R^2	0.000	0.004	.[a]	0.007	0.018	0.034
First stage						
Adj. R-sq.	0.060	0.068	0.122	0.210	0.246	0.404
Robust F stat.	32.732	33.754	14.930	16.638	14.869	28.646
Prob>F	0.000	0.000	0.000	0.000	0.000	0.000
Test of endogeneity p-value	0.931	0.775	0.011	0.034	0.009	0.002

t statistics in parentheses. * p<0.10, ** p<0.05, *** p<0.01. Constant omitted from output. Standard errors clustered at the municipality level. [a]Not reported because model sum of squares is negative, a problem often arising in 2SLS estimation.

Data source: Broadband Atlas Germany, Deutsche Telekom, BHP7510 v1

Table 9
IV, East, manufacturing

Log employment growth rate	(1)	(2)	(3)	(4)	(5)	(6)
Second stage						
DSL availability	0.172	0.156	0.107	0.082	-0.019	-0.000
	(1.33)	(0.98)	(1.13)	(1.00)	(-0.20)	(-0.00)
Establishment controls		Yes	Yes	Yes	Yes	Yes
Municipality controls			Yes	Yes	Yes	Yes
Year FE				Yes	Yes	Yes
Industry FE (3-digit)					Yes	Yes
District FE						Yes
Observations	24138	24138	24138	24138	24138	24138
Adjusted R^2	.[a]	.[a]	.[a]	0.008	0.026	0.032
First stage						
Adj. R-sq.	0.009	0.070	0.165	0.273	0.323	0.405
Robust F stat.	4.342	3.256	10.310	11.699	12.415	22.792
Prob>F	0.037	0.071	0.001	0.001	0.000	0.000
Test of endogeneity p-value	0.121	0.238	0.230	0.379	0.753	0.777

t statistics in parentheses. * p<0.10, ** p<0.05, *** p<0.01. Constant omitted from output. Standard errors clustered at the municipality level. [a]Not reported because model sum of squares is negative, a problem often arising in 2SLS estimation.

Data source: Broadband Atlas Germany, Deutsche Telekom, BHP7510 v1

Table 10
IV, East, services

Log employment growth rate	(1)	(2)	(3)	(4)	(5)	(6)
Second stage						
DSL availability	-0.161	-0.121	-0.034	-0.043	-0.057	-0.104
	(-0.19)	(-0.14)	(-0.30)	(-0.39)	(-0.50)	(-1.25)
Establishment controls		Yes	Yes	Yes	Yes	Yes
Municipality controls			Yes	Yes	Yes	Yes
Year FE				Yes	Yes	Yes
Industry FE (3-digit)					Yes	Yes
District FE						Yes
Observations	48753	48753	48753	48753	48753	48753
Adjusted R^2	.[a]	.[a]	-0.000	0.007	0.012	0.012
First stage						
Adj. R-sq.	0.000	0.027	0.139	0.261	0.275	0.386
Robust F stat.	0.104	0.083	4.711	5.271	4.645	14.427
Prob>F	0.748	0.773	0.030	0.022	0.031	0.000
Test of endogeneity p-value	0.811	0.873	0.772	0.622	0.535	0.101

t statistics in parentheses. * p<0.10, ** p<0.05, *** p<0.01. Constant omitted from output. Standard errors clustered at the municipality level. [a]Not reported because model sum of squares is negative, a problem often arising in 2SLS estimation.

Data source: Broadband Atlas Germany, Deutsche Telekom, BHP7510 v1

7.2 Knowledge- and computer-intensive industries

The results obtained so far raise the question why the employment growth effects of DSL differ between the manufacturing and service sectors. Since the proposed channel of these effects is the actual use of DSL in establishments, the main reason might be that service firms are more intense users of DSL. Akerman et al. (2015) explicitly test this channel of effects, failing to falsify it against a number of likely alternatives. Thus, the positive employment growth effect of DSL in the service sector might be driven by firms for which information is a key input and ICT is a key technology. To see whether this explanation is sound, I re-run the above IV regressions for two subsets of industries. First, I consider knowledge-intensive industries as defined by Eurostat (2016).[18] Second, I consider a subsample of computer-intensive industries, splitting the sample at the median of an index defined by Falck et al. (2016). This index is based on the PIAAC survey of adult competencies conducted by the OECD, and it reflects the intensity of computer use by workers in the respective industry.[19] As indicated by Table 11, 87 percent of the establishment observations in the Western German sample classified as knowledge-intensive are active in the service sector. Overall, only 17.5 percent of the establishments are considered as knowledge-intensive. In contrast, just 55 percent of the establishments with above-median computer use intensity belong to the service sector.

Table 11
Knowledge- and computer-use intensity by sector

frequency
row percentage
column percentage

	Knowledge intensity			Computer use intensity		
Sector	Non-KI	KI	Total	<median	≥ median	Total
Manufacturing	14,068	755	14,823	6,883	7,940	14,823
	94.91	**5.09**	**100.00**	**46.43**	**53.57**	**100.00**
	50.96	*12.87*	*44.28*	*43.75*	*44.76*	*44.28*
Services	13,537	5,113	18,650	8,850	9,800	18,650
	72.58	**27.42**	**100.00**	**47.45**	**52.55**	**100.00**
	49.04	*87.13*	*55.72*	*56.25*	*55.24*	*55.72*
Total	27,605	5,868	33,473	15,733	17,740	33,473
	82.47	**17.53**	**100.00**	**47.00**	**53.00**	**100.00**
	100.00	*100.00*	*100.00*	*100.00*	*100.00*	*100.00*

Data source: BHP7510 v1

[18] See Annex 7 “Knowledge Intensive Activities by NACE Rev.1.1” in Eurostat (2016).

[19] PIAAC stands for Programme for the International Assessment of Adult Competencies. The computer use index indicates the frequency with which employees conduct the following tasks at work: Creating or reading spreadsheets; using word-processing software; using programming language; engaging in computer-aided real-time discussions.

Table 12
IV second stage, West, knowledge-intensive industries

Log employment growth rate	(1)	(2)	(3)
DSL availability	0.381*	0.253	0.616***
	(1.86)	(1.39)	(3.12)
Establishment controls	Yes	Yes	Yes
Municipality controls	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Industry FE (3-digit)		Yes	Yes
District FE			Yes
Observations	5868	5868	5868
Adjusted R^2	0.079	0.114	0.135

t statistics in parentheses. * p<0.10, ** p<0.05, *** p<0.01. Constant omitted from output. Standard errors clustered at the municipality level.

