The Value of Connectivity: High-Speed Broadband Internet and Real Estate Prices

[***Preliminary and incomplete draft — Comments welcome***]

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Abstract

The expansion of high-speed broadband Internet is of central importance to the digital transformation, but households' economic surplus from fast Internet access is still not comprehensively understood. This paper leverages the fact that wireline broadband connections are bundled with individual houses to examine the capitalization effects of fast Internet access on real estate sale prices and rents in Germany. Our identification strategy exploits the quasi-experiment of German states' different preferences for broadband expansion in rural areas, which induced variation that was plausibly exogenous to individual house buyers and tenants. Using a novel, large micro-dataset and employing a two-stage spatial RDD with an integrated hedonic price model, we investigate the effects of Internet access for three different speed levels. Our main findings for 16 Mbit/s broadband reveal significantly positive capitalization effects of between 4 to 7 percent. The results correspond to increases of average property prices by about 13,300 euros and of monthly rents by 23 euros. For higher Internet speeds of 30 and 50 Mbit/s, we document still significantly positive capitalization effects but find diminishing returns to Internet speed. However, for each speed level the returns increase over time. Further heterogeneity analyses document stronger capitalization effects for houses rather than apartments and for more populated rural municipalities. To disentangle an important mechanism, we examine households' Internet usage and show that higher availability translates into higher uptake, indicating that the capitalization effects are driven by households' current demand for fast Internet.

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1 Introduction

The digital transformation fundamentally changes the economy, society, and our daily lives. Digitization has been accelerated by the global Covid-19 pandemic, with a shift towards working from home, attending schools and universities virtually, and consuming even more information and entertainment online. For all these purposes, digital infrastructure with the expansion of high-speed broadband Internet to all households is of central importance. Governments have invested large amounts of public funds to support the provision of fast Internet access to (rural) regions that are underserved by profit-maximizing carriers. Ambitious goals for the provision of Internet connections in rural areas can be found in many governments' broadband agendas of both industrialized as well as emerging countries. However, the economic value of the provision of fast Internet access is still not comprehensively understood and quantified.

Our analysis of households' valuation of high-speed Internet draws on the findings of capitalization effects of public infrastructure or local public goods more generally into property prices. Since they are connected to the wireline broadband network, houses are regarded as composite goods.[1] Ahlfeldt et al. (2017) were the first to adopt this approach for first-generation broadband infrastructure in England. Our paper employs the capitalization method to examine households' economic value of high-speed broadband Internet in Germany. The estimated capitalization effects are interpreted as consumer surplus from Internet consumption, which is assigned to the real estate owner in the form of a scarcity rent in addition to the surplus realized by the Internet providers. We contribute to this literature by quantifying the effect of high-speed Internet availability on real estate prices in Germany between 2010 and 2019 using novel and rich micro datasets. To establish causality, we exploit a quasi-experiment of differing broadband policies across German states in a spatial regression discontinuity design (RDD).

Broadband infrastructure is typically rolled-out by private telecommunications carriers, which is the case in Germany as well. However, while it is profitable for private providers to expand their Internet network in densely populated areas, expansion in rural areas often require public subsidies. In the absence of major federal funding – a large scale federal scheme was enacted in 2015, but only took effect over the following years -, the German states enacted expansion programs with significant differences in scope, funding, and regulations. The states' different preferences regarding broadband expansion in rural areas led them to enact different policies, which contributed to the observed significant variation in the availability of fast Internet across states. This allows us to divide German states into 'high' and 'low' broadband states, providing a quasi-experiment at the interstate borders. We identify the causal effect in rural municipalities located at different sides of the state borders, which differ in their broadband availability but are otherwise

[1] The econometric foundations of the hedonic price model date back to Oates (1969), Rosen (1974), and Sheppard (1999).

similar.

The data of our rural border sample comprise nearly 2 million real estate offerings (1.33 million sales offers and 0.65 million rent offers) and broadband availability in approximately 5,000 municipalities between 2010 and 2019. Our empirical strategy employs a spatial RDD with an integrated hedonic price model for real estate valuation. Using polynomials in longitude and latitude, we only compare directly neighboring rural areas on opposite sides of the interstate borders. Our specification includes regional socioeconomic and individual property controls as well as border region by year fixed effects such that the remaining variation in property prices across state borders can be attributed to differing broadband availability. In fact, the RD plots of our rural border sample show very few jumps in municipality and property characteristics at interstate borders.

To credibly identify the causal effect of fast Internet availability on property prices, our empirical strategy addresses endogeneity concerns. First, the spatial distribution of high-speed broadband access is not random but might be endogenous to regional socioeconomic characteristics, such as population density and housing market types, which are also correlated with housing prices. We solve this endogeneity problem by exploiting the variation in fast Internet availability originating from a quasi-experiment of German states' different broadband expansion policies that are plausibly exogenous to individual house buyers or tenants. Second, the price effect of Internet availability must be disentangled from other individual property or locational attributes, such as the property's condition or school quality. We include controls for individual properties and regional socioeconomic factors as well as fixed effects that capture differential local time trends.

Our main finding is that broadband availability indeed capitalizes into real estate prices, indicating a high economic value of fast Internet access to households. The analysis first shows that broadband availability (at least 16 Mbit/s) as percentage of households is on average 10 percentage points higher in rural border areas in 'high' broadband states than rural border areas in 'low' broadband states. Second, this difference results in an average elasticity on sale prices of about 6.7 percent, which relates to an increase of the average price per square meter by 95 euros and of the total average property price by 13,260 euros. Third, for property rents, the average estimate of 4.8 percent translates into an increase of the average rent per sqm by 0.29 euros and of the total monthly average rent by 23 euros. The absolute values of these broadband premiums, which reflect the implicit market prices and consumer surplus from fast broadband Internet at home, are sizable and likely exceed the costs of broadband provision in most regions.

In an extension, we study the effects of 30 Mbit/s and 50 Mbit/s availability on real estate prices and rents. We find that consumers have a decreasing marginal willingness to pay for speed, at least once a desired broadband speed level is reached, i. e. upgrades to 30 Mbit/s and 50 Mbit/s are valued less than to 16 Mbit/s. However, we find increasing effects for more recent years, which indicate higher utility from more recent Internet applications or that the later surplus from fast Internet was reaped on the property market by sellers and landlords while the earlier went to Internet providers. We additionally show that broadband availability capitalizes more strongly in prices and rents for houses rather than apartments. The capitalization effects are also more pronounced in slightly more populated municipalities compared to their very rural counterparts. Finally, a battery of specification, robustness, and placebo checks complement the analysis and add credibility to our findings.

To better understand the drivers of the capitalization effect, we use data from the micro-census of German households on uptake, i.e., the contracts which households purchased from their providers. We find that in states, which reached a high availability of fast Internet in rural border areas earlier, not only was the broadband availability higher but importantly also more households bought fast Internet contracts. The difference in purchased contracts for 16 Mbit/s, the main speed under consideration, is of a similar size as the difference in broadband availability. For 30 and 50 Mbit/s, the difference in uptake is about one half and one third, respectively, of the increase in availability. These findings suggest that the broadband expansion addressed existing demand and that the capitalization is driven primarily by current demand rather than expectations about future demand.

Our estimates are higher but broadly in the same range as found in previous studies. Ahlfeldt et al. (2017) evaluate the effect of Internet access on housing prices and find a broadband premium. Leveraging data from the United Kingdom over the time period of 1995 to 2010 and employing a boundary discontinuity design, the authors estimate that a first-generation broadband connection with a basic speed of 8 Mbit/s increases property values by 2.8 percent. Furthermore, the authors find that a speed upgrade to 24 Mbit/s leads to an additional increase in property prices by about 1 percent, indicating decreasing returns to scale from broadband speed. Molnar et al. (2019) show that Internet access with a broadband speed of 25 Mbit/s increases the average value of an American property by 3 percent. Further evidence on positive house price effects thanks to broadband access is provided by a large-scale analysis comprising 887 American counties (Deller and Whitacre, 2019). With regard to the German housing market, Klein (2020) examines the effects of the roll-out of high-speed fiber broadband in a case study for the rural county of Warendorf. His small-scale study supports property price increases as a result of broadband connection.

More generally, our results also compare to capitalization effects of local public goods or non-marketed externalities. A group of studies investigate the capitalization of school quality into house prices (Figlio and Lucas, 2004; Gibbons et al., 2013; Collins and Kaplan, 2017). In particular, Gibbons et al. (2013) exploit geographic discontinuities along school admission boundaries and find a positive effect of higher average test scores on real estate prices, caused by a higher willingness to pay for improved academic results and school composition. Similarly, other papers find positive house price effects of urban infrastructure, such as railway access (Gibbons and Machin, 2005), new subway lines

(Diao et al., 2017), and urban open and green spaces (Conway et al., 2010). Further studies analyze the house price effects of negative externalities, such as air pollution (Chay and Greenstone, 2005), hazardous waste (Greenstone and Gallagher, 2008), power plants (Davis, 2011), shale gas extraction (Muehlenbachs et al., 2015), cancer clusters (Davis, 2004), and neighborhood crime (Linden and Rockoff, 2008). Notably, both Chay and Greenstone (2005) and Greenstone and Gallagher (2008) employ regression discontinuity designs that exploit regulations on air quality and waste cleanup, respectively, to estimate individuals' marginal willingness to pay capitalizing in house prices. Finally, a cluster of papers analyze the capitalization of factors directly attributable to properties, such as energy efficiency (Kahn and Kok, 2014; Aydin et al., 2020) and real estate transfer taxes (Palmon and Smith, 1998; Dolls et al., 2021).

Our paper directly adds to a growing literature on the effects of broadband Internet on economic, political, and other outcomes, employing a wide range of empirical approaches and datasets. Czernich et al. (2011) show for first-generation broadband Internet that a 10 percentage points increase in broadband usage induced additional GDP per capita growth of 0.9 to 1.5 percentage points. On the household level, Greenstein and McDevitt (2011) conduct benchmark estimates that value the consumer surplus from adopting broadband Internet in the United States at between 98 and 142 dollars per month. Similarly, Nevo et al. (2016), who leverage broadband usage data, estimate the surplus from broadband availability for the average American consumer as high as 165 dollars a month. Both studies indicate that the private willingness to pay for Internet access significantly exceeds the typical cost of a broadband subscription.[2] Regarding labor market outcomes, there are small but positive employment effects, benefitting skilled labor and adversely affecting unskilled workers, while the firm-level effects are concentrated on certain sectors and locations (Akerman et al., 2015; Falck, 2017; DeStefano et al., 2018; Falck et al., 2021). With regard to political outcomes, the role of the Internet and social media have been studied in various contexts such as protests (Enikolopov et al., 2020), ideological segregation (Gentzkow and Shapiro, 2011) and the spread of fake news (Allcott and Gentzkow, 2017).

While most of the literature studies the effects of broadband Internet on the population that has access to it, most of public funding for broadband expansion is targeted towards rural areas, which have not yet been served by providers. Despite the relevance of this question for policy makers, limited evidence exists on whether these overall effects apply equally to rural areas. DeStefano et al. (2022) find heterogeneous effects on rural and urban firm performance, whereas our focus is on the value of connectivity to consumers. Since economic reasoning suggests that high-speed broadband will have different effects than first-generation broadband (Bertschek et al., 2015), it is worth examining the

[2] Allcott et al. (2020) caution that valuations of Internet services - in their study Facebook - may be be overestimated due to addiction and harmful effects. Our approach to quantifying the value of connectivity seems less susceptible to such concerns, as the valuation is based on the overall utility of the Internet rather than individual services.

differential effects of higher Internet speeds as well as how they change over time.[3] In particular, our study complements Ahlfeldt et al. (2017) with results from a more recent period and for faster Internet speeds.

The remainder of this paper is structured as follows. The next section outlines the relevant economic literature on broadband Internet and the capitalization of local public and private goods into house prices. In the third section, we outline the institutional background on broadband roll-out in Germany and the quasi-experiment of German states' different broadband expansion programs. Fourth, we describe the extensive dataset of broadband Internet availability and real estate sale prices and rents. The fifth chapter on the empirical research design explains the methodology and identification strategy. In the sixth and seventh sections, we present the findings of the empirical analysis and discuss the results. The final section concludes.

2 Institutional Background and Data

2.1 High-Speed Broadband Internet Expansion in Germany

This paper focuses on the provision of fast broadband Internet to private households in Germany through wireline connections, such as digital subscriber lines (DSL/VDSL), cable networks (CATV), or fiber-to-the-building (FTTB). We additionally include information on mobile Internet availability (3G, 4G/LTE, and 5G).[4] "High-speed" Internet is classified as wireline connections with at least 16 Mbit/s downstream capacity since they facilitate valuable Internet uses, such as rapid downloads, video calls, and streaming, among others. We define Internet availability as the location-specific share of households that are supplied with a high-speed broadband connection.

The expansion of Germany's fast Internet infrastructure provides an interesting setting thanks to a clearly defined expansion period and the importance of public subsidies for the roll-out in rural areas. The roll-out took place predominantly in the decade between 2010 and 2019, which constitutes the time period under investigation in this study. Before 2010 high-speed Internet was largely unavailable and most households used slower first-generation broadband, characterizing Germany as a late expander in international comparison (Bundesministerium für Verkehr und digitale Infrastruktur, 2010–2019; Economist, 2019).[5] To provide households with high-speed Internet, the existing

[3] Several studies confirm these positive but heterogeneous labor market and firm outcomes of broadband Internet expansion for the United States (Forman et al., 2012; Kolko, 2012; Atasoy, 2013; Zuo, 2021), Norway (Akerman et al., 2015; Bhuller et al., 2019), Italy (Canzian et al., 2019), and Germany (Briglauer et al., 2019).

[4] Mobile Internet is not at the core of our study, because it is generally slower than wireline connections and typically not used at home.

[5] First-generation dial-up and DSL Internet was based on the pre-existing telephone network, which relied on copper wires to connect houses with nearby main distribution frames. Beginning with downstream speeds of 384 kbit/s and upstream speeds of 128 kbit/s, several technological standards (ADSL, ADSL2, ADSL2+) were implement-ed over the 2000s.

infrastructure had to be upgraded by replacing the backbone of the network with fiber cables. The broad roll-out of such next generation access (NGA) networks required substantial private and public investments. Expansion was carried out by a hybrid of the primarily private roll-out by telecommunications providers and additionally state-funded programs with a focus on connecting rural areas (EY and ifo Institute, 2021). For a profit-maximizing Internet service provider, the main determinants of profitability of broadband expansion are population density, existing infrastructure, and local topography. The ratio of the number of new potential customers reached and the required extension of the broadband infrastructure are of importance. Since the marginal costs of broadband provision are lower in densely populated cities than in sparsely populated rural areas, the roll-out in cities was mainly conducted by private carriers. In contrast, the expansion of fast Internet in rural areas relied heavily on public investment and regulatory support. This paper thus focuses on public policies for broadband roll-out in rural regions.

2.2 Quasi-Experiment of German States' Policies for Broadband Expansion in Rural Areas

The expansion of high-speed Internet in rural areas generally require public subsidies and regulatory support because it is not profitable for private profit-maximizing providers. Reflecting their preferences for Internet roll-out in rural regions, the German states enacted broadband programs with significant differences in scope, funding, and regulations while federal funding was largely absent. In Appendix A we provide a detailed overview of all German states' broadband expansion policies including both subsidies and regulatory measures. In the following, we show that the states' different preferences regarding broadband expansion in rural areas led them to enact different policies, which contributed to the observed significant variation in the availability of fast Internet across states. This allows us to divide German states into 'high' and 'low' broadband states, providing a quasi-experiment at the interstate borders.

A closer look at the state programs in Appendix A suggests that the variation in public funding and regulation actually translated into different levels of broadband availability across German states. For instance, Baden-Wuerttemberg was among the first states to enact a state-level broadband expansion initiative in 2008 with significant funding. This led to the provision of 84 percent of households with 16 Mbit/s broadband and 77 percent with 50 Mbit/s in 2012. In contrast, Mecklenburg-Western Pomerania's state program for broadband roll-out was among the least ambitious of all German states. The state thus only achieved to supply 56 percent of households with 16 Mbit/s and 26 percent with 50 Mbit/s in 2012. The state of Rhineland-Palatinate offers a case study of enacting an effective regulatory measure, which was to allow rural municipalities to bundle into clusters for broadband expansion. The success of this policy is illustrated by the increase in households' coverage with 50 Mbit/s broadband from only 7 percent in

2010 to 75 percent in 2016. These examples suggest that the design of the different state policies had an effect on the provision of high-speed Internet, particularly in rural areas.

Against this background of different broadband expansion programs across German states and the associated variation in high-speed broadband availability, the core argument of this section is that there has been a quasi-experiment at the level of the 16 German states. Obviously, this state-level heterogeneity can also be partially explained by structural reasons on the side of telecommunication providers, such as required financial investments required and regional differences in economic viability of broadband expansion. However, most of the important drivers behind these business decisions, particularly local population density, can be controlled for. Moreover, federal funding for the roll-out of high-speed broadband was largely absent during the time period under investigation. After issuing the NGA framework regulation in 2015, the German federal government's broadband expansion program only gained traction after a substantial revision in 2018 (Bundesministerium für Verkehr und digitale Infrastruktur, 2015; Bundesministerium für Verkehr und digitale Infrastruktur, 2018; EY and ifo Institute, 2021). Crucially, the federal program does not confound our analysis of the period from 2010 to 2019, since the necessary lead time of infrastructure projects ensures that their effects did not materialize during our period under investigation. Therefore, we argue that the variation was largely induced by the described state-level differences in the scope, funding, and regulation of broadband expansion programs.

2.3 Micro-Dataset of Broadband Availability and Real Estate

Administrative Data on Broadband Internet Availability

The first component of our dataset used for the ensuing analysis are detailed administrative data on broadband Internet availability in the German states and municipalities. This dataset includes broadband access in all of Germany's 16 states and roughly 11,000 municipalities (in the territorial boundaries of 2018). The administrative data source used for the broadband availability data is the "broadband atlas" published by the German Federal Ministry for Transport and Digital Infrastructure (Bundesministerium für Verkehr und digitale Infrastruktur, 2010–2019).[6]

The "broadband atlas" reports the share of households covered by Internet providers' broadband infrastructure at both the state- and municipality-level. Since municipalities constitute the smallest layer of Germany's territorial division, the data are regionally fine-grained. Methodologically, this administrative data source is based on the Internet service providers' detailed reporting of their regional broadband coverage. The "broadband atlas" differentiates broadband availability by the technologies used for broadband provision as

[6]The "broadband atlas" was compiled on behalf of the German Ministry of Transport and Digital Infrastructure by TÜV Rheinland Consulting GmbH from 2010 to 2018 and by atene KOM GmbH since 2018.

well as by different broadband speeds offered to end users. With regard to the technologies, we focus on fixed-line broadband (e.g. VDSL, CATV, and FTTB), while leaving mobile technologies aside. In terms of broadband speeds, our dataset includes the provision of 16, 30, and 50 Mbit/s in all German states and municipalities. For the broadband speed of 16 Mbit/s, state-level data are available for the entire time period of 2010 to 2019, whereas the municipality-level data are only provided for the years of 2011 through 2016. For 30 Mbit/s broadband, the "broadband atlas" only started collecting data from 2013 onwards, leading to data availability from 2013 to 2019 for the states and from 2013 to 2018 for the municipalities. For the 50 Mbit/s broadband speed, the state-level data include the full period from 2010 to 2019 and the municipality-level data from 2011 through 2018.