Data source: Broadband Atlas Germany, Deutsche Telekom, BHP7510 v1

Table 13
IV second stage, West, computer-intensive industries

Log employment growth rate	(1)	(2)	(3)
DSL availability	0.237**	0.273**	0.273***
	(2.18)	(2.46)	(3.38)
Establishment controls	Yes	Yes	Yes
Municipality controls	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Industry FE (3-digit)		Yes	Yes
District FE			Yes
Observations	17740	17740	17740
Adjusted R^2	0.014	0.026	0.045

t statistics in parentheses. * p<0.10, ** p<0.05, *** p<0.01. Constant omitted from output. Standard errors clustered at the municipality level.

Data source: Broadband Atlas Germany, Deutsche Telekom, BHP7510 v1

As one might expect, the employment growth effect of DSL availability is largest (and model fit is best) in the small subsample of knowledge-intensive industries (Table 12). Since these industries cluster in the service sector, the overall positive effect in this sector is likely to be driven by knowledge-intensive industries. Regarding computer use, the relatively broad subsample considered in Table 13 consists of 45 percent manufacturing establishment observations. Nevertheless, I also find a robustly positive employment growth effect for this subsample, similar in magnitude to the service-sector estimates. These results suggest that the sectoral effect heterogeneity (already found in numerous previous studies) is likely driven by differences in knowledge intensity and computer use. More importantly, this pattern of results supports the interpretation that broadband availability affects employment growth through broadband use, meaning also that the estimated intention-to-treat effects are a suitable proxy for the effect of broadband use on employment growth.

7.3 Robustness checks

To assess the robustness of the findings obtained so far, I first test whether the estimates are sensitive to the measurement problem inherent to the distance-based IV approach. Every municipality had to be assigned a value of zero or one for the IV, depending on the distance between its centroid and the MDF. Regarding individual establishments, thus, this distance was necessarily measured with error. If a municipality's centroid is just above or just below the threshold, a substantial share of establishments may be assigned a wrong value for the IV. To tackle this issue, I consider two alternative approaches to measuring distance to the MDF, respectively, the degree to which a municipality is subject to technical obstacles. First, following Falck et al. (2014), I use a distance measure based on the municipality's population-weighted centroid, rather than its geographic centroid.[20] Thus, 13 percent of the Western German municipalities change status, mostly from being classified as above the threshold to being classified as below the threshold. This pattern is plausible because MDFs are located in buildings or other man-made structures, and therefore must be closer to the population-weighted than the geographic centroid. For the same reason, when using the population-weighted centroid, slightly more municipalities are found to be less than 4.2 km distant from their nearest (but not their assigned) MDF. As before, I drop these municipalities, resulting in a slightly smaller sample than in the previous estimations.

Second, I replace the threshold-dummy IV by the share of the municipality's land area that is more than 4.2 km distant from the assigned MDF, where distance is measured from the geographic municipality threshold.[21] The relationship between this variable and DSL availability is illustrated in Figure 5, which shows a significant negative relationship between municipalities' area share above the threshold and DSL availability. In particular, as the share of area above the threshold approaches 100 percent, DSL availability drops drastically. This is a plausible pattern: If almost the entire municipality is above the threshold, then so must be the households in the municipality, for whom DSL availability is measured. In contrast, if a substantial (but not extremely high) share of the municipality's area is above the threshold, this does not necessarily apply to the households, but possibly only to uninhabited territory. Furthermore, the graph reveals that extremely few municipalities are entirely above the distance threshold (taking on the value one on the horizontal axis). This finding reflects the dense and even distribution of MDFs across the country, and thus the exogenous location of MDFs. The share of area above the distance threshold thus should be a relevant instrument. Yet, there is no reason to prefer it over the main IV (the binary threshold dummy), since the land area too far from the MDF may not be representative of the area where most establishment are located. Nevertheless, if the 4.2 km threshold is a meaningful source of exogenous variation in DSL availability, then both the binary and the continuous IV should yield similar estimates.

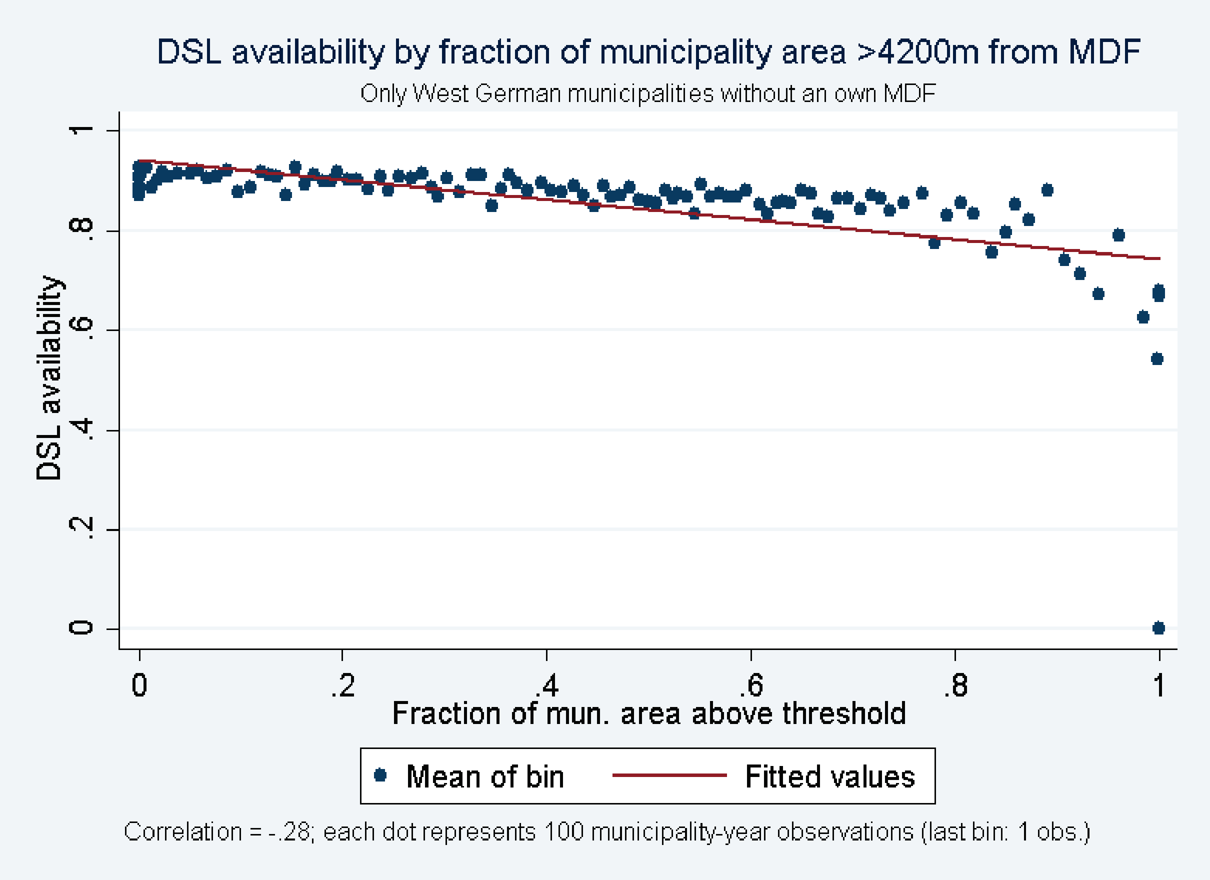
By and large, the estimates from both robustness exercises are in line with the main results (see Table 14 and Table 15). Though not statistically significant at conventional levels for manufacturing establishments, the estimated effects of DSL availability take on the same signs as in the main IV regressions, and do not differ substantially in terms of magnitude, at least for the most restrictive specification (column 3). Therefore, the estimates based on the binary

[20] For details on the identification of population-weighted centroids, see Falck et al. (2014), who use the same data on DSL availability and MDF locations.

[21] On average, for municipalities above the threshold, 70 percent of the municipality area are actually more than 4.2 km distant from the assigned MDF. Similarly, for municipalities classified as below the threshold, 74 percent of the municipality area is actually below the threshold.

distance-threshold IV are not driven by the peculiar measurement of distance between 'the municipality' and the MDF.

Figure 5
DSL availability by fraction of municipality area >4200m from the MDF



Data source: Broadband Atlas Germany, Deutsche Telekom, BHP7510 v1

Table 14
Robustness check, West: Population-weighted centroid IV

	Manufacturing			Services		
Log employment growth rate	(1)	(2)	(3)	(1)	(2)	(3)
Second stage						
DSL availability	-0.023	-0.085	-0.143	0.113	0.165	0.194**
	(-0.26)	(-1.04)	(-1.50)	(0.90)	(1.46)	(2.18)
Establishment controls	Yes	Yes	Yes	Yes	Yes	Yes
Municipality controls	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Industry FE (3-digit)		Yes	Yes		Yes	Yes
District FE			Yes			Yes
Observations	14029	14029	14029	17706	17706	17706
Adjusted R^2	0.017	0.041	0.060	0.024	0.038	0.052
First stage						
Adj. R-sq.	0.252	0.348	0.463	0.208	0.249	0.410
Robust F stat.	11.405	25.771	42.424	13.784	14.966	30.665
Prob>F	0.001	0.000	0.000	0.000	0.000	0.000
Test of endogeneity p-value	0.792	0.253	0.117	0.586	0.288	0.074

t statistics in parentheses. * p<0.10, ** p<0.05, *** p<0.01. Constant omitted from output. Standard errors clustered at the municipality level.

Data source: Broadband Atlas Germany, Deutsche Telekom, BHP7510 v1

Table 15
Robustness check, West: Share of area IV

	Manufacturing			Services		
Log employment growth rate	(1)	(2)	(3)	(1)	(2)	(3)
Second stage						
DSL availability	-0.026	-0.095	-0.053	0.032	0.106	0.225***
	(-0.28)	(-1.29)	(-0.74)	(0.29)	(1.11)	(2.87)
Establishment controls	Yes	Yes	Yes	Yes	Yes	Yes
Municipality controls	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Industry FE (3-digit)		Yes	Yes		Yes	Yes
District FE			Yes			Yes
Observations	14823	14823	14823	18650	18650	18650
Adjusted R^2	0.016	0.038	0.064	0.025	0.041	0.047
First stage						
Adj. R-sq.	0.264	0.356	0.461	0.245	0.275	0.427
Robust F stat.	16.710	34.463	33.837	17.653	18.604	35.465
Prob>F	0.000	0.000	0.000	0.000	0.000	0.000
Test of endogeneity p-value	0.784	0.167	0.444	0.912	0.534	0.010

t statistics in parentheses. * p<0.10, ** p<0.05, *** p<0.01. Constant omitted from output. Standard errors clustered at the municipality level.

Data source: Broadband Atlas Germany, Deutsche Telekom, BHP7510 v1

Another robustness check addresses the specific pattern of variation in the explanatory variable. The IV estimates are largely based on spatial variation in DSL availability (because the instruments are time-constant), while OLS uses more intertemporal variation in DSL availability. As argued above, IV is still likely to yield more accurate estimates since it alleviates problems of measurement error in DSL availability. One might object nevertheless that the IV estimates inflate the true effect of broadband on employment growth, since the IV model regresses annual employment growth rates on values of DSL availability which exhibit relatively little intertemporal variation. To address this concern, I estimate an alternative version of the main specification:

$$\ln\left(\frac{L_{it+5}}{L_{it}}\right) = \beta_0 + \beta_1 \widehat{DSL}_{mt} + \boldsymbol{\beta_2 X_{it}} + \boldsymbol{\beta_3 X'_{mt}} + \theta_c + \vartheta_j + \varepsilon_{it}, \quad (3)$$

where t = 2005. That is, instead of using the year-to-year employment growth rate (and hence five annual slices of data), I construct the employment growth rate between the beginning and end of the observation period of employment (i.e. between 2005 and 2010). The regression therefore uses only one observation per establishment (and disregards establishments not observed both in 2005 and 2010). If the IV approach truly captures the causal relationship between DSL availability and employment growth, then the estimates from this regression should be qualitatively similar to the main results.

The results of this robustness exercise are displayed in Table 16, panel A. For the service sector, the estimates confirm the significant positive effect of broadband on employment growth. In terms of magnitude, the coefficient is considerably larger – as one would expect, since it measures the effect of DSL availability in 2005 on employment growth between 2005 and 2010. For the manufacturing sector, however, the effect is virtually zero. This finding is most likely due to the negative shock of the global financial crisis in 2008/2009, which hit the export-oriented German manufacturing sector particularly hard. Figure 6 displays the mean annual employment growth rates for the Western German sample establishments of both sectors, showing that manufacturers suffered particularly sharp employment decreases and returned less quickly to normal growth rates than service firms. Thus, manufacturers experienced near-zero employment growth rates over the period 2005-2010 (on average, 0.8 percent, compared to 6.3 percent for services). Therefore, this five-year interval is a questionable time frame to assess employment growth effects for the manufacturing sector. I therefore estimate equation (3) also for the employment growth rate between 2005 and 2007, i.e. in "normal" times (Table 16, panel B).[22] The manufacturing-sector estimates remain insignificant, but clearly move towards a consistently negative effect for all specifications. Thus, the main IV results for manufacturers are broadly confirmed, but turn out less robust overall than the results for service establishments.

[22] Note that this shorter observation window yields a slightly larger sample, since there is now a larger number of establishments observed at both the beginning and end of the observation period.