As laid out in the previous section on the institutional background, the broadband data are characterized by regional and temporal variation in broadband availability across the German states as well as across urban and rural municipalities. Importantly, the data facilitate a comparison of fairly similar municipalities that are located across state borders in "high" or "low" broadband states. We will exploit this variation in order to identify the causal effect of broadband Internet availability on real estate prices.

Large Micro-Dataset on the German Real Estate Market

We use a large and novel micro-dataset on the German real estate market comprising properties for sale and for rent. This dataset was compiled by the real estate consulting firm F+B for the ifo Institute. The data are comprised of property advertisements from roughly 140 sources, covering online real estate platforms, major newspapers, and property agencies that were collected via web-scraping. Thanks to data cleaning, every property is listed only once although some were offered concurrently on multiple channels.

This large micro-dataset is, to the best of our knowledge, among the most comprehensive data sources on the German real estate market, in particular since the relevant administrative records publish aggregated data rather than micro-data at the property-level. In comparison to previous studies on the effects of broadband Internet on the German housing market, which typically rely on housing data from only one real estate website, this data source is much richer. For the time period under investigation from 2010 to 2019, the data include comprehensive information on more than 12 million properties that were offered for sale as well as on more than 13 million properties advertised for rent. This time period ensures that property prices were not affected by the Covid-19 pandemic. The observations are relatively evenly distributed over time (roughly 1 million observations per year each for sale and for rent) and geographically across the German states and municipalities. While the data encompass the near-universe of real estate offered for sale and for rent, privately sold or rented properties that did not make it to the market are not included. Moreover, the dataset is based on offerings, meaning that current prices of previously sold or rented properties are not included as well.[7]

For every property, the dataset contains information on the location, the listing date, the property type, all amenities, and the asking price. Beginning with the price as the outcome variable of interest, the data include the final offering price of all properties for sale and for rent. The final offering price can be regarded as close approximation of the actual sale price or rent. For the ensuing empirical analysis, we divide the total price by the floor space in sqm in order to generate a variable capturing the price per sqm. To simplify comparability and interpretation, we log the sale and rent prices per sqm. Regarding the location, the dataset contains information on every property's municipality via the municipality name and a unique municipality identifier, its postal code, and its state. The listing date enters the data as the year of the offering. In addition, there is thorough information on the individual properties' characteristics, which will be used as control variables. These variables include the property type (house or apartment), the number of rooms, the floor space (in sqm), the construction year, and the heating type. Additionally, we define indicator variables for equipment, such as a kitchen, a garden, a balcony, a parking spot, upscale equipment, and neighborhood attributes, such as a quiet location. We also control for publicly subsidized housing.

As part of the data cleaning process, which already ensured that properties only entered the dataset once, we exclude extreme outliers. Since the information on properties were manually provided to newspapers or entered into an online form, potential errors in the data generating process might constitute an issue. In order to mitigate concerns that our estimates could be biased by such false entries, we drop the bottom one percent and the top one percent of observations based on the sale prices and rents.

Additional Socioeconomic Data

Supplementary socioeconomic data at the level of all German municipalities constitute the third component of our dataset. These data comprise information on the types of municipalities, their population, geography, and local property taxes, which will be used as control variables in the empirical analysis. The data sources for these additional statistics are the Federal Institute for Research on Building, Urban Affairs and Spatial Development (Bundesinsitut für Bau- Stadt- und Raumforschung, 2021), the Regional Statistical Agencies of the Federal and State Governments (Statistische Ämter des Bundes und der Länder, 2021), and geographic information system (GIS) data from the Federal Agency for Cartography and Geodesy (Bundesamt für Kartographie und Geodäsie, 2019).

With respect to the socioeconomic information on municipalities, our data encompass a detailed categorization of the municipalities' types ranging from small rural communities to large cities. We use an ordinal indicator variable to capture the population

[7] For the evolution of property prices over time and the construction of appropriate price indices, see Ahlfeldt et al. (2021).

per municipality.[8] Furthermore, municipalities' growth or shrinkage trend is recorded categorically. Since municipalities are part of larger housing market regions, they are also included. Additional geographic data comprise the longitude and latitude of each municipality's centroid as well as its closest distance to the neighboring state borders. We also include indicator variables for municipalities located at state borders, the three city states, and former East Germany. Finally, we incorporate real estate transfer taxes, which vary across states and capitalize into property prices, as shown by Dolls et al. (2021).

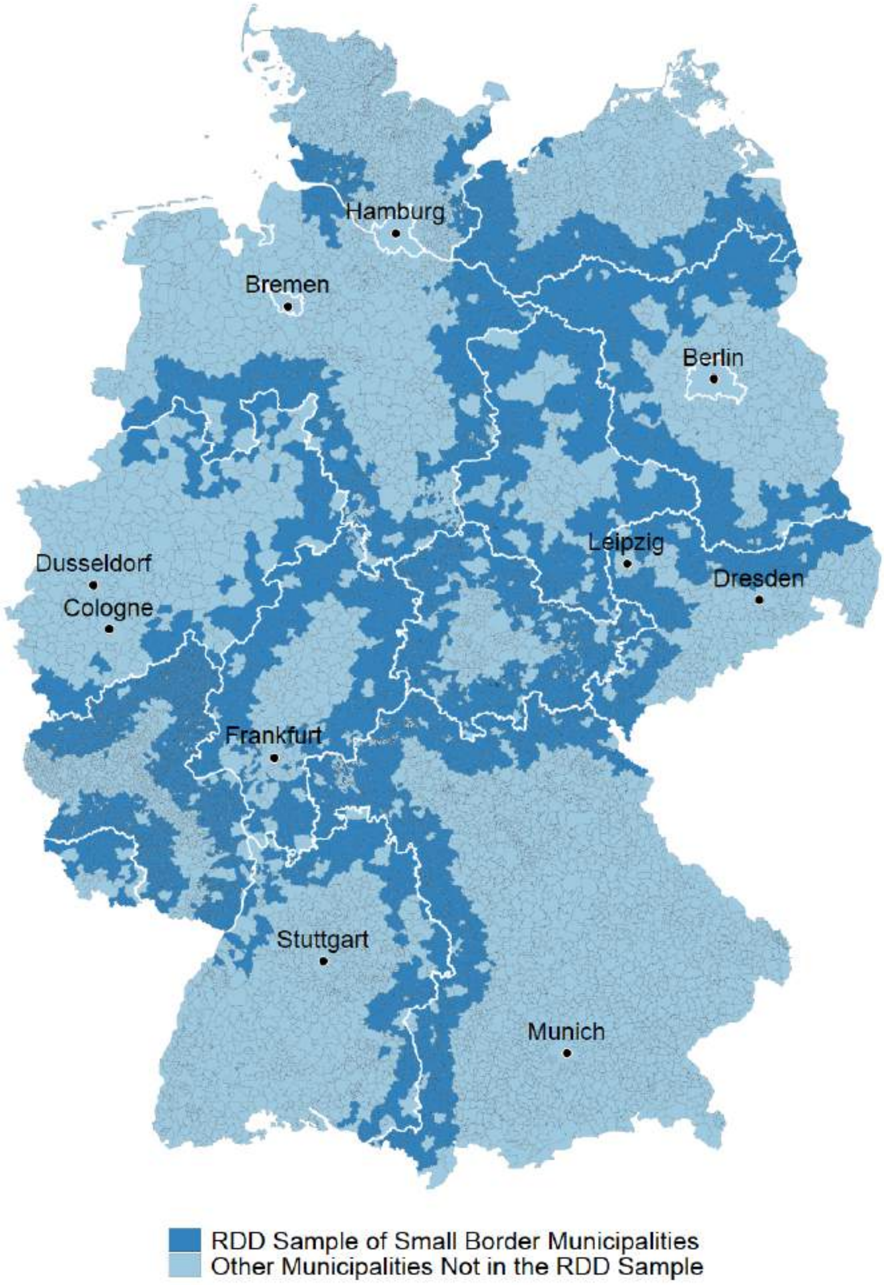
2.4 Sample Selection and Descriptive Statistics

In order to generate the sample for the ensuing analysis, the first step is to combine the three datasets described in the previous subsections. Using a micro-geographic matching approach, we merge the administrative data on broadband availability with the micro-dataset on German real estate as well as the additional data on population, geography, and taxes. As a result, we obtain two main datasets: first, one dataset comprising of properties for sale, broadband availability German states and municipalities, as well as geographic and socioeconomic control variables, which largely covers the time period between 2010 and 2019. The second dataset differs from the first in that it contains only properties for rent, while all other data on broadband access as well as geographic and socioeconomic controls are included in the same way. The rationale behind distinguishing data on properties for sale and for rent lies in acknowledging the structural differences between purchasing and renting real estate. In our empirical analysis, we will thus separately estimate the effects of broadband availability on sale prices and rents.

In a second step, we generate the samples for the ensuing empirical analysis, which will exploit the quasi-experiment of "high" and "low" broadband states by comparing broadband availability and real estate prices along their state borders. For a sound comparison of neighboring municipalities located at interstate borders, we construct groups of border regions. These border regions comprise only those small municipalities located closely to state borders, where the state on the one side of the border is considered "high" broadband while the adjacent state is classified as "low" broadband. Our sample consists of a geographically dispersed multitude of border regions, because border regions are not only comprised of pairs of two adjacent states but of up to four states whose borders lie within a bandwidth of 25 kilometers.[9] The sample includes only municipalities with fewer than 20,000 inhabitants, since the state-funded broadband expansion programs materialized in particular in smaller cities and rural areas while it was profitable for private telecommunication providers to expand Internet access in more densely populated and bigger cities. Figure **??** illustrates the main RDD sample in a map of Germany.

[8] The estimates are robust to more detailed specifications of this variable, for example a specification with 100 percentiles instead of 10 deciles. In general, the categorial variables are used instead of continuous variables in order to not remove too much of the variation at the municipality level.

[9] For instance, there are up to 81 unique border regions in our sample.



Note: This map of Germany illustrates the 16 federal states, delineated by white lines, as well as the approximately 11,000 municipalities. Highlighted in dark blue, the RDD sample is comprised of 4,897 small municipalities that are located within 25 kilometers to the next interstate border. The municipalities not included in the RDD sample are shown in light blue and are either located further away from the interstate borders or are dense urban areas with many inhabitants.

Figure 1: RDD Sample Illustration in a Map of Germany

The generated samples for the analysis differ in three respects: first, we differentiate between properties for sale and for rent due to the logic described above. Second, we make a distinction based on the broadband speeds of 16, 30, and 50 Mbit/s, since different states are considered "high" or "low" broadband for each of the three speeds.[10] This is the case because some states reach the "high" broadband status for the lower broadband speed of 16 Mbit/s, however fail to surpass the threshold for the higher speeds of 30 or 50 Mbit/s. Therefore, we estimate the effects separately instead of pooling the sample. The third dimension, in which the samples differ, is the distance of the bandwidth around the borders of "high" and "low" broadband states. In the baseline specification, which we will use for the main analysis, all municipalities that are located within a 25 km band around the shared border of "high" and "low" broadband states are included. For a robustness check, we generate a sample that contain all municipalities within a 50 km band.

Table 1 presents the descriptive statistics of the border samples for 16 Mbit/s broadband of properties for sale and rent in small municipalities that are located within 25 km of the borders of "high" and "low" broadband states. The summary statistics distinguish between the full sample in columns 1 to 4, the "low" broadband states in columns 5 to 6, and the "high" broadband states in columns 7 to 8. We first see that the sample is quite evenly split between "high" and "low" broadband states. The broadband availability in municipalities, defined as the share of households with Internet access, stands at an average of 54 percent, with "high" broadband states (68 percent) exceeding "low" broadband states (44 percent). Second, property sale prices per square meter average approximately 1,400 euros in the sample and are higher in "high" broadband states (1,600 euros) than in "low" broadband states (1,250 euros). Similarly, monthly rents per square meter average roughly 6 euros in the full sample and are 1 euro higher in "high" broadband states (6.5 euros) than in "low" broadband states (5.5 euros). Third, individual property characteristics across the sample are fairly similar, with average characteristics tending to be slightly better in "high" broadband states. Fourth, the regional socioeconomic controls resemble the previous observation, again with higher averages in the "high" broadband states.

[10]This classification is based on the threshold of providing at least 75 percent of households with a given broadband speed. See section 3.2 for the rationale.

	Full Sample				"Low" Broadband States		"High" Broadband States	
	Mean	**SD**	**Min**	**Max**	**Mean**	**SD**	**Mean**	**SD**
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**
Outcome and Main Explanatory Variables								
High Broadband States 16 Mbit/s	0.52	0.50	0.00	1.00	0.00	0.00	1.00	0.00
Broadband Availability Municipalities 16 Mbit/s	0.54	0.33	0.00	1.00	0.44	0.33	0.68	0.29
Property Sale Price Total	197,906.40	134,162.28	8,250.00	3,100,000.00	174,303.09	113,869.79	223,958.51	149,202.18
Property Sale Price per sqm	1,414.75	791.44	243.90	7,187.50	1,248.76	644.24	1,597.95	891.99
Property Rent Total (Monthly)	478.44	253.58	89.00	3,600.00	440.05	227.62	529.58	276.35
Property Rent per sqm (Monthly)	5.94	1.76	3.53	20.00	5.56	1.49	6.45	1.94
Control Variables								
Property Type	1.78	0.56	1.00	3.00	1.80	0.55	1.77	0.57
Number of Rooms in the Property	4.87	2.55	0.00	57.00	4.84	2.50	4.90	2.61
Floor Space of the Property in sqm	145.94	67.54	33.00	470.00	144.56	66.38	147.45	68.76
Age of Property	8.48	6.11	1.00	18.00	8.79	6.24	8.13	5.95
Newly Constructed Building	0.15	0.35	0.00	1.00	0.13	0.33	0.17	0.37
Renovation Status	3.54	1.11	1.00	5.00	3.58	1.06	3.50	1.16
Equipped with Kitchen	0.23	0.42	0.00	1.00	0.21	0.41	0.26	0.44
Equipped with Garden	0.31	0.46	0.00	1.00	0.27	0.44	0.36	0.48
Equipped with Balcony or Terrace	0.30	0.46	0.00	1.00	0.25	0.43	0.37	0.48
Equipped with Basement	0.41	0.49	0.00	1.00	0.39	0.49	0.43	0.50
Parking Lot or Garage Available	0.61	0.49	0.00	1.00	0.59	0.49	0.63	0.48
Exclusive/Luxury Equipment or Villa	0.04	0.20	0.00	1.00	0.03	0.18	0.05	0.22
Equipped with Pool, Whirlpool, or Sauna	0.06	0.24	0.00	1.00	0.05	0.23	0.07	0.26
Bright Rooms	0.17	0.37	0.00	1.00	0.14	0.35	0.20	0.40
Heating Type	0.30	0.95	0.00	5.00	0.25	0.89	0.35	1.02
Central Heating	0.87	0.98	0.00	2.00	0.81	0.97	0.93	0.99
Quiet Location	0.12	0.32	0.00	1.00	0.12	0.32	0.12	0.32
Publicly Subsidized Housing	0.03	0.17	0.00	1.00	0.04	0.20	0.02	0.12
Real Estate Transfer Tax Rate	0.05	0.01	0.04	0.06	0.04	0.01	0.05	0.01
Municipality Growth Trend	0.05	1.26	-2.00	2.00	-0.03	1.27	0.13	1.24
Housing Market Region Type	3.58	1.12	1.00	5.00	3.50	1.13	3.67	1.11
School Quality (PISA Results)	505.44	9.46	493.00	525.00	506.07	9.66	504.75	9.18
Crime Rate per 10,000 Inhabitants	0.07	0.01	0.05	0.09	0.07	0.01	0.06	0.01
Mobile Internet Availability	0.80	0.18	0.42	1.00	0.69	0.14	0.91	0.14

Note: The descriptive statistics of the border samples for 16 Mbit/s report information on properties for sale and for rents in small municipalities, which are located within 25 km of the borders of "high" and "low" broadband states for the broadband speed of 16 Mbit/s. Columns 1 to 4 report the mean, standard deviation, minimum, and maximum for the full samples, whereas columns 5 to 6 state the mean and standard deviation for "low" broadband states only, and columns 7 to 8 report the analogous values for "high" broadband states.

Table 1: Descriptive Statistics of the Border Samples for 16 Mbit/s Broadband

For the broadband speeds of 30 and 50 Mbit/s, the descriptive statistics tables are provided in Appendix A and are rather similar to those in Table 1.

In Figure 2, we show that we investigate the relevant period during which high-speed Internet access was greatly expanded in Germany. By plotting annual histograms and population-weighted means of broadband availability in municipalities, we document that around 40 percent of all municipalities in our sample were connected to high-speed broadband during the observation period. Very notably, there is a large difference in Internet expansion between “high” and “low” broadband states. Both the level and the growth trend of Internet access is much higher in “high” broadband states. While this figure displays the development for 16 Mbit/s broadband, Appendix A includes the respective figures for higher broadband speeds of 30 and 50 Mbit/s, which show the same time trend although on lower levels.

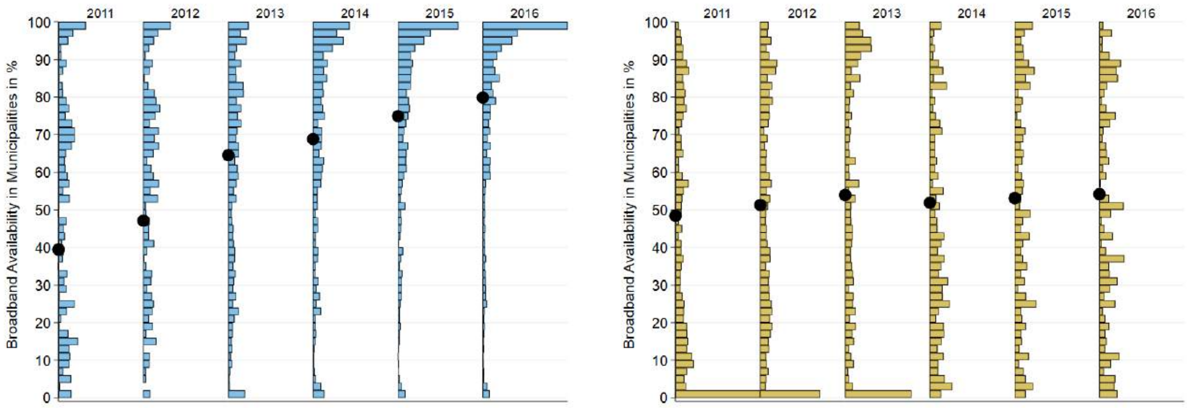


Figure 2: High-Speed Internet Availability in “High” and “Low” Broadband States
Note: This figure shows annual histograms of the availability of 16 Mbit/s broadband Internet in municipalities (measured as share of households per municipality with access to this Internet speed). Panel A on the left portrays fast Internet availability in municipalities located in “high” broadband states, while Panel B on the right displays broadband access in “low” broadband states. The black dots represent yearly population-weighted means across all municipalities. The figure indicates differences in both level and time trend of Internet availability between “high” and “low” broadband states.

3 Empirical Research Design

3.1 Spatial Regression Discontinuity Design

Finding an empirical strategy that credibly estimates the causal effect of high-speed Internet on property prices is crucial. However, causal identification is difficult in this setting and might be subject to selection bias, time-varying confounders, simultaneity, path dependencies, or reverse causality, among others. The availability of high-speed broadband Internet in municipalities might be endogenous to locational factors, such as population density, which are probably correlated with housing prices. This endogeneity problem can be solved by exploiting the variation in fast broadband Internet access originating from the quasi-experiment of different state programs for broadband expansion that are plausibly exogenous to individual house buyers or tenants. Our analysis thus conducts a comparison along the boundaries of “high” and “low” broadband states.

For this purpose, we employ a two-stage geographic regression discontinuity design (RDD). The basic concept of this geographic RDD is to compare similar properties in similar municipalities, which are located adjacent to each other but across state borders and thus only differ in their broadband availability. The properties in “high” broadband states form the treatment group, whereas those on the other side of the border in “low” broadband states belong to the control group. While both the treatment and control groups are comprised of several German states, our econometric specification will ensure to compare only properties located closely to each other in joint border regions.

The identifying assumption of this geographic RDD is that municipalities located at state borders are valid comparison groups if controlling for regional socioeconomic and individual property characteristics. Since property prices likely vary across state borders for other reasons than broadband availability, it is important to include these characteristics as controls. Conditional on property and regional control variables as well as on including year and border region fixed effects, the remaining variation in property prices due to differing broadband availability across states can be regarded as good as exogenous. Moreover, this RDD utilizes “high” broadband states as an instrument reflecting the state-level differences in broadband availability from the quasi-experiment of German states’ different programs, which are external to individual house buyers or tenants, rather than the potentially endogenous variation of broadband availability in municipalities.

The two-stage geographic RDD estimates the treatment effects of “high” broadband states on three main outcomes: in the first stage on broadband availability in municipalities and in the reduced form on real estate sale prices and rents. The reasoning behind the first stage in instrumental variable regressions is to demonstrate the instrument’s relevance and exogeneity, meaning that it affects the probability of treatment, in this case that “high” broadband states in comparison to “low” broadband states have an influence on local broadband availability. For an instrument to be valid, it is required to be strong, independent (uncorrelated with the error term), and to fulfill the exclusion restriction (affect the outcomes of interest, i.e. real estate sale prices and rents, only through the treatment variable, i.e. broadband availability in municipalities) (Angrist and Pischke, 2009). Furthermore, the reduced form estimates capture the effects on real estate sale prices and rents. The estimates for these two outcome variables will show how and to which extent the state-wide surpassing of the “high” broadband threshold indeed capitalizes into housing prices. This is an application of the hedonic price model within the RDD framework, which estimates the implicit market price of broadband availability as a local attribute of properties. The results provide the key to examining our research question.

Our employed two-stage geographic RDD follows the well-established econometric methods of general and geographic RDDs as well as hedonic price models. Fundamentally, a RDD is a quasi-experimental research design that allows estimating treatment effects in nonexperimental settings when treatment is assigned once a running variable exceeds a known threshold (Angrist and Pischke, 2009; Cattaneo et al., 2019). An important feature of RDDs is that at around the threshold the probability of receiving treatment changes discontinuously (sharp or fuzzy) while the other covariates change continuously. This allows for the identification of the local causal effect of treatment under comparatively mild assumptions. While RDDs are mostly internally valid, the external validity depends on the generalizability of the investigated setting. In our case, we exploit the discontinuity in broadband Internet availability at the borders of "high" and "low" broadband states. The core assumption behind identification is that while the broadband status changes discontinuously at the border, the other covariates of border regions change continuously. The descriptive statistics in Table 1 indeed indicate that most control variables vary relatively smoothly between treatment and control groups.

Pioneering work on geographic RDDs have been conducted by Black (1999), Dell (2010), Gibbons et al. (2013), Becker et al. (2016), as well as more recently by Keele and Titiunik (2015) and Cantoni (2020), among others. In her seminal paper, Dell (2010) investigates the long-run effects of Peru's forced mining labor system by comparing communities situated close to the border, finding persisting impacts of this past forced labor system. Causal identification is established based on the exploitation of the historical boundary. Dell (2010) uses two specifications of her multidimensional geographic RDD, estimating the effects for both the distance to the border as a one-dimensional running variable as well as for two-dimensional polynomials in longitude and latitude. Similarly, Becker et al. (2016) follow the same approach to examine the long-run impact of the former Habsburg Empire on institutions in Eastern Europe. Their geographic RDD employs specifications in distance to border as well as in longitude and latitude in order to identify the causal effect. As will be laid out in the ensuing subsection, our multidimensional geographic RDD follows these seminal studies by estimating the effects with similar specifications.

Additionally, our estimates are based on the previous research using hedonic price models as described in the literature review. Essentially, hedonic pricing assumes that house prices consist of the implicit prices of all property characteristics, including internal attributes as well as local public and private goods, with implicit prices reflecting consumers' willingness to pay. To mitigate concerns of omitted variable bias or selection on unobservables, well-identified studies analyze the capitalization of a certain locational factor into house prices by comparing treated and control properties that are located very closely to each other. By leveraging the geographic discontinuity between "high" and "low" broadband states, we pursue exactly this approach.

3.2 Hypotheses and Estimation Strategy

For the derivation of hypotheses on the causal effect of high-speed Internet on property prices, it is important to emphasize that the consumption of broadband Internet and housing typically constitute fixed bundles. Internet access at home offers opportunities for remote working, information and entertainment, and digital social interactions via social media or videotelephony. It is thus reasonable to assume a generally positive relationship between broadband availability and property prices. However, both buyers and tenants might anticipate a future roll-out of high-speed broadband to currently underserved regions. If this anticipation is factored into the prices, we might not see an effect at all or only a weak effect. Against this background, our first hypothesis is that the state-wide surpassing of the "high" broadband threshold translates into higher broadband availability in municipalities. We secondly expect that "high" broadband states have a positive effect on both real estate sale prices and rents.

We estimate the two-stage geographic RDD through the following two equations:

$$\begin{aligned} y_{mt} = \alpha + \beta highbroadbandstate_{mt} + f(geographic\ location)_{b(m)} \\ +\ X'_{mt}\gamma + \delta_{b(m)} \times \delta_t + \epsilon_{mt} \end{aligned} \tag{1}$$

$$\begin{aligned} y_{imt} = \alpha + \beta highbroadbandstate_{mt} + f(geographic\ location)_{b(m)} \\ +\ X'_{imt}\gamma + \delta_{b(m)} \times +\delta_t + \epsilon_{imt} \end{aligned} \tag{2}$$

Equation (1) refers to the first stage and equation (2) to the reduced form. Both estimation equations are similar and share the same treatment level, but they differ in their outcome level, since the first stage investigates effects at the municipality-level while the reduced form analyzes effects at the level of individual properties located within municipalities.

Specifically, in equation (1) for the first stage, the outcome variable of interest y_{mt} is broadband availability in municipality m in year t. On the left-hand side, we are mainly interested in the coefficient of the explanatory variable $highbroadbandstate_{mt}$, which is an indicator taking the value of 1 if the municipality m belongs to a "high" broadband state for a given broadband speed in year t, and 0 otherwise. The function $f(geographiclocation)_{b(m)}$ is the geographic RD polynomial that exploits the discontinuity at the borders of "high" and "low" broadband states. A vector of covariates X_{mt} is included to control for socioeconomic characteristics at the municipality-year level. The border region fixed effects $\delta_{b(m)}$ ensure that only municipalities within particular boundary segments of "high" and "low" broadband states are compared, thereby reducing potential bias from omitted variables. Including the year fixed effects δ_t accounts for common time trends in and shocks to broadband availability. The border region and year fixed effects are interacted to ensure that differential time trends across border regions do not bias our estimates. α is the constant and ϵ_{mt} the error term. Finally, standard errors are clustered at the municipality-level.

In comparison, the reduced form equation (2) estimates the effects for the outcome variable y_{imt}, which captures the log sale price of property we in municipality m in year t. We run this regression separately for rents, where y_{imt} is the log rent of property we in municipality m in year t. We are again interested in the coefficient of the explanatory variable $highbroadbandstate_{mt}$ when estimating with the geographic RD polynomial $f(geographiclocation)_{b(m)}$. The estimation at the individual property-level in this multivariate regression facilitates controlling for variation in the observable property characteristics X_{imt}. The border region fixed effects $\delta_{b(m)}$ and year fixed effects δ_t are included based on the same rationale, but here they also control for time trends in and shocks to real estate prices. Still, α is the constant and ϵ_{imt} the error term. We use heteroskedasticity-robust standard errors for the reduced form estimates of individual properties.[11]

We estimate the effects of "high" broadband states on broadband availability in municipalities, real estate sale prices, and rents separately for the broadband speeds of 16, 30, and 50 Mbit/s. We employ two specifications of the geographic RDD: first an estimation with linear, quadratic, and linear interacted RD polynomials in the one-dimensional distance to border. The second specification estimates the effects using linear, quadratic, cubic, and quartic RD polynomials in the two-dimensional boundary discontinuity in longitude and latitude. While the first specification in distance to border is very intuitive and close to the original RDD concept, it does not use all available information on the location of properties and municipalities. In contrast, the second specification in longitude and latitude is more accurate, because it uses the two-dimensional geographic information to only compare very closely located properties and municipalities. Estimating the regressions with different functional forms of the RD polynomial is useful, because more flexible functional forms provide better approximations to the unknown true regression functions but at the expense of a loss of precision caused by more terms in the functional forms (Cattaneo et al., 2019). For all specifications, the main bandwidth chosen is a maximum distance of 25 km from the municipality' centroid to the boundary between "high" and "low" broadband states. We will provide a robustness check of conducting the same estimations with a larger band around state borders of 50 km. We thereby address the bias vs. variance (efficiency) tradeoff that is inherent to the bandwidth choice in RDDs: the larger the bandwidth the more precise are the point estimates thanks to more observations, but with a larger bandwidth the estimator gets more biased and the approximation loses precision (Cattaneo et al., 2019). Finally, the effects we estimate in all specifications

[11] The reasoning behind the decision not to cluster the standard errors for property sale prices and rents is that we estimate at the level of individual properties. Clustering at the level of individual properties is not a viable option. Although not our preferred econometric specification, the following regression results remain significant when we cluster at the municipality-level.

are intention-to-treat effects of the discontinuity in broadband availability in “high” and “low” broadband states. This is because we do not have data on the actual uptake of broadband access, but Internet availability was shown to be a good proxy for usage (Falck et al., 2014).

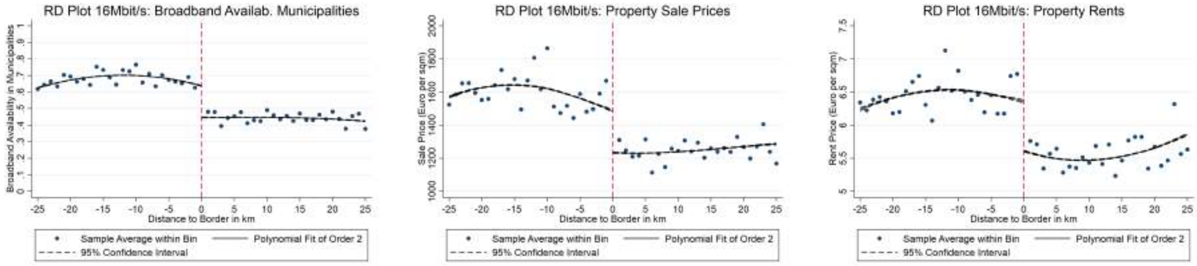
4 Empirical Findings

4.1 Graphical RDD Evidence

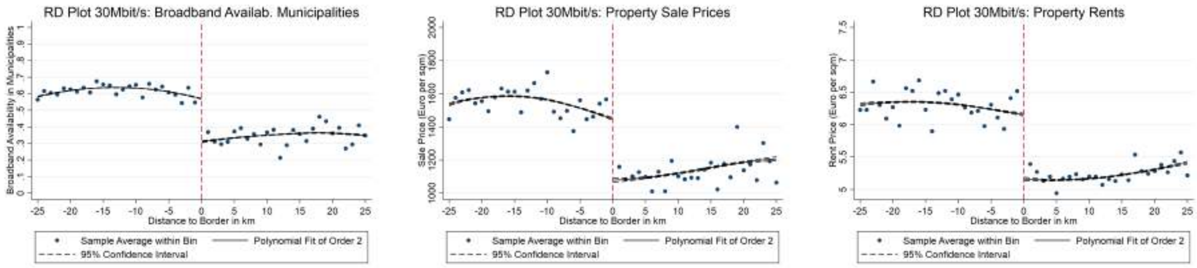
Using the two-stage spatial RDD and the border samples as detailed above, we analyze the effects of “high” broadband states on broadband availability in municipalities (first stage estimates) as well as on real estate sale prices and rents (reduced form estimates). We estimate the effects for these outcomes separately for the three broadband speeds 16, 30, and 50 Mbit/s using the samples of all municipalities located within 25 km of the state borders. The geographic RDD is employed with two main specifications: first an estimation with RD polynomials in the one-dimensional distance to border, and second with RD polynomials in the two-dimensional boundary discontinuity in longitude and latitude. In view of the empirical design, we identify the intention-to-treat effects of high-speed broadband Internet through the “high” broadband state instrument for the average property in the average treated municipality.

Figure 3 provides an overview of the graphical evidence for the effects of “high” broadband states broadband availability in municipalities, property prices, and rents for each of the broadband speeds 16, 30, and 50 Mbit/s. The underlying geographic RDD is specified in the distance to border. The outcome variables are plotted in levels on the y-axis and distance to border is displayed on the x-axis, with negative values belonging to “high” broadband states and positive values to “low” broadband states. A vertical red line highlights the geographic boundary. The dots in the RD plots were generated by an evenly spaced number of bins using a data-driven approach and represent the sample average within each bin, accompanied by the respective 95 percent confidence intervals. The approximation lines on both sides of the boundary reflect quadratic RDD polynomials.

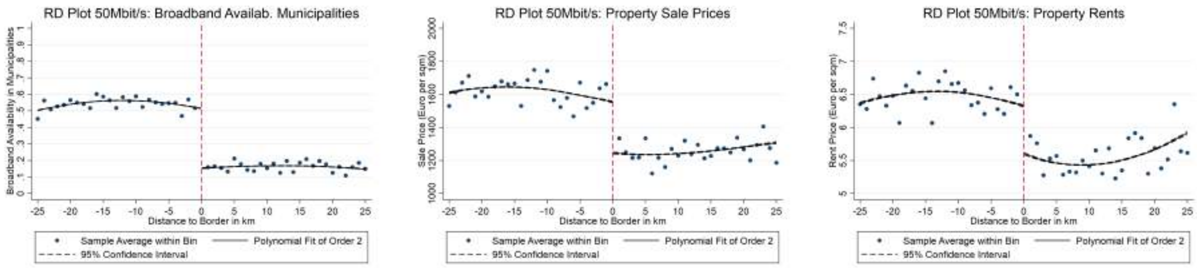
Panel A illustrates the RD estimates for the broadband speed of 16 Mbit/s. With respect to broadband availability in municipalities, it becomes evident that there is a clear cutoff at the border. Whereas in “high” broadband states on average 60 to 75 percent of households have access to 16 Mbit/s broadband, the coverage across the border in “low” broadband states ranges only between 40 and 50 percent. Similarly, real estate sale prices are much higher in “high” broadband states with an average of approximately 1,600 euros per sqm. These values are substantially lower for properties in “low” broadband states averaging about 1,300 euros. The RD plot for property rents indicates a price premium of “high” broadband states as well, with monthly rents standing at about 6.50 euros per sqm there compared with 5.5 euros in “low” broadband states.



(a) *RD Plots for 16 Mbit/s*



(b) *RD Plots for 30 Mbit/s*



(c) *RD Plots for 50 Mbit/s*

Figure 3: Spatial RD Plots for Broadband Availability in Municipalities, Property Sale Prices, and Property Rents

Note: Shown are the RD plots of the three outcomes of the two-stage geographic RDD in the distance to border specification for each of the broadband speeds 16, 30, and 50 Mbit/s. The outcome variables are plotted in levels on the y-axis and distance to border is displayed on the x-axis. The data-driven RD plots were generated by an evenly spaced number of bins, representing the sample average within each bin. The graphs additionally display solid lines for the quadratic fit and dotted lines for the 95 percent confidence intervals. The RD plots display the raw observations with fixed effects for property sale prices and rents, whereas border region fixed effects and control variables are not included.

Panel B shows the same RD estimates for the 30 Mbit/s broadband speed and reveals a similar pattern. The broadband availability in municipalities is again significantly higher in “high” broadband states (55 to 65 percent) than in “low” broadband states (30 to 40 percent). Likewise, property sale prices in “high” broadband states (1,400 to 1,700 euros per sqm) exceed their counterparts on the other side of the border (around 1,200 euros per sqm). The monthly rents are also higher in “high” broadband states (around 6.25 euros per sqm) than in “low” broadband states (about 5.75 euros per sqm).

Finally, Panel C displays the RD plots for the broadband speed of 50 Mbit/s, adding to the bigger picture. For broadband availability in municipalities, the differences are even more pronounced with "high" broadband states (50 to 60 percent of households) exceeding "low" broadband states (10 to 20 percent) by about 40 percentage points. While the findings for property sale prices indicate a strong divide (about 1,600 compared to 1,300 euros per sqm), the RD plot for property rents shows that the cutoff is a bit weaker although the absolute difference remains (about 6.50 compared to 5.50 euros per sqm).

Having presented graphical evidence of a pronounced discontinuity in broadband availability, we show that other relevant variables affecting rent and sale prices are not discontinuous at the state borders in our sample. Figure 4 shows various characteristics of the properties in the first ten plots. For all of them, the averages on both sides of the border are very similar and the plots look smooth. In addition to the quality of the property itself, sale and rent prices are determined by its location. Important location characteristics are shown in the last five plots. Crime rate and school quality as well as attributes of the local market are barely changing across the border region. The last location characteristic shown in the Figure 4 is the share of households with mobile internet. This variable is related to broadband access and shows a discontinuity as well. It is likely driven by the same state-level policy preferences as broadband expansion. However, both sides of the border are at a high level of availability. Furthermore, mobile internet *at home* is likely to be only important in the absence of a (usually faster and cheaper) broadband connection that also provides wireless Internet access to smartphones and tablets.