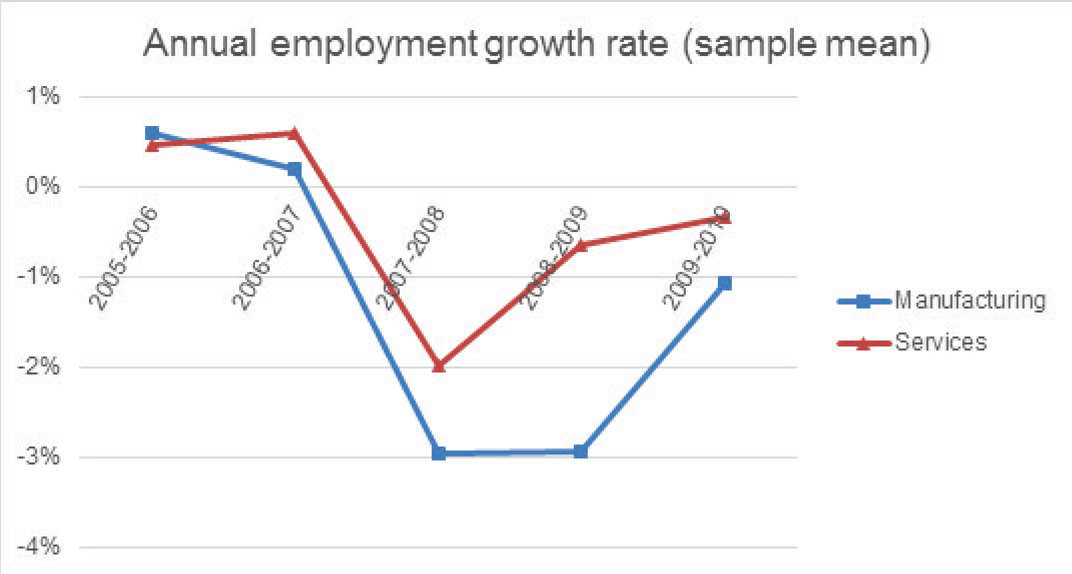
Table 16
Robustness check, West: long-run employment growth rates

	Manufacturing			Services		
A: 2005-2010	(1)	(2)	(3)	(1)	(2)	(3)
Second stage						
DSL availability	0.826	0.236	-0.505	1.620*	1.708*	0.923*
	(0.47)	(0.27)	(-0.72)	(1.66)	(1.91)	(1.84)
Establishment controls	Yes	Yes	Yes	Yes	Yes	Yes
Municipality controls	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Industry FE (3-digit)		Yes	Yes		Yes	Yes
District FE			Yes			Yes
Observations	2520	2520	2520	2983	2983	2983
Adjusted R^2	0.119	0.693	0.758	.[a]	.[a]	0.138
B: 2005-2007	(1)	(2)	(3)	(1)	(2)	(3)
Second stage						
DSL availability	-0.703	-0.777	-0.534	0.938	0.926*	0.877**
	(-1.30)	(-1.46)	(-1.34)	(1.58)	(1.66)	(2.05)
Establishment controls	Yes	Yes	Yes	Yes	Yes	Yes
Municipality controls	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Industry FE (3-digit)		Yes	Yes		Yes	Yes
District FE			Yes			Yes
Observations	2775	2775	2775	3379	3379	3379
Adjusted R^2	.[a]	.[a]	0.171	.[a]	0.204	0.307

t statistics in parentheses. * p<0.10, ** p<0.05, *** p<0.01. Constant omitted from output. Standard errors clustered at the municipality level. [a]Not reported because model sum of squares is negative, a problem often arising in 2SLS estimation.

Data source: Broadband Atlas Germany, Deutsche Telekom, BHP7510 v1

Figure 6
Annual employment growth rate by sector, West



Data source: BHP7510 v1

I report a number of further robustness checks in the Appendix. In Table A3, I drop the top percent of establishments in terms of size (full-time employment). These establishment observations have considerable weight in the above regressions, which are weighted by full-time employment. However, the results are not sensitive to removing these establishments. Only the manufacturing-sector estimates turn out lower and only marginally significant. The service-sector estimates barely move in size and significance. Furthermore, in Table A4 and Table A5 I use full-time, respectively full-time-equivalent, employment rather than total employment to construct the employment growth rate. Again, the results do not change substantially for most specifications. In the service sector, only the full-time equivalent (but not the full-time) employment growth rate reacts significantly to DSL availability. This deviating finding is probably due to a higher share of part-time workers (and hence a larger discrepancy between full-time and full-time equivalent employment) in services, which however makes full-time employment a less interesting outcome for service establishments in the first place.

To summarize the results, it can be stated that DSL availability appears to have accelerated employment growth in Western German service establishments. This effect is probably driven by knowledge-intensive industries, which concentrate in the service sector. Similarly, computer-intensive industries (which comprise also a substantial share of manufacturing industries) grew faster in response to the expansion of first-generation broadband. The manufacturing sector at large, in contrast, tended to experience negative growth effects, although the evidence is somewhat less robust for this sector. For Eastern Germany, the analysis did not find any statistically significant employment growth effects due to increased DSL availability.

8 Limitations and outlook

The main limitation of the results in this study concerns external validity: Do the effects found, in particular the findings for the sample of rural Western German municipalities, extend to urban Western Germany? This question is of interest because the bulk of establishments and employees are located in urban municipalities which are not included in the estimation sample, and because previous studies find different effects for rural and urban regions (where no consensus has been reached yet, see e.g. Fabritz, 2013 versus What Works Centre for Local Economic Growth, 2015). With the data at hand, I cannot address this question. The finding that knowledge- and computer-intensive industries are particularly (positively) affected by broadband expansion, however, seems likely to extend beyond the limited geographical scope of this paper.

Furthermore, given the available data, I can only investigate the effects of broadband availability on labor demand at the margin of employment, but not work hours. In the short run, which this analysis focuses on, broadband may not increase (or decrease) labor demand at both margins, let alone at the same time. Instead, adjustments of hours might take place before adjustments in the number of employees. The employment growth effects found above thus might understate the total short-run labor demand effects of broadband expansion. In the longer run, in contrast, broadband expansion in the sense of increasing availability is likely to be less important economically, and less relevant to policymakers, than the increasing bandwidths (data transfer rates) of existing broadband connections (see Ahlfeldt et al., forthcoming, for an assessment of bandwidth in the context of property value). Further research thus should consider newer generations of broadband technology.

Another interesting question raised by the results of this study is whether broadband expansion triggered a reallocation of employment from manufacturing towards services and knowledge- and computer-intensive industries. The data and methodology used in this study are a suitable base for investigating this question, but they would need to be complemented by individual-level or linked employer-employee data. Using such data, one could also investigate the skill heterogeneity of broadband effects in Germany – that is, whether broadband yields gains for the high-skilled and losses for the low-skilled (as found by Akerman et al., 2015). Furthermore, one might consider studying the heterogeneity of broadband effects with respect to age groups. Recent empirical studies point to an age bias in ICT proficiency, relevant for labor market outcomes, with young workers (“digital natives”) being more apt than older workers (Falck et al., 2016), and to an increased reallocation of young workers into ICT-intensive sectors (Autor and Dorn, 2009). Further research should explore these dimensions of effect heterogeneity.

9 Conclusion

This article investigates the effect of local broadband internet availability on the employment growth of German business establishments. To obtain credible causal estimates, technical frictions which impeded the rollout of broadband in rural Western Germany and urban Eastern Germany are used to construct instrumental variables (IVs) for broadband availability. In line with previous studies, the empirical findings for Western Germany provide evidence of a positive employment growth effect for service-sector establishments; in contrast, I find negative employment growth effects for manufacturers. Seeking to explain this divergence of effects, I find positive employment growth effects for knowledge- and computer-intensive industries, which tend to be concentrated in the service sector. This pattern of results likely reflects a higher importance of knowledge as a factor of production, and computers as a core technology, in the service sector.

For Eastern Germany, I find no significant employment growth effects of broadband expansion in either sector. This finding could be due to the different geographic structure of the Eastern German sample (which is much more urban than the Western German sample, by the design of the IV approach), but also to the differences in industrial structure and technological development between both parts of the country. The internal validity of the findings is supported by a number of robustness checks, including the use of alternative instruments. However, one can only speculate about external validity, that is, whether the significant employment growth effects found for rural Western Germany apply to urban Western Germany, too.

The findings raise questions to be addressed by further research, for instance whether the opposing employment growth effects for manufacturing and services reflect a reallocation of workers between the two sectors. This question calls for additional analyses at the individual level, which could also address individual-level effect heterogeneity, in particular, between skill and age groups. Related empirical studies suggest that the employment and wage gains from broadband expansion fall disproportionately to the high-skilled, and potentially also to younger workers. In this context, the German experience might be of particular interest to policymakers, given the importance of medium-skilled workers trained in the apprenticeship system, and the ageing German population.

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Appendix

Table A1
Summary statistics, Western sample

Establishment level	**count**	**mean**	**sd**	**min**	**max**
Log empl. growth rate	33473	-0.007	0.263	-1.099	0.827
Full-time employment	33473	9.840	36.765	1.000	1377.000
Log full-time empl. (estab.)	33473	1.247	1.179	0.000	7.228
Log median wage (estab.)	33473	4.157	0.499	2.306	5.246
Young estab.	33473	0.080	0.271	0.000	1.000
Mid-age estab.	33473	0.378	0.485	0.000	1.000
Share high-skilled (occ.)	33473	0.075	0.191	0.000	1.000
Dummy manufacturing	33473	0.443	0.497	0.000	1.000
Dummy services	33473	0.557	0.497	0.000	1.000
Municipality level					
DSL availability	10901	0.865	0.166	0.000	1.000
Distance to assigned MDF >4200m	10901	0.374	0.484	0.000	1.000
Distance to assigned MDF >4200m, pop.-w. centroid	10356	0.283	0.450	0.000	1.000
Fraction of municipality area >4200m from assigned MDF	10901	0.428	0.299	0.000	1.000
Log FT empl., municip.	10901	5.140	1.248	0.693	10.113
Log FT empl. dens., municip.	10901	2.527	1.224	-1.816	7.617
Log mean wage (FT), municip.	10901	4.339	0.172	2.913	5.137
Log full-time empl. growth rate, municip.	10901	0.004	0.144	-3.091	1.497
Share high-skilled (occ.), municip.	10901	0.118	0.077	0.000	0.649
Own MDF (yes/no)	10901	0.000	0.000	0.000	0.000
Distance to assigned MDF	10901	3875.177	1430.371	304.452	10200.920
Distance to assigned MDF, pop.-w. centroid	10901	3577.541	1557.988	25.692	10093.380
Distance to nearest MDF	10901	3744.732	1316.459	86.527	9988.840
Distance to nearest MDF, pop.-w. centroid	10901	3343.899	1362.057	25.692	9338.061

Data source: Broadband Atlas Germany, Deutsche Telekom, BHP7510 v1

Table A2
Summary statistics, Eastern sample

Establishment level	count	mean	sd	min	max
Log empl. growth rate	72891	-0.014	0.272	-1.099	0.827
Full-time employment	72891	10.855	41.330	1.000	3172.000
Log full-time empl. (estab.)	72891	1.336	1.211	0.000	8.062
Log median wage (estab.)	72891	3.912	0.468	2.306	5.208
Young estab.	72891	0.102	0.303	0.000	1.000
Mid-age estab.	72891	0.613	0.487	0.000	1.000
Share high-skilled (occ.)	72891	0.113	0.244	0.000	1.000
Dummy manufactur-ing	72891	0.331	0.471	0.000	1.000
Dummy services	72891	0.669	0.471	0.000	1.000
Municipality level	**count**	**mean**	**sd**	**min**	**max**
DSL availability	7774	0.755	0.282	0.000	1.000
OPAL municipalitiy	7774	0.105	0.306	0.000	1.000
OPAL area, pop.-w. centroid	7529	0.105	0.306	0.000	1.000
Fraction of municipal-ity area >4200m from assigned MDF	7774	0.340	0.221	0.000	1.000
Log FT empl., mu-nicip.	7774	5.974	1.593	0.693	11.963
Log FT empl. dens., municip.	7774	2.644	1.322	-1.688	6.182
Log mean wage (FT), municip.	7774	4.078	0.152	3.142	4.861
Log full-time empl. growth rate, municip.	7774	-0.009	0.128	-1.521	2.570
Share high-skilled (occ.), municip.	7774	0.147	0.076	0.000	0.620
Own MDF (yes/no)	7774	0.668	0.471	0.000	1.000
Distance to assigned MDF	7774	2297.083	1494.680	75.316	12144.847
Distance to assigned MDF, pop.-w. centroid	7774	1978.502	1856.296	26.243	14080.074
Distance to nearest MDF	7774	2084.063	1133.629	47.045	4199.971
Distance to nearest MDF, pop.-w. centroid	7774	1604.050	1342.296	26.243	5983.694

Data source: Broadband Atlas Germany, Deutsche Telekom, BHP7510 v1

Sample restrictions

The samples of establishments I use are based on a ten percent random sample from all establishments observed in the BHP between 2005 and 2009. I restrict this sample as follows. First, I exclude establishments which appear in the BHP for the first time in 2005 or later, since these may have been attracted to their particular location exactly because of broadband availability. To do so, I use the BHP's information on the first appearance of each establishment ID. These are the establishment ID entry variable created by Hethey and Schmieder (2010) and the first appearance date of the ID.