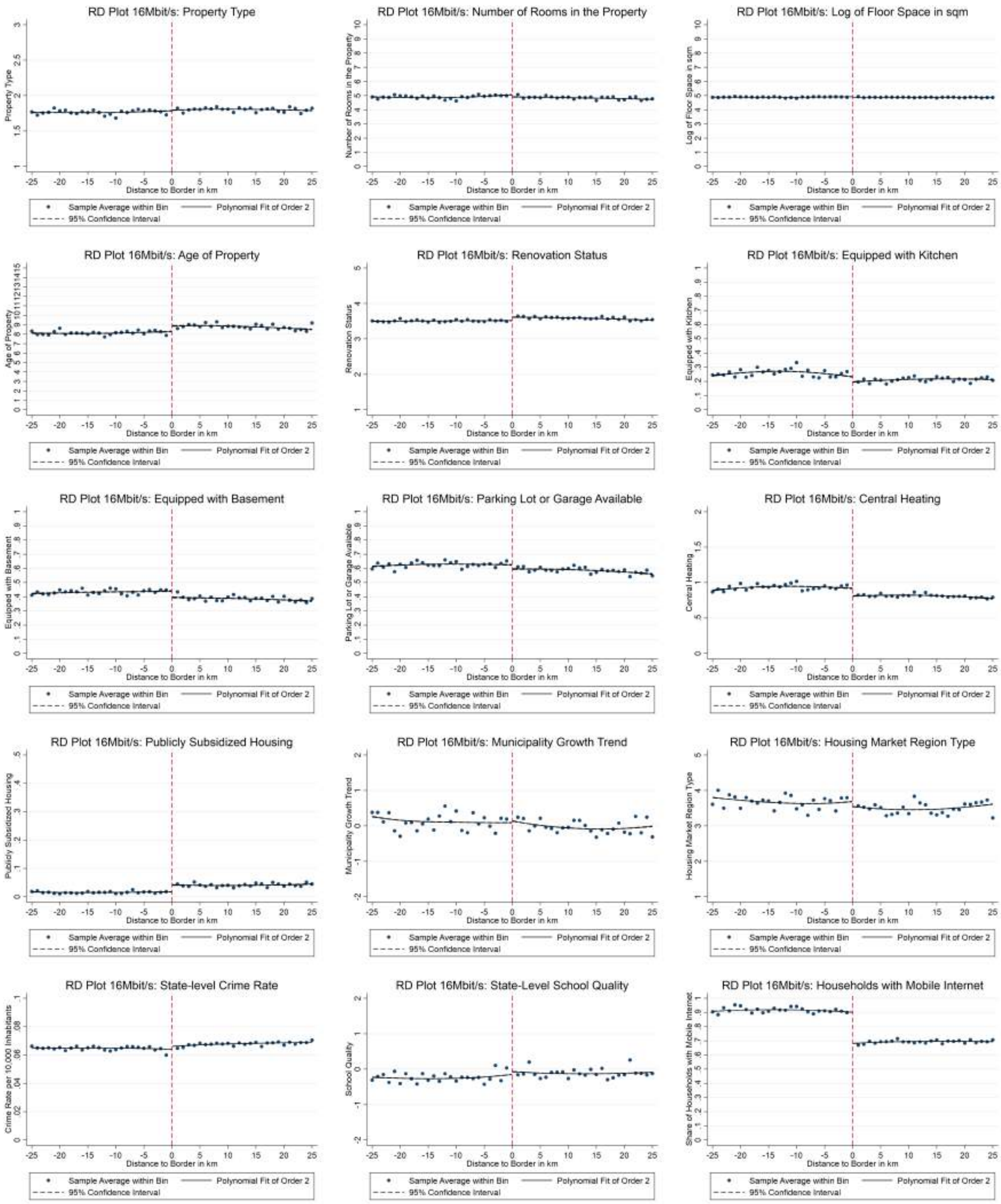


Figure 4: Graphical Evidence of Balanced Covariates Around Interstate Borders

Note: This combined figure of RD plots shows various individual property and regional socioeconomic characteristics around the interstate borders that are used as the boundary in the main analysis. The outcome variables are plotted in levels on the y-axis and distance to border is displayed on the x-axis. The graphs additionally display solid lines for the quadratic fit and dotted lines for the 95 percent confidence intervals. The variables are property type; number of rooms; floor space; age of property; renovation status; equipped with kitchen; equipped with basement; parking lot or garage available; central heating; publicly subsidized housing; municipality growth trend; housing market region type; state-level crime rate; state-level school quality; households with mobile Internet. While the ensuing RD analyses control for all of these property and regional control variables, it is notable that the only other discontinuity around interstate borders is visible for mobile Internet access, which might be due to the same state-level preferences for fast Internet expansion that we exploit as the external variation in our main analysis.

4.2 Main Results

The ensuing table reports the main results of our two-stage spatial RDD. These RDD estimates present the exact empirical results with all control variables and fixed effects. In all three tables in this section and the next, column 1 displays the first stage estimates of the effect of "high" broadband states on broadband availability in municipalities. The reduced form estimates for real estate sale prices and rents are shown in columns 2 and 3, respectively. Since sale prices and rents are logged, it is simple to compare their elasticities. Furthermore, the tables are divided into an upper and a lower panel to reflect the two different specifications of the geographic RDD. The upper panel presents the estimates for linear, quadratic, and linear interacted RDD polynomials in distance to border. In contrast, the lower panel reports results for estimations based on linear, quadratic, cubic, and quartic RDD polynomials in longitude and latitude. Since the latter specification uses two-dimensional geographic information, it more accurately controls for regional differences and thus constitutes our preferred specification. Within the tables, each cell shows the point estimates and standard errors of the "high" broadband state variable from a separate regression. Throughout the specifications, border region and year fixed effects as well as regional socioeconomic controls are employed in all regressions, while individual property controls are only used for the reduced form estimations. We cluster standard errors for the first stage estimations of local broadband availability and use heteroskedasticity-robust standard errors for the reduced form estimates of individual properties.

Main Spatial RDD Estimates	Broadband Availability in Municipalities	Real Estate Sale Prices per sqm	Real Estate Rents per sqm
	(1)	**(2)**	**(3)**
Panel A: RDD Polynomials in Distance to Border			
Linear	0.0999***	0.0602***	0.0525***
	(0.0234)	(0.0020)	(0.0013)
Quadratic	0.0990***	0.0635***	0.0439***
	(0.0174)	(0.0015)	(0.0010)
Linear Interacted	0.1086***	0.0483***	0.0429***
	(0.0202)	(0.0018)	(0.0012)
Panel B: RDD Polynomials in Longitude and Latitude			
Linear	0.0970***	0.0644***	0.0425***
	(0.0174)	(0.0015)	(0.0010)
Quadratic	0.0979***	0.0743***	0.0483***
	(0.0172)	(0.0015)	(0.0010)
Cubic	0.0931***	0.0701***	0.0435***
	(0.0174)	(0.0015)	(0.0010)
Quartic	0.1023***	0.0743***	0.0449***
	(0.0172)	(0.0016)	(0.0011)
Border Region by Year FE	✓	✓	✓
Regional Socioeconomic Controls	✓	✓	✓
Individual Property Controls		✓	✓
Observations		1,333,193	648,519
Municipalities	4,897	4,897	4,570
Data Availability Period	2011-2016	2010-2019	2010-2019

Note: Shown are the coefficients and standard errors for "high broadband state" under different specifications of the RDD polynomials, with each cell in the table reporting the result of a separate regression. Panel A displays estimates for linear, quadratic, and linear interacted RDD polynomials in distance to border, whereas Panel B presents the results for linear, quadratic, cubic, and quartic RDD specifications in longitude and latitude. Property sale prices and rents are log values to facilitate better comparability of the estimates. Standard errors are robust against heteroskedasticity and clustered at the municipality-level for municipal broadband access. *p<0.1; **p<0.05; ***p<0.01.

Table 2: Main Results of the Two-Stage Spatial RDD for 16 Mbit/s Broadband

Table 2 reports the main results of the two-stage spatial RDD for the broadband speed of 16 Mbit/s. The first stage estimates in column 1 show throughout the RDD specifications a significantly positive effect of "high" broadband states on broadband availability in municipalities in the range of 9.5 to 11.2 percentage points. This suggests that the geographic boundary discontinuity of "high" and "low" broadband states indeed has sizable effects on households' local broadband access, even when controlling for regional characteristics, including border region and year fixed effects, and clustering the standard errors at the municipality-level. The effect is identified from variation across 4,985 municipalities over 6 years. The positive and significant result provides evidence that the "high" broadband state instrument is relevant and valid.[12]

Regarding the reduced form estimates, the findings are consistently positive as well. For the real estate sale prices in column 2, the main finding is that "high" broadband states have a significantly positive effect of between 5.2 and 7.7 percent on property prices. Importantly, this result shows that access to high-speed broadband of 16 Mbit/s indeed capitalizes into housing prices. Following the hedonic pricing model, these estimates can be interpreted as house buyers' implicit price for high-speed Internet. This means that their marginal willingness to pay for fast Internet access, for which the consumption is bundled with housing, capitalizes into prices on the property market. This result provides thereby an important answer to our research question.

The estimates for the property rents in column 3 are equally informative and consistent with those for sale prices. The main results find that "high" broadband states capitalize into property rents with a positive price elasticity of between 4.3 and 5.3 percent. Again, all estimates are highly significant across all RDD specifications. The slight difference in the magnitude of the estimates for sale prices and rents might be due to the different structure and legal framework of the German housing market for renting, which restricts landlords' scope in the pricing of rents.[13] We will further investigate these findings by decomposing the effects in additional analyses in the subsequent subsections.

Moreover, it is useful to relate the estimated percentage changes to the average property prices in order to make the results more tangible.[14] For 16 Mbit/s, the average estimated effect on sale prices of 6.7 percent relates to an increase of the price per square meter by 95 euros and of the property price by 13,260 euros. For property rents, the average estimate of 4.8 percent translates into increases of the rent per sqm by 0.29 euros and of the total monthly rent by 23 euros. The absolute values of these broadband premiums, which reflect the implicit market prices and consumer surplus from fast broadband Internet at home, are sizable and might exceed the costs of broadband provision in most regions.

In addition, there is another interesting econometric interpretation of the estimates. Since the "high" broadband state instrument is binary, the Wald estimator can be used to rescale the reduced form estimates by the first stage in order to determine the local average

[12] The relevance of the first stage estimates is underscored by F-statistics, which exceed the threshold of 10 in all RDD specifications.

[13] For instance, in 2015 the German government enacted restrictions for increasing rental prices ("Mietpreisbremse"). Combined with regulations to follow the "rent level" set by municipalities ("Mietspiegel"), the possibilities of landlords to increase rents were considerably limited. This particularly affected new leases, which make up the data under investigation in this study.

[14] The results on prices per square meter and on total prices are reported in Tables 17 and 18 in the Appendix.

treatment effect (LATE) (Angrist and Pischke, 2009). In our analysis, the different units of the first stage (percentage points) and reduced form (percent) complicate this issue. Nevertheless, the Wald estimator implies that for 16 Mbit/s broadband an increase in broadband availability by 10 percentage points is associated with an increase in property sale prices by 6.7 percent. Note that the estimate of a LATE is driven by municipalities "affected" by the instrument, i.e. municipalities whose availability changes with the state becoming a "high" broadband state. Rescaling the estimated effect to calculate the effect of changing availability in a municipality from zero to 100 percent would be invalid, as the price effect is unlikely to be uniformly equal to the effect on marginal municipalities affected by the instrument. Hence our estimates approximate an intention-to-treat effect of broadband expansion in rural areas driven by policy preferences in a state.

Nonetheless the estimated capitalization effects of broadband Internet are large. The absolute amount of 13,260 euros would easily finance the installation of a new kitchen, the renovation of a bathroom or planting a new garden. The sizable implicit price of fast Internet connections reflects consumers' high average willingness to pay, which might however be unequally distributed among house buyers. In comparison to previous studies that investigated the capitalization effects of broadband in other countries, our findings for the German real estate market are of a similar magnitude. For instance, the estimated effects are higher but broadly in the same range as Ahlfeldt et al. (2017) who estimate 2.8 percent for 8 Mbit/s and 3.8 percent for 24 Mbit/s in the United Kingdom. They also compare well to the results by Molnar et al. (2019) of 3 percent for 25 Mbit/s in the United States. Combined, these findings highlight a rather uniform importance of broadband Internet across advanced economies. More broadly, our results for the capitalization effect of high-speed Internet correspond to improved school quality by approximately half a standard deviation (Gibbons et al., 2013). They are higher than the introduction of air pollution regulations in affected American counties (Chay and Greenstone, 2005) as well as the removal of nearby toxic waste sites (Greenstone and Gallagher, 2008). However, the magnitude of the estimated effect is sizably lower than the opening of a new subway line within 600 meters in Singapore (Diao et al., 2017).

4.3 Heterogeneities

Diminishing Returns to Higher Internet Speeds

Having established the main results for the broadband speed of 16 Mbit/s, this subsection turns to higher internet speeds of 30 and 50 Mbit/s. This subsection shows that there are diminishing returns to these higher internet speeds, indicating a lower valuation of households for even faster broadband compared to the baseline speed. Again, the RDD results tables present the estimates of “high” broadband states on broadband availability in municipalities, property sale prices and rents, while differentiating between several RDD specifications in distance to border as well as in longitude and latitude.

Spatial RDD Estimates	Broadband Availability			Sale Prices			Rents		
	16 Mbit/s	30 Mbit/s	50 Mbit/s	16 Mbit/s	30 Mbit/s	50 Mbit/s	16 Mbit/s	30 Mbit/s	50 Mbit/s
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Panel A: RDD Polynomials in Distance to Border									
Linear	0.0999***	0.1239***	0.1735***	0.0602***	0.0178***	-0.0017	0.0525***	0.0094***	0.0295***
	(0.0234)	(0.0183)	(0.0170)	(0.0020)	(0.0032)	(0.0020)	(0.0013)	(0.0016)	(0.0013)
Quadratic	0.0990***	0.1371***	0.1944***	0.0635***	0.0251***	0.0090***	0.0439***	0.0127***	0.0330***
	(0.0174)	(0.0193)	(0.0178)	(0.0015)	(0.0031)	(0.0019)	(0.0010)	(0.0016)	(0.0013)
Linear Interacted	0.1086***	0.1312***	0.1874***	0.0483***	0.0183***	0.0015	0.0429***	0.0095***	0.0294***
	(0.0202)	(0.0189)	(0.0176)	(0.0018)	(0.0031)	(0.0019)	(0.0012)	(0.0016)	(0.0013)
Panel B: RDD Polynomials in Longitude and Latitude									
Linear	0.0970***	0.1386***	0.1948***	0.0644***	0.0231***	0.0065***	0.0425***	0.0114***	0.0298***
	(0.0174)	(0.0192)	(0.0178)	(0.0015)	(0.0031)	(0.0019)	(0.0010)	(0.0016)	(0.0013)
Quadratic	0.0979***	0.1369***	0.1910***	0.0743***	0.0266***	0.0099***	0.0483***	0.0152***	0.0319***
	(0.0172)	(0.0191)	(0.0174)	(0.0015)	(0.0031)	(0.0019)	(0.0010)	(0.0016)	(0.0013)
Cubic	0.0931***	0.1307***	0.1836***	0.0701***	0.0235***	0.0035*	0.0435***	0.0096***	0.0242***
	(0.0174)	(0.0185)	(0.0171)	(0.0015)	(0.0032)	(0.0019)	(0.0010)	(0.0016)	(0.0013)
Quartic	0.1023***	0.1316***	0.1912***	0.0743***	0.0428***	0.0064***	0.0449***	0.0258***	0.0260***
	(0.0172)	(0.0180)	(0.0161)	(0.0016)	(0.0032)	(0.0019)	(0.0011)	(0.0017)	(0.0013)
Border Region by Year FE	✓	✓	✓	✓	✓	✓	✓	✓	✓
Regional Socioeconomic Controls	✓	✓	✓	✓	✓	✓	✓	✓	✓
Individual Property Controls				✓	✓	✓	✓	✓	✓
Observations				1,333,193	566,353	1,479,717	648,519	362,064	752,252
Municipalities	4,897	4,832	4,907	4,897	4,832	4,907	4,570	4,396	4,606
Data Availability Period	2011-2016	2013-2018	2011-2018	2010-2019	2013-2019	2010-2019	2010-2019	2013-2019	2010-2019

Note: Shown are the coefficients and standard errors for "high broadband state" under different specifications of the RDD polynomials, with each cell in the table reporting the result of a separate regression. Panel A displays estimates for linear, quadratic, and linear interacted RDD polynomials in distance to border, whereas Panel B presents the results for linear, quadratic, cubic, and quartic RDD specifications in longitude and latitude. Property sale prices and rents are log values in order to facilitate better comparability of the estimates. Standard errors are robust against heteroskedasticity and clustered at the municipality-level for municipal broadband access. *p<0.1; **p<0.05; ***p<0.01.

Table 3: Heterogeneity by Internet Speeds: Results of the Two-Stage Spatial RDD for 16, 30, and 50 Mbit/s Broadband

The RDD results for the broadband speeds of 30 and 50 Mbit/s are shown in Table 3. At a glance, for these higher speed levels the effects of "high" broadband states are more pronounced for broadband availability in municipalities but are less strong for property sale prices and rents.

In particular, the first stage estimates for broadband availability in municipalities are significantly positive and stand consistently between 12.3 and 13.9 percentage points across all RDD specifications for 30 Mbit/s. Since the elasticity for 30 Mbit/s is approximately 3 percentage points larger than for 16 Mbit/s, this suggests that the differences in the states' broadband expansion programs play a greater role for higher broadband speeds. With respect to the reduced form estimates of real estate sale prices, "high" broadband states have a significantly positive effect of approximately 2 percent, in the quartic longitude-latitude specification even 4.3 percent. For property rents and 30 Mbit/s broadband, the estimated effects are significantly positive averaging about 1 percent, again with a higher estimate of 2.6 percent in the quartic longitude-latitude specification. Combined, the reduced form estimates demonstrate again that high-speed broadband Internet indeed capitalizes into housing prices, suggesting that house buyers have a positive willingness to pay for it. However, there does not seem to be an additional premium for faster speeds, because the magnitude of the estimates falls considerably short of those for 16 Mbit/s. Instead, our results point towards decreasing returns to faster Internet speeds. An alternative explanation for this finding could lie in the different data availability period for 30 Mbit/s broadband speed, which only covers years from 2013 onwards, and a potential change in the importance of high-speed Internet over time. In order to investigate a potential heterogeneity of these effects over time, we conduct a respective heterogeneity analysis in a subsequent subsection.

The highest broadband speed under investigation in our study is 50 Mbit/s. The results for this speed level paint the overall picture that the effect on local broadband availability is even stronger, whereas the effects on property sale prices and rents are somewhat weaker. In particular, the first stage estimates for broadband access in municipalities indicate that "high" broadband states have a significantly positive impact of around 19 percentage points in the preferred RDD specification. This suggests that the states' broadband expansion programs are of even greater importance for the higher broadband speed of 50 Mbit/s. Notably, the data availability period underlying these estimates, which ranges until 2018, is the longest of all broadband speeds for the first stage. Moreover, the reduced form estimates for real estate sale prices in the preferred longitude-latitude specification are significantly positive with an average of about 0.5 percent. In comparison, the results for property rents indicate a more positive effect with price elasticities of around 3 percent. Overall, the reduced form estimates for 50 Mbit/s broadband are in the same ballpark as those for 30 Mbit/s, but considerably lower than for the baseline high-speed broadband of 16 Mbit/s. This suggests that the availability of this higher speed compared to the lower speed is valued less by home buyers and tenants, who have a lower willingness to pay for it. Therefore, our main economic interpretation of these results for 50 Mbit/s is again that there are decreasing returns to broadband Internet speed. An alternative interpretation could be that consumers require less than 50 Mbit/s broadband to maximize their utility given current subscription prices and therefore have a lower willingness to pay for this higher speed level.