Furthermore, I limit the sample to establishment observations with at least one full-time employee, since only for these, the establishment's median gross daily wage, an important control variable, is observed (the IAB data do not contain precise working hours or hourly wages). I also check for implausible values and outliers in important establishment characteristics, dropping some rare establishment observations with a reported median daily wage for full-time workers below 10 Euros (this concerns less than one percent of establishment observations). Such implausibly low values can arise if a substantial fraction of an establishment's workers (typically in very small establishments) hold a position but are not actively working, as is the case during sickness leave (after six weeks), maternity leave, or sabbaticals.

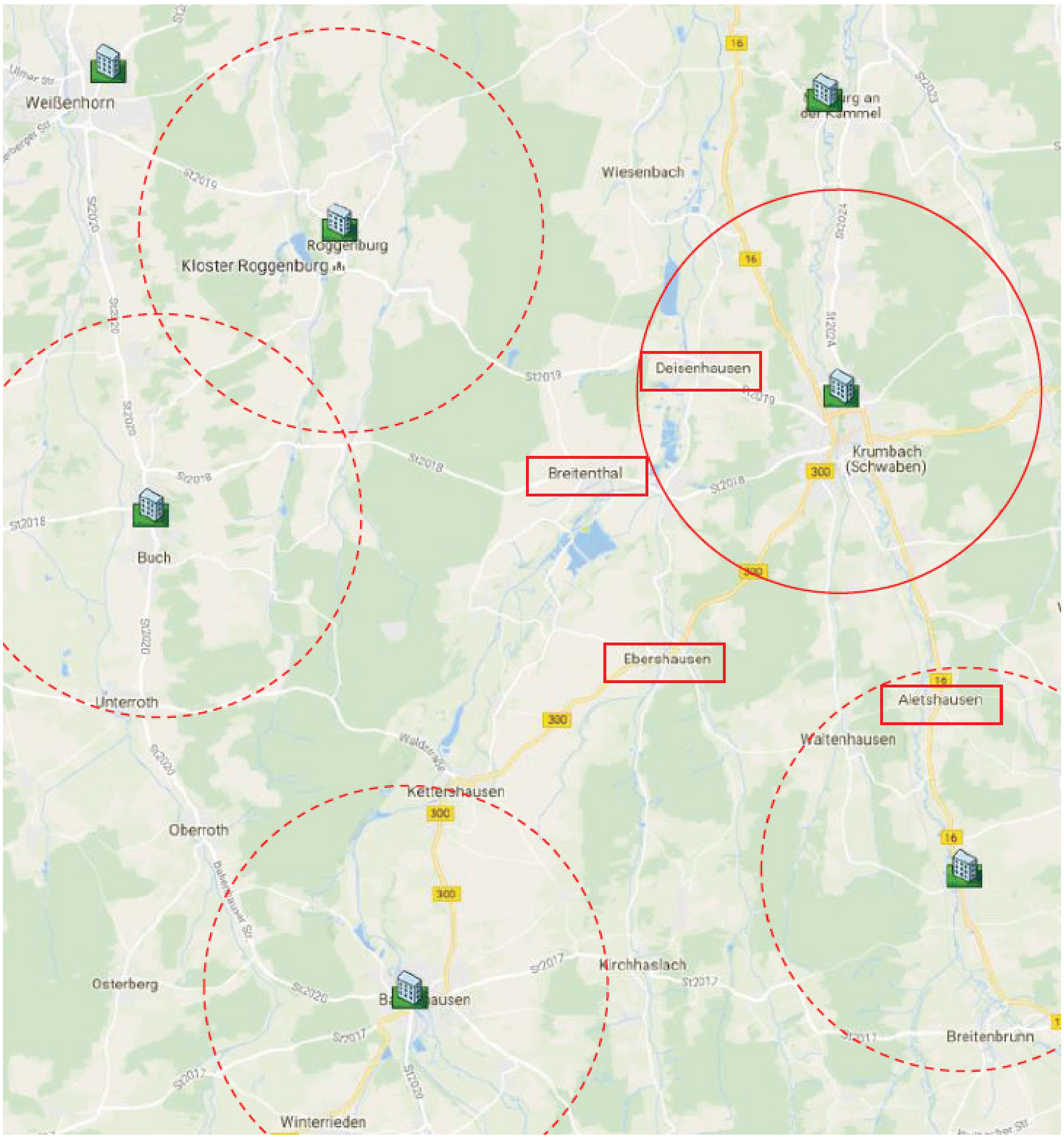
Finally, I drop all observations below the first and above the 99th percentile in terms of employment growth, as there are a small number of establishment observations with implausibly small (negative) or large growth rates.

At the municipality level, I drop the federal state of Berlin because the DSL data do not report separate values of DSL availability for the formerly separate Eastern and Western parts of the city, although these have historically different telecommunication infrastructures and thus probably also systematically different DSL availability rates.

Figure A1
MDF locations (Western Germany) and OPAL areas (Eastern Germany)

Source: Falck et al. (2014), online appendix.

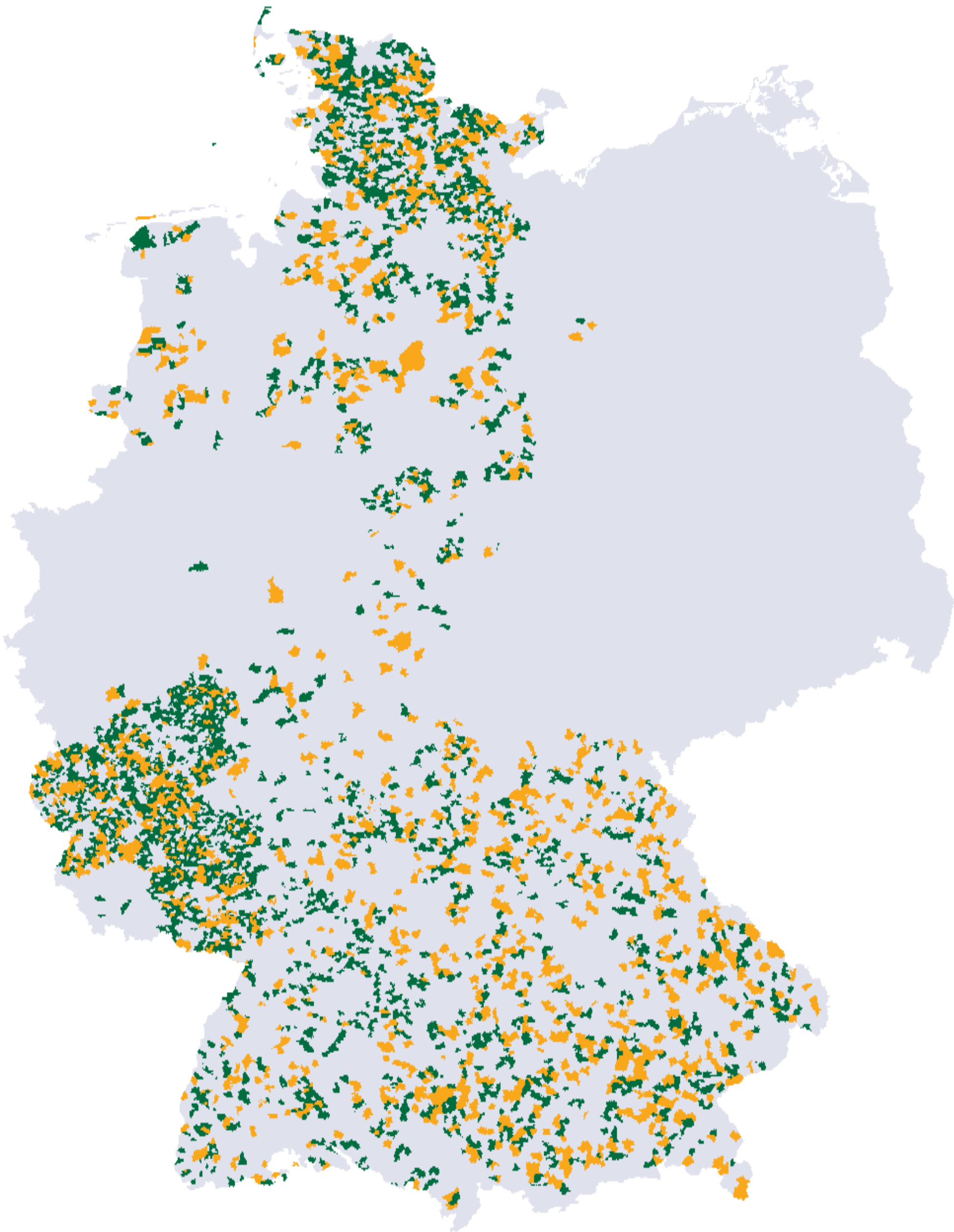
Figure A2
Example of MDF catchment areas and distance thresholds used to construct the Western German IV.



The map shows four municipalities (highlighted in rectangles) in a rural area in Bavaria and five MDFs. These four municipalities are assigned to the MDF in Krumbach, whose catchment area (with 4.2 km radius) is illustrated approximately by the solid circle. The Northernmost highlighted municipality (Deisenhausen) is within 4.2 km of its assigned MDF. For this municipalitiy, the IV would have the value zero, as there is no technical impediment. The most Southeastern highlighted municipality (Aletshausen) is more than 4.2 km from the assigned MDF, but within 4.2 km from its nearest MDF (to the South), whose catchment area is represented by a dashed circle. For this municipality, the IV therefore is set to missing, and the municipality is excluded from the estimation sample. The two Westernmost municipalities (Breitenthal and Ebershausen) are more than 4.2 km both from their assigned MDF and from any other MDF. For these municipalities, the IV has the value one, indicating a technical impediment to obtaining DSL service.

Source: http://meinkontes.de/hvt/, accessed November 23, 2016. Map data © 2016 GeoBasis-DE/BKG (© 2009), Google.

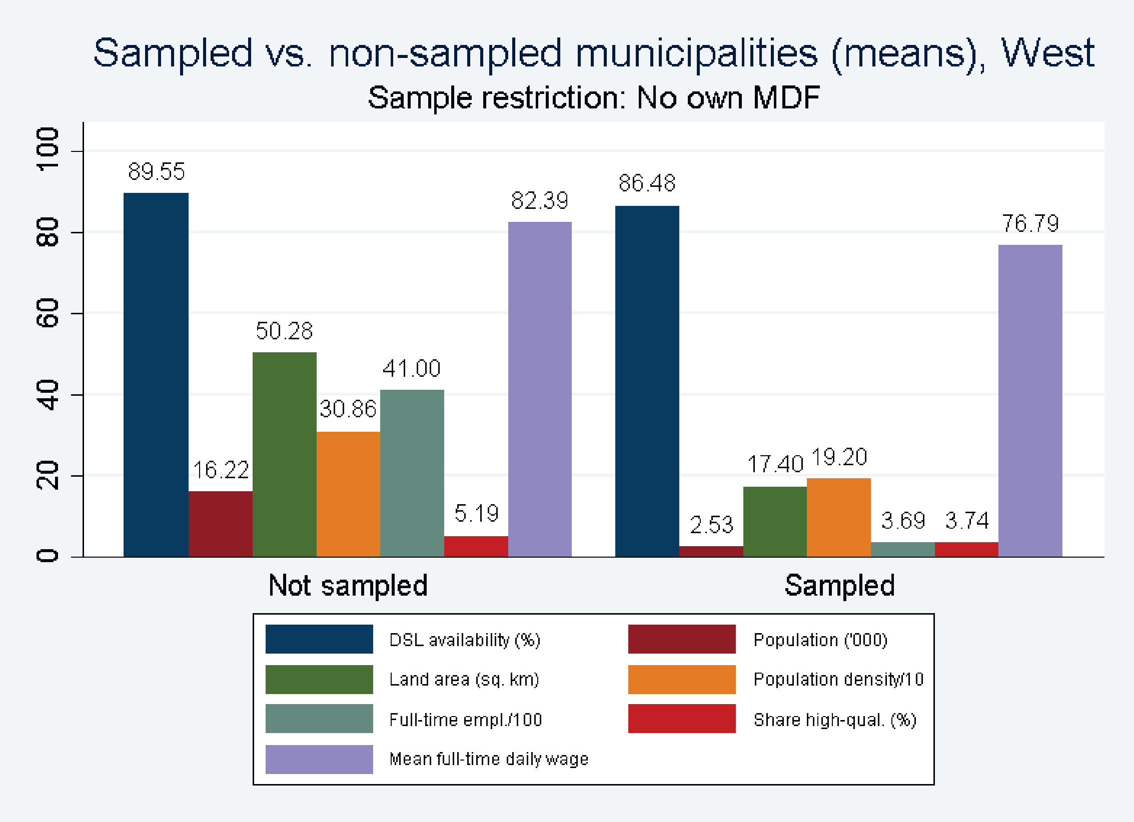
Figure A3
Municipalities above vs. below the 4.2 km threshold (distance to assigned MDF).