While the spatial RDDs for 30 and 50 Mbit/s have consistently shown that broadband availability indeed capitalizes into real estate prices, it is again useful to relate the estimated percentage changes to the average property prices. For 30 Mbit/s, the average estimated effect on sale prices of 2 percent relates to an increase of the price per sqm by 28 euros and of the property price by 3,960 euros. For property rents, the average estimate of 1 percent translates into increases of the rent per sqm by 0.07 euros and of the total monthly rent by 5 euros. Likewise, the capitalization effects for 50 Mbit/s broadband relate to property sale price increases of 7 euros per sqm and of 990 euros in total. For rents, the average estimate of 3 percent is equal to higher square meter prices of 0.19 euros and of total monthly rents by 14 euros.

Increasing Value of Higher Internet Speeds over Time

Faster Internet speeds tend to enable new applications, which in turn make faster Internet speeds more useful. These applications take time to be developed and may require a user base of a certain size due to network effects. Therefore the value of higher speeds may increase over time. This subsection analyzes the heterogeneity of the main results of the two-stage geographic RDD with regard to the time period under investigation, showing the coefficients for an interaction term of the "high broadband state" variable with a dummy which is equal to one for the years from 2015 and later for 16 Mbit/s, 2016 and later for 30 Mbit/s and 2017 and later for 50 Mbit/s. The results are reported in Table 4.

With regard to the estimates for 16 Mbit/s, it is notable that the effects of "high" broadband states on broadband availability in municipalities are marginally stronger but generally comparable. However, the reduced form estimates are heterogeneous. The size of the effects on property sale prices increases slightly in most specifications and significantly by 3 percentage points in the preferred longitude-latitude RDD specification compared to the baseline estimate of approximately 7.4 percent. By contrast, the estimated impact of "high" broadband states on real estate rents is significantly lower for the time period after 2015. One reason for this difference between sales and rents in the change of the effect over time could be that owners may expect to stay longer than tenants, which is in line with the lower effect on rents in our main results.

The first stage results on the effect of "high" broadband states on broadband availability for 30 Mbit/s in column 2 are very similar in terms of significance and magnitude to those for 16 Mbit/s in column 1. The corresponding results for 50 Mbit/s in column 3, by contrast, are negative, although less significant. This negative coefficient on the interaction term is evidence of lagging states catching up especially on very fast Internet connections, e.g. by leap-frogging technologies with lower connection speeds.

Column 5 shows that the effect of “high” broadband states on sale prices increases over time. In the preferred longitude-latitude RDD specification it increases by about 2.5 percentage points, a more than 50 percent increase in effect size. For rents, the effect changes less across most specifications in column 8, but is sizable and positive in our preferred specification.

Interestingly, despite the fact that the advantage of the better connected states for 50 Mbit/s decreases in later years, the results in columns 6 and 9 of Table 4 indicate that the difference in sale prices and rents does not decrease. In our preferred specification, it even increases further, implying that the increased value of very fast Internet connections over time dominates the effect of lagging states catching up.

Combined, these findings suggest a divergence in the estimated price elasticities over time, with indications for a stronger effect in more recent years. The increased capitalization of broadband access into house prices could indicate a rise in households' willingness to pay for fast Internet over time. Notably, there are also less “low” broadband states in the post-2013 samples, but they saw a more sizable impact on housing prices.

Spatial RDD Estimates	Broadband Availability			Sale Prices			Rents		
	16 Mbit/s	30 Mbit/s	50 Mbit/s	16 Mbit/s	30 Mbit/s	50 Mbit/s	16 Mbit/s	30 Mbit/s	50 Mbit/s
	>= 2015	>= 2016	>= 2017	>= 2015	>= 2016	>= 2017	>= 2015	>= 2016	>= 2017
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Panel A: RDD Polynomials in Distance to Border									
Linear	0.0839***	0.0843***	-0.0447	0.0046	0.0206***	0.0635***	-0.0427***	0.0009	0.0033
	(0.0268)	(0.0245)	(0.0304)	(0.0041)	(0.0060)	(0.0051)	(0.0022)	(0.0031)	(0.0029)
Quadratic	0.0835***	0.0812***	-0.0637**	0.0051	0.0187***	0.0548***	-0.0437***	-0.0002	-0.0007
	(0.0269)	(0.0246)	(0.0303)	(0.0041)	(0.0060)	(0.0051)	(0.0022)	(0.0031)	(0.0029)
Linear Interacted	0.0846***	0.0831***	-0.0564*	0.0038	0.0207***	0.0612***	-0.0435***	0.0007	0.0034
	(0.0270)	(0.0246)	(0.0305)	(0.0041)	(0.0060)	(0.0051)	(0.0022)	(0.0031)	(0.0029)
Panel B: RDD Polynomials in Longitude and Latitude									
Linear	0.0866***	0.0795***	-0.0586*	0.0017	0.0238***	0.0494***	-0.0443***	0.0028	0.0015
	(0.0267)	(0.0247)	(0.0302)	(0.0041)	(0.0060)	(0.0051)	(0.0022)	(0.0031)	(0.0029)
Quadratic	0.0893***	0.0830***	-0.0562*	0.0085**	0.0255***	0.0613***	-0.0331***	0.0104***	0.0132***
	(0.0266)	(0.0243)	(0.0299)	(0.0041)	(0.0060)	(0.0051)	(0.0023)	(0.0032)	(0.0029)
Cubic	0.0844***	0.0851***	-0.0576**	0.0114***	0.0279***	0.0619***	-0.0346***	0.0127***	0.0116***
	(0.0254)	(0.0242)	(0.0286)	(0.0041)	(0.0060)	(0.0051)	(0.0023)	(0.0032)	(0.0029)
Quartic	0.0669***	0.0733***	-0.0537*	0.0315***	0.0252***	0.0746***	-0.0077***	0.0198***	0.0352***
	(0.0251)	(0.0233)	(0.0283)	(0.0042)	(0.0061)	(0.0051)	(0.0023)	(0.0032)	(0.0030)
Border Region by Year FE	✓	✓	✓	✓	✓	✓	✓	✓	✓
Regional Socioeconomic Controls	✓	✓	✓	✓	✓	✓	✓	✓	✓
Individual Property Controls				✓	✓	✓	✓	✓	✓
Observations	1,333,598	566,571	1,479,515	1,333,598	566,571	1,479,515	648,658	363,651	752,722
Municipalities	4,897	4,832	4,907	4,897	4,832	4,907	4,570	4,396	4,606
Data Availability Period	2010-2019	2010-2019	2010-2019	2010-2019	2010-2019	2010-2019	2010-2019	2010-2019	2010-2019

Note: Shown are the coefficients and standard errors for an interaction term of the "high broadband state" variable with a dummy denoting one for the later years in the sample under different specifications of the RDD polynomials, with each cell in the table reporting the result of a separate regression. Panel A displays estimates for linear, quadratic, and linear interacted RDD polynomials in distance to border, whereas Panel B presents the results for linear, quadratic, cubic, and quartic RDD specifications in longitude and latitude. Property sale prices and rents are log values in order to facilitate better comparability of the estimates. Standard errors are robust against heteroskedasticity and clustered at the municipality-level for municipal broadband access. *p<0.1; **p<0.05; ***p<0.01.

Table 4: Heterogeneity by Time: Results of the Two-Stage Spatial RDD for 16, 30, and 50 Mbit/s Broadband

Property and Municipality Types

The main results reported the estimates for a pooled sample of all houses and apartments offered for sale or for rent. The heterogeneity analysis aims to identify potential drivers of the effects on real estate sale prices and rents by separately estimating the elasticities for houses and apartments. In order to allow for a comparison with the main results, we use the baseline samples. Tables 12 in the Appendix reports the results of this heterogeneity analysis. Taking a closer look at the elasticities for the broadband speed of 16 Mbit/s, it becomes clear that the effect on both sale prices and rents is higher for houses than for apartments. One reason for this difference may be lower average moving costs for apartments, whether owned or rented, such that the value of a fast Internet connection is expected to be useful for a shorter time horizon.

Table 13 provides another heterogeneity analysis, splitting the sample based on municipality types. The results show that capitalization effects are more pronounced in slightly more populated municipalities compared to their very rural counterparts. This is the case for both sale prices and rents. While the effects are significantly positive throughout the sample, this heterogeneity may be relevant for the optimal prioritization of regions in broadband expansion policies.

5 Robustness Checks

In the following, we provide a comprehensive battery of robustness checks that aim to underscore the validity of the main results. Our robustness checks address a wide range of potential concerns regarding our two-stage spatial RDD, using specification checks, varying the German states and regions in the sample, and Placebo tests.

5.1 Specification Checks

This subsection carries out several specification checks to investigate potential sensitivity of the estimates to different RDD specifications. The first set of specification checks uses different bandwidths, both larger and smaller than the main bandwidth of 25 kilometers around state borders. In Figures 25 and 26 in the Appendix, we present graphical evidence in RD plots for bandwidths of 5 and 50 kilometers, respectively. Table 14 complements the graphs with the corresponding RDD estimates for the smaller and larger bandwidths, as well as the 25 kilometer bandwidth for comparison. Overall, both the figures and the estimation results show that the effects hold and our main results do not qualitatively depend on the specific choice of bandwidth in our main specification. The magnitude of the effect size is somewhat lower with the 5 and 50 kilometer bandwidths. The main 25 kilometer bandwidth balances the advantages and disadvantages of changing the bandwidth. A narrower area around interstate borders leads to more similar locations and regional characteristics, but properties that are very close to the border may be peculiar in other ways. Furthermore, as Table 14, the 5 kilometer bandwidth leads to a much smaller sample size. By contrast, a larger area around the borders increases the sample size, but implies that properties are more distant from each other and thus less comparable.

As an additional specification check specifically aimed at the issue that properties that are very close to the border may not be representative of rural municipalities overall, Table 15 in the Appendix applies a "donut hole" approach. While the bandwidth is again 25 kilometers, as in our main specification, properties which are very close to the border are excluded. The table shows that omitting a 2, 5, or 10 kilometer radius from the border does not change the effect of “high” broadband states on sale prices and rents much either.

In a next step, we study the sensitivity of our results to the inclusion of border region by year fixed effects control variables in Table 16 in the appendix. The results show that fixed effects are necessary to account for a sizable share of the differences in availability, sale prices and rents between border regions. The effects on all three outcomes are reduced only slightly with when regional socioeconomic controls and individual property controls are added.

5.2 Robustness Checks on Sample

The following robustness checks show that our results do not rely on any particular region or state in our sample. The estimates essentially hold when we leave individual border regions out or run the RDD separately for East and West Germany, without Bavaria in 2018-2019, and without Rhineland-Palatinate.

As a first robustness check, we examine the role of former East Germany as a potential driver of the effects. The reasoning is that even though Germany was reunified in 1990, there are still notable differences between the old and new German states. With the German reunification, the states Brandenburg, Mecklenburg-Western Pomerania, Saxony, Saxony-Anhalt, and Thuringia were created and the former West and East Berlin were merged into today’s city state of Berlin, which is a city state and not included in our sample. The concern is that the structural differences of former East Germany could potentially induce omitted variable bias. It is worth emphasizing that part of the comparison along the borders of “high” and “low” broadband states include purely East German border regions. Nevertheless, it is important to investigate whether the estimated effects of the two-stage geographic RDD remain positive and significant when estimating with a subsample of only West German states. In Appendix F.1.2, we estimate the RDD without the East German states. The overall finding is that all estimates remain significantly positive. For the first stage estimates of broadband availability in municipalities, there is a notable reduction for the broadband speeds of 16 Mbit/s with estimates ranging between 5.2 and 8.1 percentage points. Regarding the reduced form estimates of property sale prices and rents, the estimates are significantly positive in this subsample and of a similar magnitude as in our main results. Combined, these findings suggest that East Germany does not drive sign of the effects, but rather might have an attenuation bias on the reduced form estimates.[15]

In the second robustness check, we address a potential concern based on a recent study by Krolage (2020), which showed that the Bavarian state subsidy for real estate purchases capitalized into property prices. From 2018 onwards, the Bavarian state government paid eligible owner-occupiers a purchase subsidy of 10,000 euros ("Bayerische Eigenheimzulage").[16] Although aimed at reducing purchasing costs, Krolage (2020) finds that the subsidy passed through into housing prices, increasing the prices of Bavarian real estate more than in neighboring states. Since Bavaria is considered a "high" broadband state in 2018 and 2019, this could positively bias the RDD estimates through Bavarian border regions with "low" broadband states. For an investigation of this potential problem, we estimate the geographic RDD without Bavaria for the years 2018 and 2019. The results are shown in Appendix F.1.4. The estimated effects hardly change at all, which is further underscored by the fact that dropping Bavaria in those years resulted in losing only between 5,000 and 15,000 observations from sample sizes between 650,000 and 1.3 million. This is because in 2018 and 2019 almost all states surrounding Bavaria were already classified as "high" broadband. Therefore, we conclude that the Bavarian real estate purchase subsidy does not affect our RDD estimates.

The third robustness check investigates the role of Rhineland-Palatinate. The state is characterized by a unique municipality structure with lots of very small municipalities. This structure contrasts with other states, which have conducted territorial reforms over the years and merged formerly independent communities. In addition, Rhineland-Palatinate was a "low" broadband state for the broadband speed of 16 Mbit/s until 2013. One might thus argue that Rhineland-Palatinate's municipality structure in combination with the states' slow roll-out of high-speed broadband Internet could affect the results. Therefore, we estimate the two-stage spatial RDD without Rhineland-Palatinate. The results are provided in Appendix F.1.5. In comparison to the main results, the estimated effects on broadband availability in municipalities are slightly higher with an average of approximately 12.5 percentage points. For the reduced form effects on property sale prices and rents, the estimated elasticities are slightly lower with about 4.6 percent for sale prices and 1.2 percent for rents, but remain significantly positive. Thus, it can be ruled out that the unique municipality structure of Rhineland-Palatinate drives the effects.

A fourth robustness check in Appendix F.1.6 adds bigger cities to the sample. The effects of "high" broadband states on availability, sale prices and rents are significantly

[15] For completeness, Appendix F.1.3 reports the results for a sample consisting only of East German states as well, with overall similar results.

[16] At the same time, the German government implemented a real estate purchase subsidy ("Baukindergeld"), which was eligible to all German households. Since this policy can be regarded as a common shock to housing market, it is not relevant to our geographic boundary RDD. This potential problem is additionally alleviated by the inclusion of fixed effects.

positive and larger than in our main sample.

Further results show the robustness of our results to increasing or decreasing the cutoff for the classification of “high” broadband states (from 75 to 85 or 65 percent; see Appendix F.3) and to the addition of further controls for population density, gender and age composition as well as commuting times (Appendix F.2). [17]

5.3 Placebo Tests

We conduct placebo tests, because the correctness and validity of an RDD can never be fully proven, but standing up to falsification checks provides suggestive evidence for a causal effect (Cattaneo et al., 2019). The way in which this paper conducts falsification checks is to test for placebo outcomes. Specifically, we use the control variables as dependent variables instead of the main outcomes of interest. In the best case, the estimated effects of the “high” broadband coefficient are hardly significant.

In the Appendix, we report two types of placebo tests. In Table 29, four property control variables are tested as dependent variables of “high” broadband states in the main sample for 16 Mbit/s broadband: the number of rooms in the property, the floor space in sqm, the building age, and the indicator for sophisticated equipment. As described in the descriptive statistics in Table 1, properties in “high” and “low” broadband states share fairly similar characteristics. It is thus good to see that most estimates are not significant. Likewise, we test the regional controls as placebo outcomes. The findings in Table 30 suggest that that the municipality growth trend, the housing market region type, the state-level school quality, the state-level crime rate per 10,000 inhabitants, and mobile Internet availability are significant. This might be due to the large sample size of more than 1.3 million observations.

Our interpretation of these placebo tests is that our two-stage spatial RDD seems largely valid, with most of the placebo estimates remaining insignificant. It is also important to note that these mixed placebo regression results need to be treated with caution, because the placebo outcomes were not pre-determined. For the individual properties, there is a complete lack of data regarding property characteristics before the broadband roll-out. In fact, these property characteristics were observed simultaneously with the outcome variable of interest, the sale price or rent. Similarly, the regional socioeconomic control variables that, which the placebo tests used as dependent variables, were observed during the time period under investigation.

6 Mechanisms and Internet Usage

Any conceivable causal channel from broadband access to real estate prices and rents runs through Internet usage. I.e. uptake is necessary for any sale price or rent effect,

[17] Appendix F.4 adds descriptive evidence on the validity of our instrument.

regardless of the specific applications driving demand such as video conferencing for work from home, streaming or gaming for entertainment, and various others.

Hence, the observed capitalization effects of “high” broadband states on property sale prices and rents are due to households’ demand for fast Internet connections. However, both current and expected future demand affect capitalization. Therefore, this section explores the relationship between availability of fast Internet access and the speed levels households actually purchase from their providers.

In exploring households’ current Internet usage as one potential channel of the effects, our objective is to find out whether people in “high” broadband states actually use more and faster Internet connections than those in neighboring “low” broadband states. To examine this mechanism, we draw on survey data from the 2018 German micro-census that provide information on regional variation in broadband usage. Importantly, this dataset allows us to correlate households’ actual Internet usage with the mere broadband availability that we used for our main analyses.[18] In particular, the micro-census contains information about which Internet speeds households have chosen according to their contracts. If there is significant uptake, i.e. households in counties with faster available speeds actually purchase faster plans from their providers, this suggests that capitalization effects are driven by contemporary demand. By contrast, if there is little uptake, capitalization effects are driven primarily by expectations about future demand.

Table 5 shows descriptive statistics on available and contractual speed levels in municipalities. Panel A displays the availability of different speed levels in the respective groups of municipalities for 16, 30, and 50 Mbit/s. Panel B portrays the speeds purchased by households from their Internet providers in those municipalities according to the micro-census. The speed categories in Panel B differ from Panel A due to the answer options provided in the survey. The three sets of columns split the sample according to whether the German states have been "early adopters" of 16, 30, and 50 Mbit/s, respectively, i.e. whether they were among the earlier half of states in our sample to be classified as “high” broadband states for this speed level. This adjustment of the classification is necessary as in 2018, the only year with the relevant question in the micro-census, all states were already classified as “high” broadband states for 16 Mbit/s. For consistency, the same approach is applied to 30 and 50 Mbit/s. Thus variation comes from the differences in how long these speed levels have been available in states, not from whether it was available at the time of the survey. Another reason for this approach is that uptake likely follows availability with some delay, e.g. households might switch provider and upgrade once their existing contracts expire. “Early adopter” states are classified as “high” broadband states for 16 Mbit/s for more than six years in the sample, i.e. they have become a “high” broadband state in 2013 or earlier. The samples in the first, second, and third column correspond to the samples used in the main analyses for 16, 30 and 50 Mbit/s, respectively.

[18]Micro-census responses are available at the county level. We merge the municipalities in our sample to the counties they belong to.

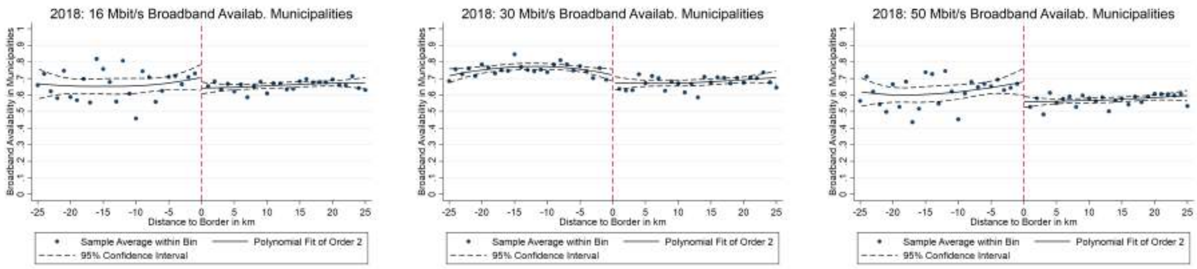
	High Broadband States 16 Mbit/s			High Broadband States 30 Mbit/s			High Broadband States 50 Mbit/s		
	Early	**Late**	**Diff**	**Early**	**Late**	**Diff**	**Early**	**Late**	**Diff**
	(1)	(2)		(3)	(4)		(5)	(6)	
Panel A: Broadband Availability in Municipalities									
16 Mbit/s	71.34	63.07	8.27	72.12	52.98	19.15	70.33	59.84	10.49
30 Mbit/s	76.97	67.36	9.61	76.96	57.22	19.75	74.63	65.17	9.46
50 Mbit/s	66.08	53.26	12.81	64.93	41.77	23.16	63.57	49.57	14.00
Panel B: Speed of Households' Purchased Internet Contracts									
>6 Mbit/s	72.99	72.05	0.94	71.80	73.61	-1.80	72.14	72.73	-0.59
>16 Mbit/s	52.38	43.64	8.74	49.18	41.18	8.01	48.75	44.01	4.74
>50 Mbit/s	19.21	13.05	6.16	16.86	11.56	5.30	17.14	12.59	4.54
Municipalities	1,764	3,118	4,882	3,381	1,436	4,817	2,872	2,019	4,891

Note: This table shows the share of households in the micro-census reporting that they have a contract with their Internet provider offering a speed above 6, 16 and 50 Mbit/s, respectively. The first pair of columns uses the sample of municipalities used for the main analyses with 16 Mbit/s. Municipalities are split based on whether their state has been an early adopter or a late adopter, i.e. whether they are among the earlier half of states to be classified as a high broadband state for this speed. The second pair of columns is divides the municipalities from the 30 Mbit/s sample from the main analyses based on whether their state is a high broadband state for 30 Mbit/s in 2018. The third pair of columns uses the 50 Mbit/s sample and also splits according to 50 Mbit/s availability in 2018.

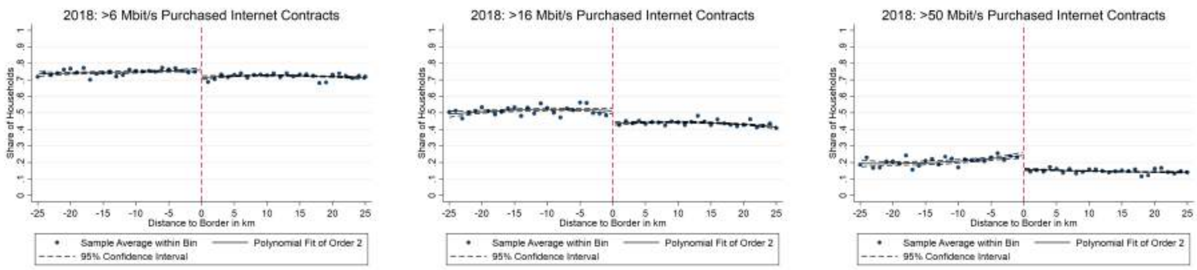
Table 5: Mechanism: High-Speed Internet Availability and Households' Uptake Based on the German Micro-Census

Panel A shows that the availability of at least 16 Mbit/s is 8 percentage points higher in early adopters than in late adopters of this speed. For 30 Mbit/s availability, there is a 10 percentage point difference in the first set of columns. Comparing these numbers to the uptake of Internet connections with more than 16 Mbit/s shows that the difference is roughly the same. Thus there seems to be significant contemporary demand for these Internet speeds and additional availability is used fully. In the second set of columns, which splits the 30 Mbit/s sample into early and late adopting states of 30 Mbit/s, the difference in availability of 30 Mbit/s is more pronounced (20 percentage points). The difference in uptake of connections faster than 16 Mbit/s is 8 percentage points, i.e. slightly less than half the difference in availability. The third set of columns allows us to evaluate demand for the fastest available Internet connections, splitting the 50 Mbit/s sample into early and late adopters of 50 Mbit/s. The availability of 50 Mbit/s in municipalities in states which were early adopters is 14 percentage points higher than in late adopters. The difference in uptake of Internet connections above 50 Mbit/s, however, is only about one third of that. Despite the imperfect match of speed levels in the two data sets, these statistics suggest that there is sizable contemporary demand for broadband Internet above 16 Mbit/s. In line with diminishing returns to speed, we find lower demand for very fast connections. The data only show the situation in 2018, however, and capacity utilization for higher speeds is likely to increase over time, in line with our results on the increasing value of fast Internet connections over time. Also, providers may lower prices for these speeds eventually. Overall capitalization effects seem to be driven by current demand and not primarily by expectations about future needs. In addition to these statistics and discounting of future utility, a further argument for why contemporary demand should matter more for capitalization than expected future demand, is that participants in the market may expect availability to increase everywhere eventually, e.g. through further broadband expansion policies.

Note that an increase in purchased speeds in regions where higher speed is available can have multiple reasons. First, we cannot observe unmet demand for higher speeds in regions where such connections are not offered yet. Thus, part of the increase in uptake is simply that this demand can be met as a result of broadband expansion, as suggested by the descriptive statistics. Second, network effects may play a role and increase demand even for lower speeds that have already been available before the broadband expansion. For instance, colleagues and neighbors with faster Internet connections may start using video calls, making speeds that are just fast enough to allow such applications more attractive. Third, behavioral effects may lead users to choose intermediate speeds among those offered by Internet providers. This may increase demand for a speed that used to be the highest available one before expansion. Finally, advertisements and increased salience of broadband access may increase demand among the population for all speeds.



(a) *Broadband Availability in Municipalities*



(b) *Households' Purchased Internet Speed Contracts*

Figure 5: Spatial RD Plots for Broadband Availability and Purchased Internet Speed
Note: Shown are the RD plots of the outcomes broadband availability and purchased speed, each at three different speed levels, of the two-stage geographic RDD in the distance to border specification for each of the broadband speeds 16, 30, and 50 Mbit/s. The outcome variables are plotted in levels on the y-axis and distance to border is displayed on the x-axis. The data-driven RD plots were generated by an evenly spaced number of bins, representing the sample average within each bin. The graphs additionally display solid lines for the quadratic fit and dotted lines for the 95 percent confidence intervals. The RD plots display the raw observations with fixed effects for property sale prices and rents, whereas border region fixed effects and control variables are not included.

Figure 5 allows a visual comparison of the three pairs of groups of municipalities in Table 5 and shows the discontinuity at the state border. In Figure 5a, for all three speed levels, the availability on the left side, i.e. in the "high" broadband states, is higher than on the right side. In Figure 5b, the discontinuity in purchased Internet speeds is clearly visible. The discontinuity appears even sharper for purchased speeds than for availability, which may be due to network effects or offered plans by Internet providers. The figures are in line with significant contemporary demand for fast Internet connections as the main driver of the capitalization effects identified in the main analysis.

7 Conclusions

The main conclusion of our empirical analysis is that high-speed broadband Internet availability indeed capitalizes into real estate prices in Germany. This result is established based on exploiting the quasi-experiment of German states' different broadband expansion programs, which induced variation that was plausibly exogenous to individual house buyers and tenants, and using a novel and large micro-dataset. Using a two-stage spatial

RDD with specifications in distance to border and in longitude and latitude to compare municipalities and properties along boundary regions, we estimate the local causal intention-to-treat effects. The first stage results consistently show that "high" broadband states have a significantly positive effect of at least 10 percentage points on broadband availability in municipalities. Regarding the main outcomes of interest, the reduced form estimations reveal that real estate sale prices increase by 5.2 to 7.7 percent in "high" broadband states. Reflecting implicit market prices for high-speed Internet access at home, these capitalization effects relate to sizable increases of average property prices by about 95 euros per square meter and between 13,300 euros in total. For property rents, our analyses find capitalization effects of between 4.3 to 5.3 percent, which relate to increases of monthly rents by 0.29 euros per square meter and 23 euros in total. We find that consumers have the highest willingness to pay for 16 Mbit/s broadband rather than for 30 Mbit/s or 50 Mbit/s, which indicates decreasing returns from broadband speed, at least once a desired speed level is reached. In addition, we find increasing effects over time. Through a battery of specification, robustness and placebo checks, we establish the validity our spatial RDD.

The main policy implication based on these key findings is that high-speed broadband Internet should be expanded to maximize consumer surplus. In view of consumers' sizable willingness to pay for fast broadband Internet access at home, it should be a political priority to reduce inequality in broadband availability, thereby facilitating equal social participation, and in times of the pandemic, working from home and digital schooling. The insights from this paper are highly relevant to the policy debate and could contribute to the ongoing evaluation of broadband expansion in Germany.

Future research is required regarding the heterogeneous capitalization effects of broadband Internet in property sale prices and rents as well as the role of urban and rural areas as potential additional drivers of the estimated effects. Moreover, the changing importance of different broadband speeds and changing use of the Internet over time could be interesting avenues for future research.

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A Broadband Expansion Policies in Germany's Federal States

Broadband Expansion Programs in the 16 Federal States: Part I

Federal State	Time Period	State's Broadband Expansion Program	Expansion Program Type	Expansion Program Details
Baden-Württemberg	2008-2009	Rural Broadband Initiative [1]-[4]	Financial funding as an investment cost subsidy	Financial funding for municipalities in rural areas with no or insufficient broadband coverage of EUR 20 million.
	2015-2022	Baden-Württemberg Broadband initiative II / Baden-Württemberg NGA funding regulation [5]-[8]	Financial funding in the operator model	Financial funding for municipalities, associations of municipalities and rural districts in rural-and commercial areas on the outskirts of towns that are in "NGA white and grey areas", after an internal revision by a specialist office or by the Landesanstalt für Kommunikation Baden-Württemberg and an approval from the European Commission in the case of "NGA grey areas", amounting to EUR 253.6 million.
			Support of a simplified legal framework	Financial funding of coordination and management operations in inter-municipal cooperations in the construction of NGA networks, leading to economies of scale of public authorities and thus speeding up the application process.
Bavaria	2008-2010	Broadband development in rural areas of Bavaria [9]	Financial funding in the profitability gap model	Financial funding for small and medium-sized enterprises in rural areas of Bavaria with little or no existing broadband use, after a verification by public authorities regarding the project's profitability gap, amounting to EUR 20 million.
	2012-2019	Directive on the funding of the establishment of high-speed networks in the Free State of Bavaria [10]-[11]	Financial funding in the profitability gap model	Financial funding for municipalities, associations of municipalities and municipal associations in the Free State of Bavaria where an improvement in existing broadband coverage can be achieved, amounting to EUR 1.5 billion.
			Support of a simplified legal framework	Financial funding in the form of an increase in the maximum funding amount in the case of inter-municipal cooperation.
Berlin	2014-2020	Law on the Joint Task "Improvement of the Regional Economic Structure" (GRW Law) [12]	Financial funding in the profitability gap model and operator model	Financial funding for the measure sponsors, Berlin districts, natural persons or legal entities that are not profit-oriented in "NGA white" commercial areas/commercial collections, after a market investigation procedure and an application to the Senate Department for Economic Affairs, Energy and Operations.
			Support of a simplified legal framework	Direct funding of network operators, eliminating thus administrative burdens on districts.
Brandenburg	from 2013 onwards	Brandenburg Fiber Optics 2020 [13]-[15]	Financial funding as an investment cost subsidy	Financial funding for TC companies in areas with no connection to backhaul fiber-optic networks and in which broadband coverage cannot be attributed to competing broadband infrastructures, amounting to EUR 94 million.
Bremen	2014-2021	GA/GRW funding program [16]	Financial funding in the profitability gap model	Financial funding in areas that lack NGA infrastructure and in "NGA white areas". The determination of "NGA white areas" must be verified within the scope of a market investigation procedure. The classification of Bremen into a C or D funding area, according to which the funding rate can vary, should be noted. Bremen remains a GRW eligible area beyond 2021.
Hamburg	from 2015 onwards	Federal funding program for broadband expansion [17]-[18]	Financial funding in the profitability gap model, operator model and in consulting services	Financial funding for local authorities in which the project area is located, especially municipalities, city states, administrative districts, municipal special-purpose associations or another local authority or an association under the respective local authority law of the federal states.
Hesse	2016-2020	Directive on the funding of broadband supply in the state, Hesse-Part 6: Federal state funding for broadband infrastructure expansion [19]-[20]	Financial funding in the profitability gap model and operator model	Financial funding for municipalities, associations of municipalities, local authorities and 100 publicly owned private companies in areas with no broadband coverage, amounting to EUR 46 million from the digital dividend II and from federal state funds.
			Support of a simplified legal framework	Financial funding of coordination and management operations in inter-municipal cooperations in the construction of NGA networks, leading thus to economies of scale of public authorities and speeding up the application process.
Mecklenburg-Western Pomerania	from 2015 onwards	Federal funding program for broadband expansion [21]-[22]	Financial funding in the profitability gap model, operator model and in consulting services	Financial funding for local authorities in which the project area is located, especially municipalities, city states, administrative districts, municipal special-purpose associations or another local authority or an association under the respective local authority law of the federal states, amounting to EUR 520 million as co-financing for the government funds and for the municipal share.

Note: All federal states offer financial funding as project share financing in the form of a non-repayable grant. Baden-Württemberg also offers the possibility of a fixed grant as funding. In the states Berlin, Bremen, Hamburg and Mecklenburg-Western Pomerania the programs are not state funding programs, but federal funding programs for broadband expansion or other, such as the GRW funding program.

Table 6: Broadband Expansion Programs Part I

Broadband Expansion Programs in the 16 Federal States: Part II

Federal State	Time Period	State's Broadband Expansion Program	Expansion Program Type	Expansion Program Details
Lower Saxony	2016-2021	Directive Broadband Expansion Lower Saxony [23]-[27]	Financial funding in the operator model	Financial funding for local authorities, joint municipalities and municipal associations, after an application to the Nbank, amounting to EUR 58 million from the digital dividend II.
	from 2019 onwards	Directive Giganet Expansion Lower Saxony [28]	Financial funding in the profitability gap model and operator model	Financial funding in counties, independent cities, the Hanover region and local authorities (first-time recipients) that are "NGA white areas".
North Rhine-Westphalia	2016-2021	Directive on the granting of subsidies to promote NGA in rural areas [29]	Financial funding in the profitability gap model and operator model	Financial funding for municipalities, associations of municipalities and districts in residential areas, mixed areas and rural areas in North Rhine-Westphalia with a funding volume taken from the digital dividend II and the Eler.
Rhineland-Palatinate	2015-2020	Directive on the funding of the rollout of high-speed broadband networks [30]-[31]	Financial funding in the profitability gap model and operator model	Financial funding for administrative districts, associations of associations, municipalities not belonging to associations, special-purpose associations and legally responsible institutions under public law in "NGA white areas", after a review by the Ministry of the Interior, Sports and Infrastructure and often a feasibility study, amounting to EUR 124.7 million.
Saarland	2019-2022	Directive on the funding of individual fiber-optic connections for high-demand customers in the Saarland ("Gigabit Premium") [32]	Financial funding	Financial funding for businesses, cultural institutions, and non-profit organizations in the Saarland that need a fiber-optic connection ("high-need users").
Saxony	2018-2023	Directive Digital Offensive Saxony [33]-[34]	Financial funding in the profitability gap model, operator model and in consulting services	Financial funding, based on the federal funding program, for consulting services of broadband projects and for hot spots/WLAN in public areas relevant to tourism, amounting to EUR 200 million from state funds, EUR 80 million from EU funds and EUR 32 million from the digital dividend II.
Saxony-Anhalt	from 2015 onwards	Directive on the granting of subsidies to fund next generation access - broadband expansion in Saxony-Anhalt [35]-[36]	Financial funding in the profitability gap model, operator model and in consulting services	Financial funding for municipalities, including administrative districts, and special-purpose municipal associations, amounting to EUR 350 million (70 million from EAFRD, 24 million from EFRD, 4 million from federal government, other funds).
			Support of a simplified legal framework	Funding for certified broadband consultants who support and advise grantees on broadband investments. Funding for planning services only if these are provided by certified broadband consultants.
Schleswig-Holstein	2017-2021	Directive on the promotion of broadband supply in rural areas of Schleswig-Holstein (Broadband Directive) [37]-[38]	Financial funding in the profitability gap model, operator model and in consulting services	Financial funding for municipalities and associations of municipalities in rural areas, with proof of a lack of or inadequate broadband supply, amounting to EUR 71 million (EUR 36 million from GAK, EAFRD, GRW, EUR 14 million from the state of Schleswig-Holstein, EUR 21 million from the digital dividend II).
Thuringia	2017-2020	Directive of the Free State of Thuringia to promote the expansion of high-performance broadband infrastructures (Broadband Expansion Directive) [39]-[40]	Financial funding in the profitability gap model, operator model and in consulting services	Financial funding for local authorities, associations of local authorities or mergers of local authorities in the Free State of Thuringia, public-law companies, companies organized under private law and owned by public-law bodies, and private TC companies, amounting to EUR 520 million (175 million of which from federal state funds).
			Support of a simplified legal framework	Financial funding of inter-municipal cooperation.

Note: All federal states offer financial funding as project share financing in the form of a non-repayable grant. Baden-Württemberg also offers the possibility of a fixed grant as funding. In the states Berlin, Bremen, Hamburg and Mecklenburg-Western Pomerania the programs are not state funding programs, but federal funding programs for broadband expansion or other, such as the GRW funding program.