The map shows Western German municipalities without an own MDF. Municipalities colored in green are less than 4.2 km from their assigned MDF. Municipalities colored in yellow are more than 4.2 km from their assigned MDF. Distance between each municipality and its assigned MDF is measured using the municipality's geographic centroid. The strikingly high number of sample municipalities in Rhineland-Palatinate in the Southwest and their low number in North-Rhine Westphalia in the West is due to extreme differences in municipality size. North-Rhine Westphalian municipalities are on average ten times as large as those in Rhineland-Palatinate (86 vs. 8.6 square km). Thus, there are a very large (small) number of municipalities without an own MDF in Rhineland-Palatinate (North-Rhine Westphalia).

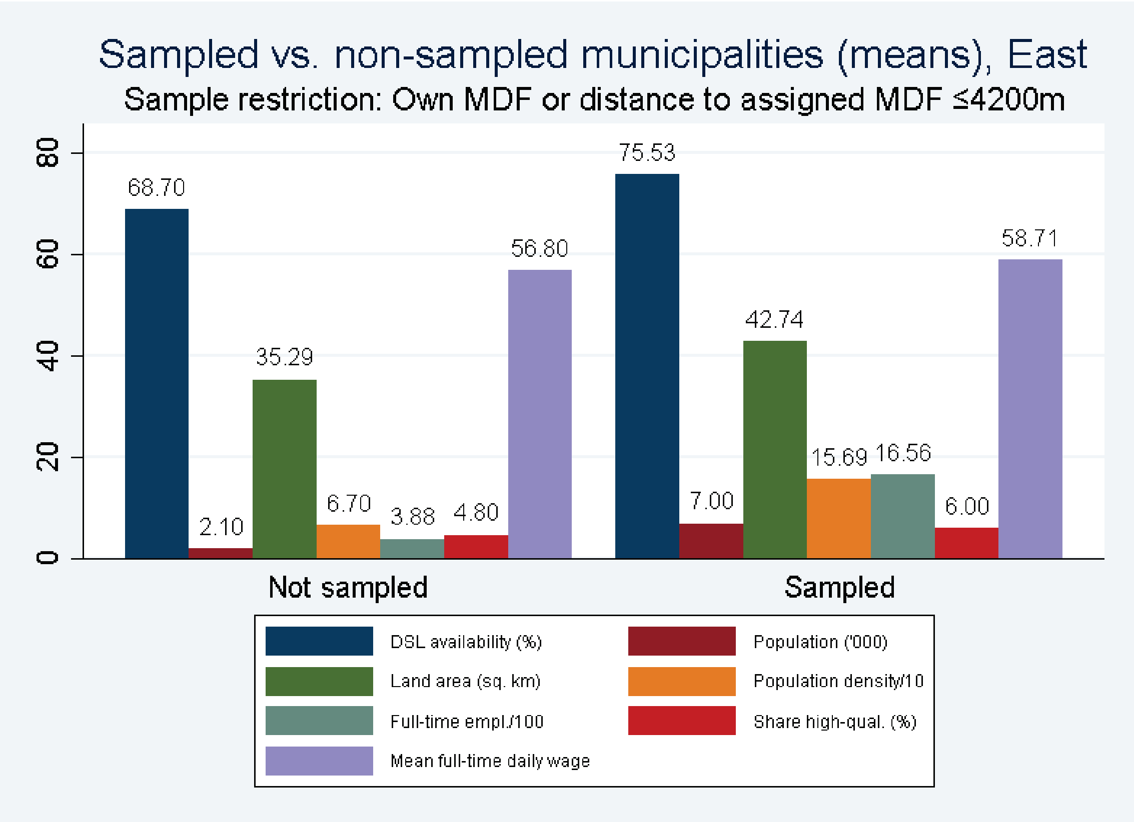
Data source: Deutsche Telekom

Figure A4



Data source: Broadband Atlas Germany, Deutsche Telekom, BHP7510 v1

Figure A5



Data source: Broadband Atlas Germany, Deutsche Telekom, BHP7510 v1

Table A3
Robustness check, West: Excluding 1% largest establishments

	(1)	(2)	(3)
A: Manufacturing			
DSL availability	-0.078	-0.119	-0.203*
	(-0.87)	(-1.30)	(-1.86)
Observations	14565	14565	14565
Adjusted R^2	0.010	0.031	0.037
B: Services			
DSL availability	0.307***	0.308***	0.313***
	(2.75)	(2.71)	(3.14)
Observations	18571	18571	18571
Adjusted R^2	.[a]	.[a]	0.005
Specification details for A and B			
Establishment controls	Yes	Yes	Yes
Municipality controls	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Industry FE (3-digit)		Yes	Yes
District FE			Yes

t statistics in parentheses. * p<0.10, ** p<0.05, *** p<0.01. Constant omitted from output. Standard errors clustered at the municipality level. [a]Not reported because model sum of squares is negative, a common problem arising in 2SLS estimation. Note: The extremely low R-squared value found in Panel B, column 3 is due to the 2SLS estimation procedure. An OLS estimation using "manually" constructed fitted values of DSL availability found an adjusted R-squared of 0.035.

Data source: Broadband Atlas Germany, Deutsche Telekom, BHP7510 v1

Table A4
Robustness check, West: Full-time employment growth rate

	(1)	(2)	(3)
A: Manufacturing			
DSL availability	-0.110	-0.156	-0.261**
	(-1.17)	(-1.55)	(-2.18)
Observations	14823	14823	14823
Adjusted R^2	0.017	0.035	0.042
B: Services			
DSL availability	0.170	0.207	0.155
	(1.18)	(1.46)	(1.13)
Observations	18650	18650	18650
Adjusted R^2	0.024	0.036	0.051
Specification details for A and B			
Establishment controls	Yes	Yes	Yes
Municipality controls	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Industry FE (3-digit)		Yes	Yes
District FE			Yes

t statistics in parentheses. * p<0.10, ** p<0.05, *** p<0.01. Constant omitted from output. Standard errors clustered at the municipality level.

Data source: Broadband Atlas Germany, Deutsche Telekom, BHP7510 v1

Table A5
Robustness check, West: Full-time equivalent employment growth rate

	(1)	(2)	(3)
A: Manufacturing			
DSL availability	-0.115	-0.143	-0.237**
	(-1.27)	(-1.58)	(-2.20)
Observations	14823	14823	14823
Adjusted R^2	0.012	0.035	0.046
B: Services			
DSL availability	0.220*	0.262**	0.246**
	(1.88)	(2.16)	(2.28)
Observations	18650	18650	18650
Adjusted R^2	0.012	0.025	0.044
Specification details for A and B			
Establishment controls	Yes	Yes	Yes
Municipality controls	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Industry FE (3-digit)		Yes	Yes
District FE			Yes

t statistics in parentheses. * p<0.10, ** p<0.05, *** p<0.01. Constant omitted from output. Standard errors clustered at the municipality level.

Data source: Broadband Atlas Germany, Deutsche Telekom, BHP7510 v1

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