Table 7: Broadband Expansion Programs Part II

Information Sources Regarding The Broadband Expansion Programs From Tables I and II[19]:

[1] https://mlr.baden-wuerttemberg.de/de/unser-service/presse-und-oeffentlichkeitsarbeit/pressemitteilungen/pressemitteilung/pid/erstmalig-landesfoerderung-zum-ausbau-der-breitbandinfrastruktur-im-laendlichen-raum-1/

[2] https://mlr.baden-wuerttemberg.de/de/unser-service/presse-und-oeffentlichkeitsarbeit/pressemitteilungen/pressemitteilung/pid/initiative-baden-wuerttembergs-bei-der-agrarministerkonferenz-erfolgreich-1/

[3] https://mlr.baden-wuerttemberg.de/de/unser-service/presse-und-oeffentlichkeitsarbeit/pressemitteilungen/pressemitteilung/pid/ministerrat-gibt-gruenes-licht-fuer-deutschlands-umfassendste-breitband-initiative-laendlicher-raum-1/

[4] https://www.baden-wuerttemberg.de/fileadmin/redaktion/m-im/intern/dateien/publikationen/20200911_Breitbandbericht_Baden-Württemberg.pdf

[5] https://mlr.baden-wuerttemberg.de/de/unser-service/presse-und-oeffentlichkeitsarbeit/pressemitteilungen/pressemitteilung/pid/leben-und-arbeiten-40-breitbandausbau-kommt-nach-baden-wuerttembergischem-modell-mit-hochgeschwind/

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B Descriptives

B.1 Descriptive Statistics

B.1.1 Descriptive Statistics of the Border Samples for 16 Mbit/s

	Full Sample				"Low" Broadband States		"High" Broadband States	
	Mean	**SD**	**Min**	**Max**	**Mean**	**SD**	**Mean**	**SD**
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**
Outcome and Main Explanatory Variables								
High Broadband States 16 Mbit/s	0.52	0.50	0.00	1.00	0.00	0.00	1.00	0.00
Broadband Availability Municipalities 16 Mbit/s	0.54	0.33	0.00	1.00	0.44	0.33	0.68	0.29
Property Sale Price Total	197,906.40	134,162.28	8,250.00	3,100,000.00	174,303.09	113,869.79	223,958.51	149,202.18
Property Sale Price per sqm	1,414.75	791.44	243.90	7,187.50	1,248.76	644.24	1,597.95	891.99
Property Rent Total (Monthly)	478.44	253.58	89.00	3,600.00	440.05	227.62	529.58	276.35
Property Rent per sqm (Monthly)	5.94	1.76	3.53	20.00	5.56	1.49	6.45	1.94
Control Variables								
Property Type	1.78	0.56	1.00	3.00	1.80	0.55	1.77	0.57
Number of Rooms in the Property	4.87	2.55	0.00	57.00	4.84	2.50	4.90	2.61
Floor Space of the Property in sqm	145.94	67.54	33.00	470.00	144.56	66.38	147.45	68.76
Age of Property	8.48	6.11	1.00	18.00	8.79	6.24	8.13	5.95
Newly Constructed Building	0.15	0.35	0.00	1.00	0.13	0.33	0.17	0.37
Renovation Status	3.54	1.11	1.00	5.00	3.58	1.06	3.50	1.16
Equipped with Kitchen	0.23	0.42	0.00	1.00	0.21	0.41	0.26	0.44
Equipped with Garden	0.31	0.46	0.00	1.00	0.27	0.44	0.36	0.48
Equipped with Balcony or Terrace	0.30	0.46	0.00	1.00	0.25	0.43	0.37	0.48
Equipped with Basement	0.41	0.49	0.00	1.00	0.39	0.49	0.43	0.50
Parking Lot or Garage Available	0.61	0.49	0.00	1.00	0.59	0.49	0.63	0.48
Exclusive/Luxury Equipment or Villa	0.04	0.20	0.00	1.00	0.03	0.18	0.05	0.22
Equipped with Pool, Whirlpool, or Sauna	0.06	0.24	0.00	1.00	0.05	0.23	0.07	0.26
Bright Rooms	0.17	0.37	0.00	1.00	0.14	0.35	0.20	0.40
Heating Type	0.30	0.95	0.00	5.00	0.25	0.89	0.35	1.02
Central Heating	0.87	0.98	0.00	2.00	0.81	0.97	0.93	0.99
Quiet Location	0.12	0.32	0.00	1.00	0.12	0.32	0.12	0.32
Publicly Subsidized Housing	0.03	0.17	0.00	1.00	0.04	0.20	0.02	0.12
Real Estate Transfer Tax Rate	0.05	0.01	0.04	0.06	0.04	0.01	0.05	0.01
Municipality Growth Trend	0.05	1.26	-2.00	2.00	-0.03	1.27	0.13	1.24
Housing Market Region Type	3.58	1.12	1.00	5.00	3.50	1.13	3.67	1.11
School Quality (PISA Results)	505.44	9.46	493.00	525.00	506.07	9.66	504.75	9.18
Crime Rate per 10,000 Inhabitants	0.07	0.01	0.05	0.09	0.07	0.01	0.06	0.01
Mobile Internet Availability	0.80	0.18	0.42	1.00	0.69	0.14	0.91	0.14

Note: The descriptive statistics of the border samples for 16 Mbit/s report information on properties for sale and for rents in small municipalities, which are located within 25 km of the borders of "high" and "low" broadband states for the broadband speed of 16 Mbit/s. Columns 1 to 4 report the mean, standard deviation, minimum, and maximum for the full samples, whereas columns 5 to 6 state the mean and standard deviation for "low" broadband states only, and columns 7 to 8 report the analogous values for "high" broadband states.

Table 8: Descriptive Statistics of the Border Samples for 16 Mbit/s Broadband

B.1.2 Descriptive Statistics of the Border Samples for 30 Mbit/s

	Full Sample				"Low" Broadband States		"High" Broadband States	
	Mean	**SD**	**Min**	**Max**	**Mean**	**SD**	**Mean**	**SD**
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**
Outcome and Main Explanatory Variables								
High Broadband States 30 Mbit/s	0.46	0.50	0.00	1.00	0.00	0.00	1.00	0.00
Broadband Availability Municipalities 30 Mbit/s	0.56	0.33	0.00	1.00	0.44	0.33	0.73	0.27
Property Sale Price Total	204,173.97	141,232.18	9,000.00	3,200,000.00	178,862.51	123,386.02	234,074.97	154,513.40
Property Sale Price per sqm	1,462.84	856.22	243.90	7,175.00	1,296.20	727.09	1,659.69	950.30
Property Rents Total (Monthly)	471.71	259.05	90.00	4,000.00	440.48	238.79	528.95	283.78
Property Rents per sqm (Monthly)	5.99	1.80	3.53	20.00	5.69	1.56	6.55	2.05
Control Variables								
Property Type	1.78	0.56	1.00	3.00	1.78	0.56	1.78	0.57
Number of Rooms in the Property	4.86	2.62	0.00	45.00	4.77	2.60	4.97	2.64
Floor Space of the Property in sqm	146.32	68.49	33.00	470.00	143.54	67.76	149.61	69.20
Age of Property	8.47	6.09	1.00	18.00	8.81	6.18	8.07	5.96
Newly Constructed Building	0.16	0.37	0.00	1.00	0.14	0.35	0.18	0.39
Renovation Status	3.51	1.14	1.00	5.00	3.54	1.10	3.47	1.19
Equipped with Kitchen	0.28	0.45	0.00	1.00	0.30	0.46	0.25	0.43
Equipped with Garden	0.35	0.48	0.00	1.00	0.33	0.47	0.38	0.49
Equipped with Balcony or Terrace	0.35	0.48	0.00	1.00	0.30	0.46	0.40	0.49
Equipped with Basement	0.42	0.49	0.00	1.00	0.41	0.49	0.43	0.49
Parking Lot or Garage Available	0.62	0.49	0.00	1.00	0.63	0.48	0.61	0.49
Exclusive/Luxury Equipment or Villa	0.05	0.21	0.00	1.00	0.04	0.21	0.05	0.22
Equipped with Pool, Whirlpool, or Sauna	0.07	0.25	0.00	1.00	0.06	0.24	0.08	0.26
Bright Rooms	0.19	0.39	0.00	1.00	0.17	0.38	0.20	0.40
Heating Type	0.35	1.01	0.00	5.00	0.32	0.98	0.38	1.05
Central Heating	0.92	0.98	0.00	2.00	0.90	0.98	0.95	0.99
Quiet Location	0.12	0.32	0.00	1.00	0.12	0.33	0.12	0.32
Publicly Subsidized Housing	0.02	0.12	0.00	1.00	0.02	0.15	0.01	0.08
Real Estate Transfer Tax Rate	0.05	0.01	0.04	0.06	0.05	0.01	0.05	0.01
Municipality Growth Trend	-0.10	1.28	-2.00	2.00	-0.23	1.30	0.06	1.24
Housing Market Region Type	3.47	1.17	1.00	5.00	3.39	1.21	3.57	1.11
School Quality (PISA Results)	506.17	10.11	493.00	525.00	507.31	10.25	504.82	9.77
Crime Rate per 10,000 Inhabitants	0.07	0.01	0.05	0.09	0.07	0.01	0.06	0.01
Mobile Internet Availability	0.94	0.05	0.80	1.00	0.92	0.05	0.98	0.02

Note: The descriptive statistics of the border samples for 30 Mbit/s report information on properties for sale and for rents in small municipalities, which are located within 25 km of the borders of "high" and "low" broadband states for the broadband speed of 30 Mbit/s. Columns 1 to 4 report the mean, standard deviation, minimum, and maximum for the full samples, whereas columns 5 to 6 state the mean and standard deviation for "low" broadband states only, and columns 7 to 8 report the analogous values for "high" broadband states.

Table 9: Descriptive Statistics of the Border Samples for 30 Mbit/s Broadband

B.1.3 Descriptive Statistics of the Border Samples for 50 Mbit/s

	Full Sample				"Low" Broadband States		"High" Broadband States	
	Mean	**SD**	**Min**	**Max**	**Mean**	**SD**	**Mean**	**SD**
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**
Outcome and Main Explanatory Variables								
High Broadband States 50 Mbit/s	0.43	0.37	0.00	1.00	0.30	0.34	0.63	0.31
Broadband Availability Municipalities 50 Mbit/s	0.54	0.33	0.00	1.00	0.44	0.33	0.68	0.29
Property Sale Price Total	211,377.01	141,144.80	8,800.00	3,100,000.00	185,676.21	123,805.42	243,224.02	154,213.74
Property Sale Price per sqm	1,503.00	831.55	243.90	7,187.50	1,335.64	708.31	1,710.38	921.36
Property Rents Total (Monthly)	502.98	268.09	89.00	4,000.00	470.30	250.12	561.10	288.36
Property Rents per sqm (Monthly)	6.17	1.87	3.53	20.00	5.84	1.69	6.75	2.04
Control Variables								
Property Type	1.78	0.57	1.00	3.00	1.78	0.56	1.78	0.57
Number of Rooms in the Property	4.90	2.58	0.00	72.00	4.80	2.56	5.03	2.59
Floor Space of the Property in sqm	147.09	67.92	33.00	470.00	144.46	67.11	150.34	68.77
Age of Property	8.27	6.07	1.00	18.00	8.57	6.15	7.90	5.95
Newly Constructed Building	0.16	0.37	0.00	1.00	0.14	0.35	0.19	0.39
Renovation Status	3.51	1.14	1.00	5.00	3.56	1.09	3.46	1.20
Equipped with Kitchen	0.24	0.43	0.00	1.00	0.24	0.43	0.24	0.43
Equipped with Garden	0.31	0.46	0.00	1.00	0.27	0.44	0.36	0.48
Equipped with Balcony or Terrace	0.34	0.47	0.00	1.00	0.28	0.45	0.41	0.49
Equipped with Basement	0.42	0.49	0.00	1.00	0.40	0.49	0.44	0.50
Parking Lot or Garage Available	0.61	0.49	0.00	1.00	0.61	0.49	0.62	0.49
Exclusive/Luxury Equipment or Villa	0.04	0.21	0.00	1.00	0.04	0.19	0.05	0.22
Equipped with Pool, Whirlpool, or Sauna	0.06	0.25	0.00	1.00	0.06	0.24	0.07	0.26
Bright Rooms	0.18	0.39	0.00	1.00	0.16	0.37	0.21	0.41
Heating Type	0.32	0.98	0.00	5.00	0.29	0.94	0.36	1.03
Central Heating	0.90	0.98	0.00	2.00	0.87	0.98	0.94	0.99
Quiet Location	0.12	0.32	0.00	1.00	0.12	0.33	0.11	0.32
Publicly Subsidized Housing	0.02	0.15	0.00	1.00	0.03	0.18	0.01	0.10
Real Estate Transfer Tax Rate	0.05	0.01	0.04	0.06	0.04	0.01	0.05	0.01
Municipality Growth Trend	0.11	1.23	-2.00	2.00	0.05	1.26	0.19	1.20
Housing Market Region Type	3.65	1.10	1.00	5.00	3.57	1.12	3.75	1.06
School Quality (PISA Results)	505.88	9.83	493.00	525.00	506.70	10.45	504.85	8.91
Crime Rate per 10,000 Inhabitants	0.06	0.01	0.05	0.09	0.07	0.01	0.06	0.01
Mobile Internet Availability	0.85	0.17	0.42	1.00	0.79	0.17	0.93	0.14

Note: The descriptive statistics of the border samples for 50 Mbit/s report information on properties for sale and for rents in small municipalities, which are located within 25 km of the borders of "high" and "low" broadband states for the broadband speed of 50 Mbit/s. Columns 1 to 4 report the mean, standard deviation, minimum, and maximum for the full samples, whereas columns 5 to 6 state the mean and standard deviation for "low" broadband states only, and columns 7 to 8 report the analogous values for "high" broadband states.

Table 10: Descriptive Statistics of the Border Samples for 50 Mbit/s Broadband

B.2 Graphical Evidence: Descriptive Figures

B.2.1 Broadband Development in Municipalities

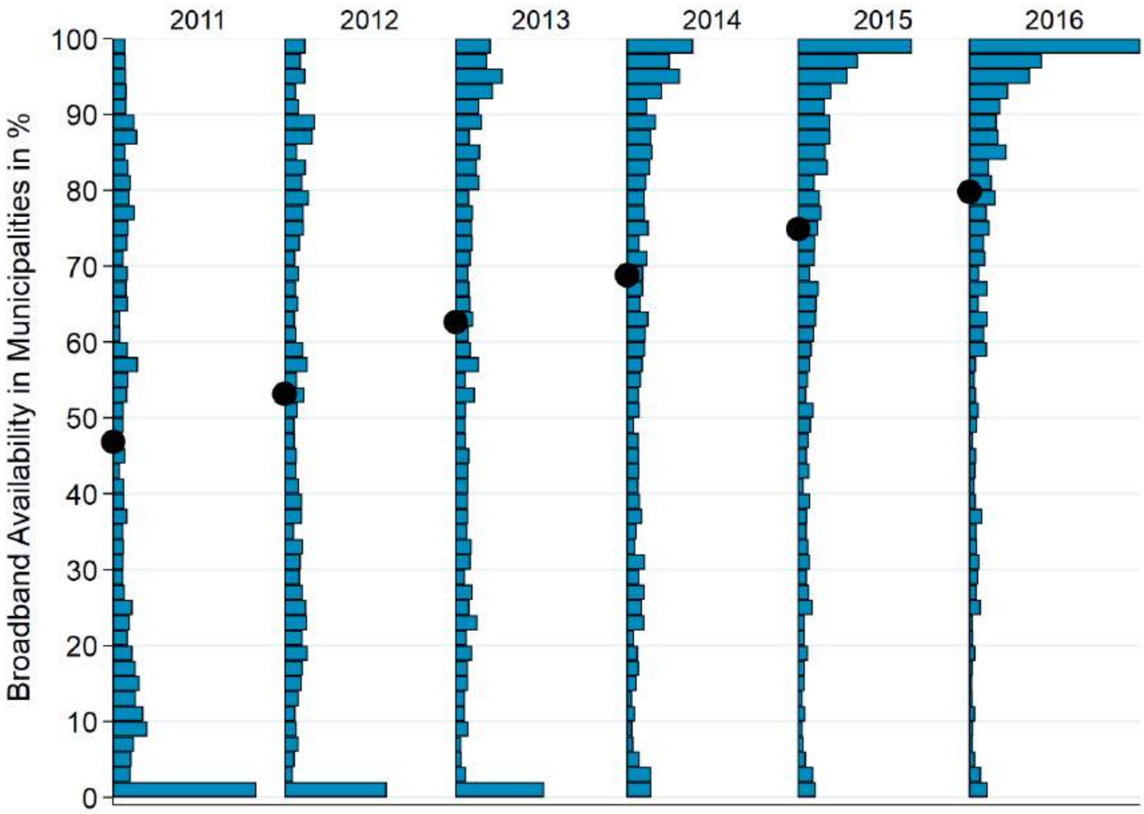


Figure 6: Development of 16 Mbit/s Broadband Availability in Municipalities

Note: The figure shows annual histograms of 16 Mbit/s broadband availability in municipalities (measured as the share of households for which this Internet speed is available) within our sample. The black dots represent the yearly population-weighted averages across all municipalities.

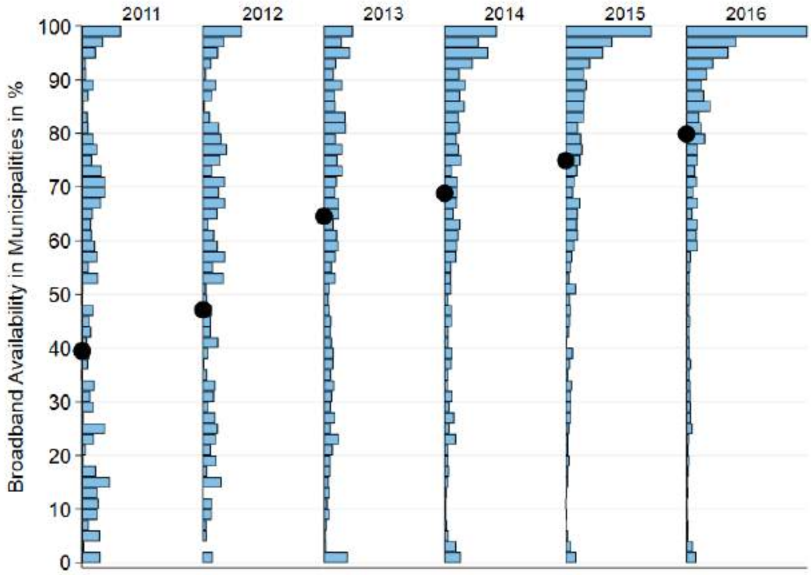


Figure 7: Development of 16 Mbit/s Broadband Availability in "High" Broadband States
Note: The figure shows annual histograms of 16 Mbit/s broadband availability in municipalities in "high" broadband states (measured as the share of households for which this Internet speed is available) within our sample. The black dots represent the yearly population-weighted averages across all municipalities.

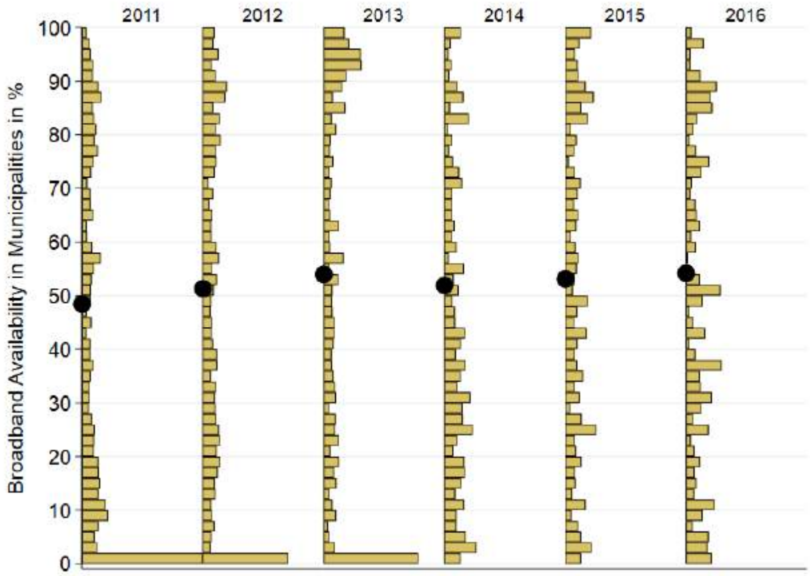


Figure 8: Development of 16 Mbit/s Broadband Availability in "Low" Broadband States
Note: The figure shows annual histograms of 16 Mbit/s broadband availability in municipalities in "low" broadband states (measured as the share of households for which this Internet speed is available) within our sample. The black dots represent the yearly population-weighted rolling averages across all municipalities.

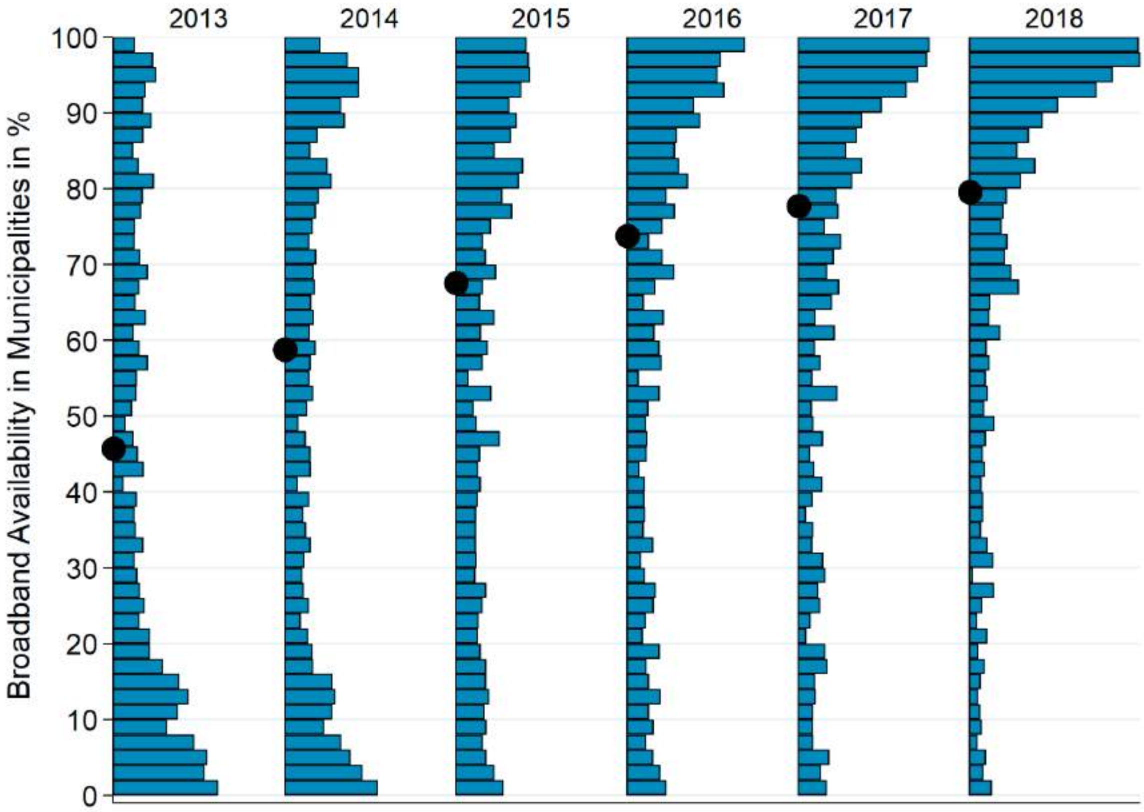


Figure 9: Development of 30 Mbit/s Broadband Availability in Municipalities

Note: The figure shows annual histograms of 30 Mbit/s broadband availability in municipalities (measured as the share of households for which this Internet speed is available) within our sample. The black dots represent the yearly population-weighted averages across all municipalities.

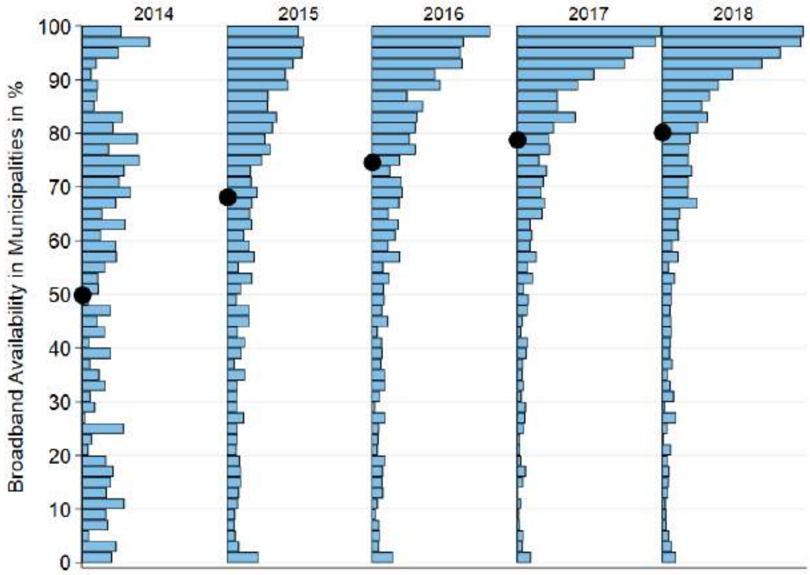


Figure 10: Development of 30 Mbit/s Broadband Availability in “High” Broadband States
Note: The figure shows annual histograms of 30 Mbit/s broadband availability in municipalities in “high” broadband states (measured as the share of households for which this Internet speed is available) within our sample. The black dots represent the yearly population-weighted averages across all municipalities.

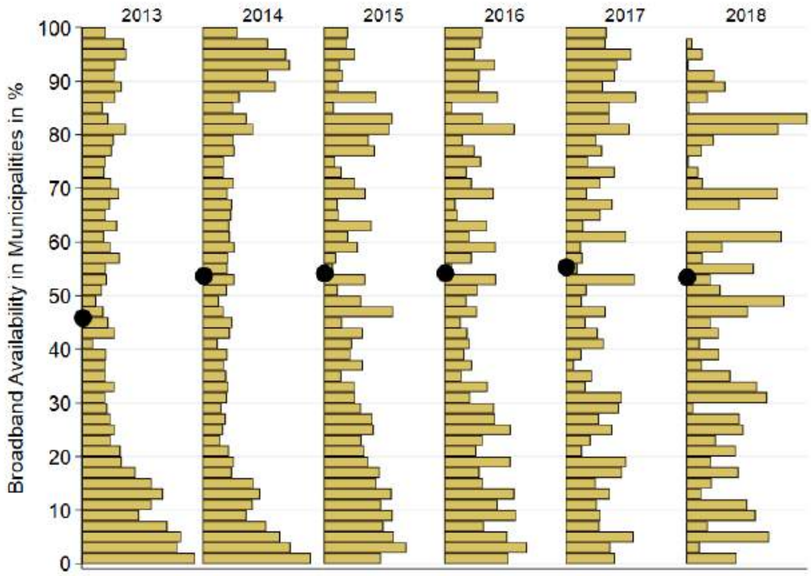


Figure 11: Development of 30 Mbit/s Broadband Availability in “Low” Broadband States
Note: The figure shows annual histograms of 30 Mbit/s broadband availability in municipalities in “low” broadband states (measured as the share of households for which this Internet speed is available) within our sample. The black dots represent the yearly population-weighted rolling averages across all municipalities.

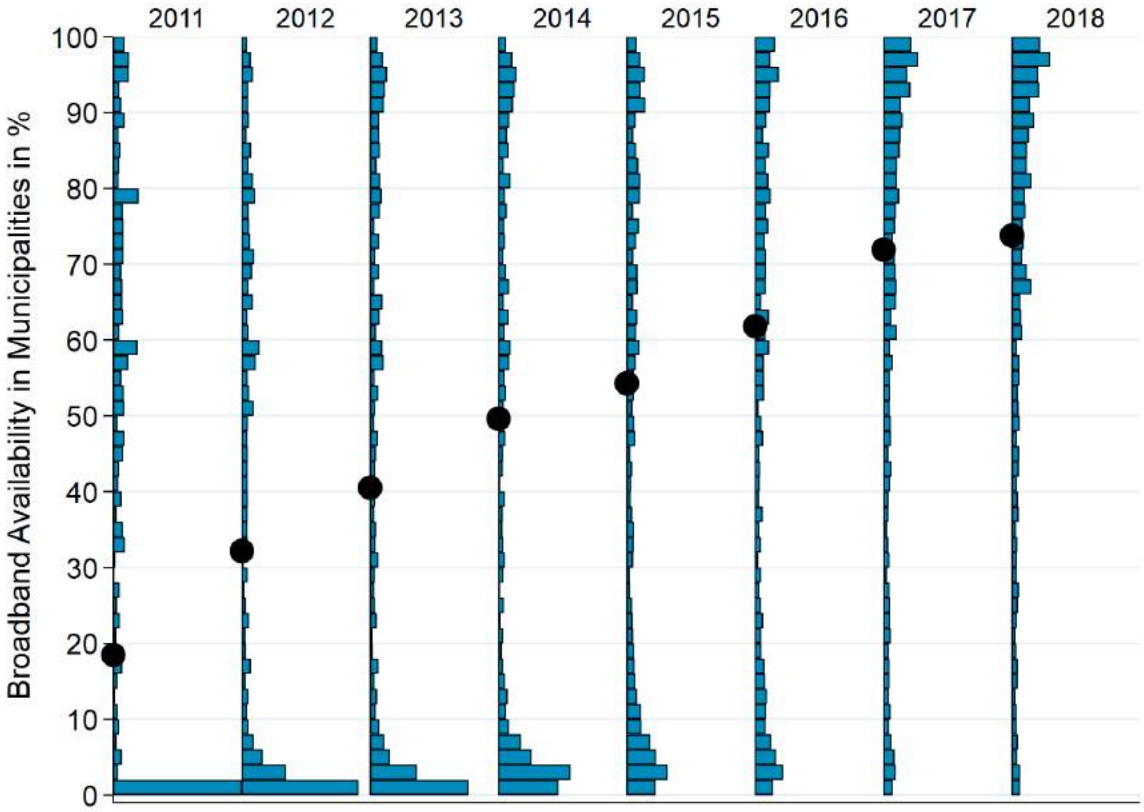


Figure 12: Development of 50 Mbit/s Broadband Availability in Municipalities

Note: The figure shows annual histograms of 50 Mbit/s broadband availability in municipalities (measured as the share of households for which this Internet speed is available) within our sample. The black dots represent the yearly population-weighted averages across all municipalities. For better visibility, the scaling of the bars has been slightly altered while maintaining the relative distribution.

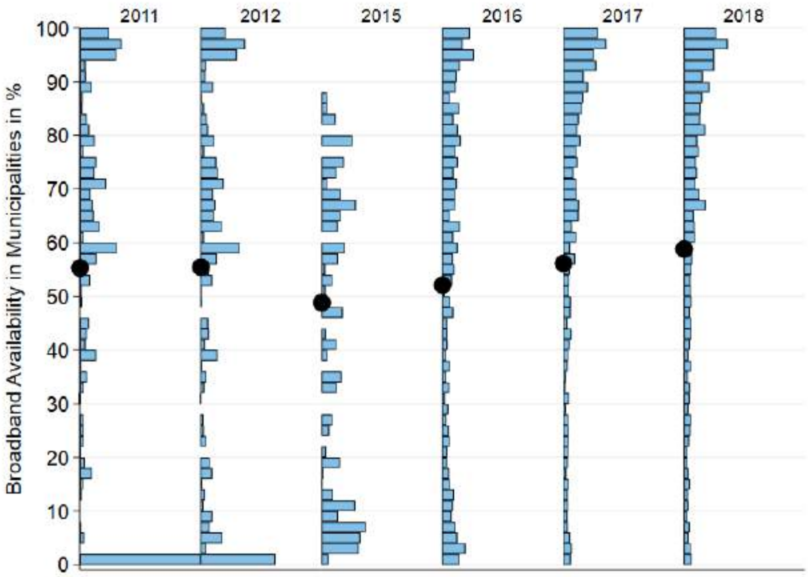


Figure 13: Development of 50 Mbit/s Broadband Availability in "High" Broadband States
Note: The figure shows annual histograms of 50 Mbit/s broadband availability in municipalities in "high" broadband states (measured as the share of households for which this Internet speed is available) within our sample. The black dots represent the yearly population-weighted rolling averages across all municipalities.

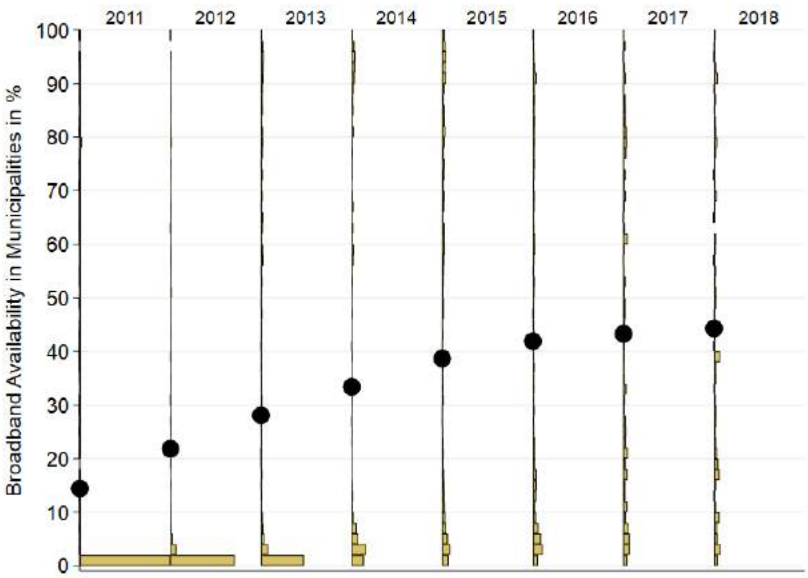


Figure 14: Development of 50 Mbit/s Broadband Availability in "Low" Broadband States
Note: The figure shows annual histograms of 50 Mbit/s broadband availability in municipalities in "low" broadband states (measured as the share of households for which this Internet speed is available) within our sample. The black dots represent the yearly population-weighted rolling averages across all municipalities.

B.2.2 Sample Distribution over Time

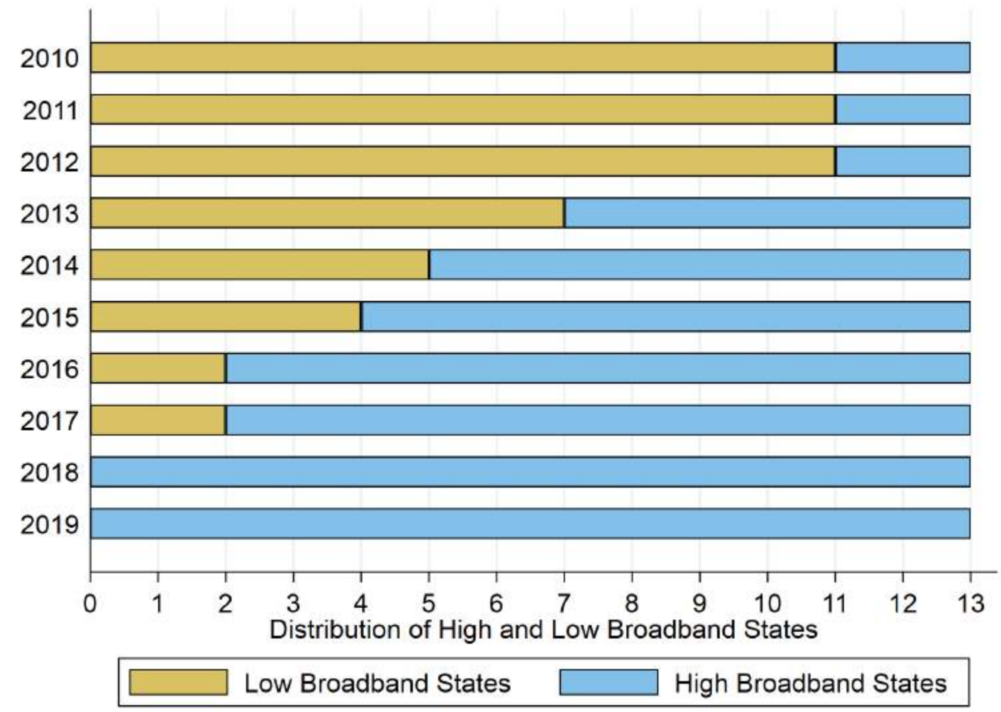


Figure 15: Stacked Chart of 16 Mbit/s High and Low Broadband States over Time

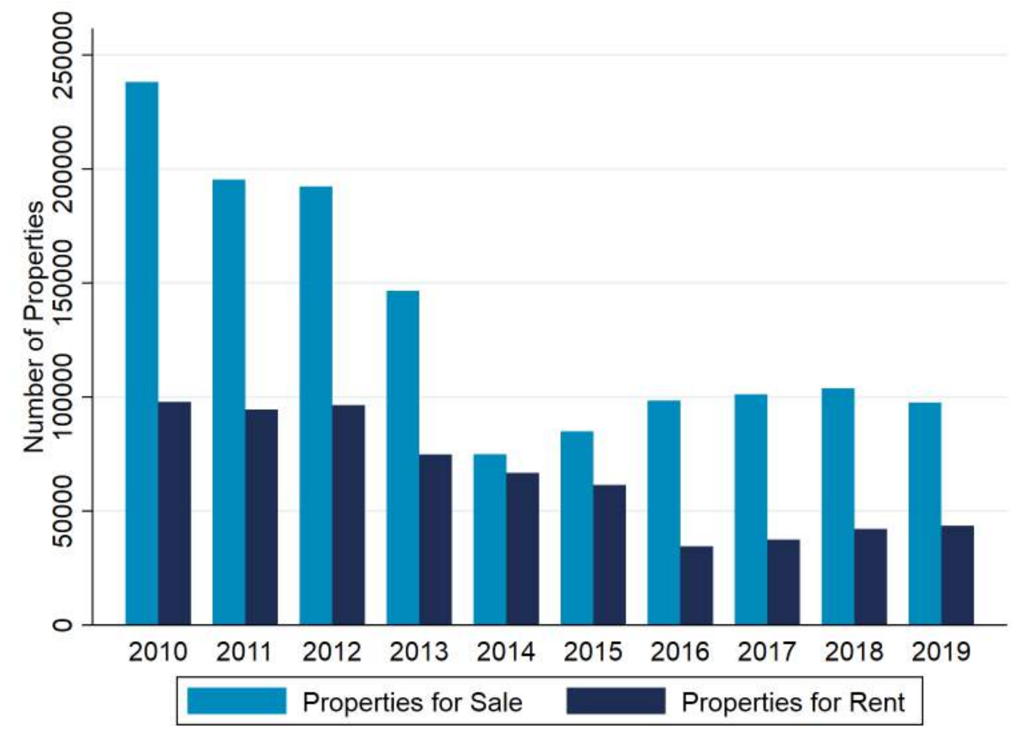


Figure 16: Sample Distribution over Time for 16 Mbit/s Broadband

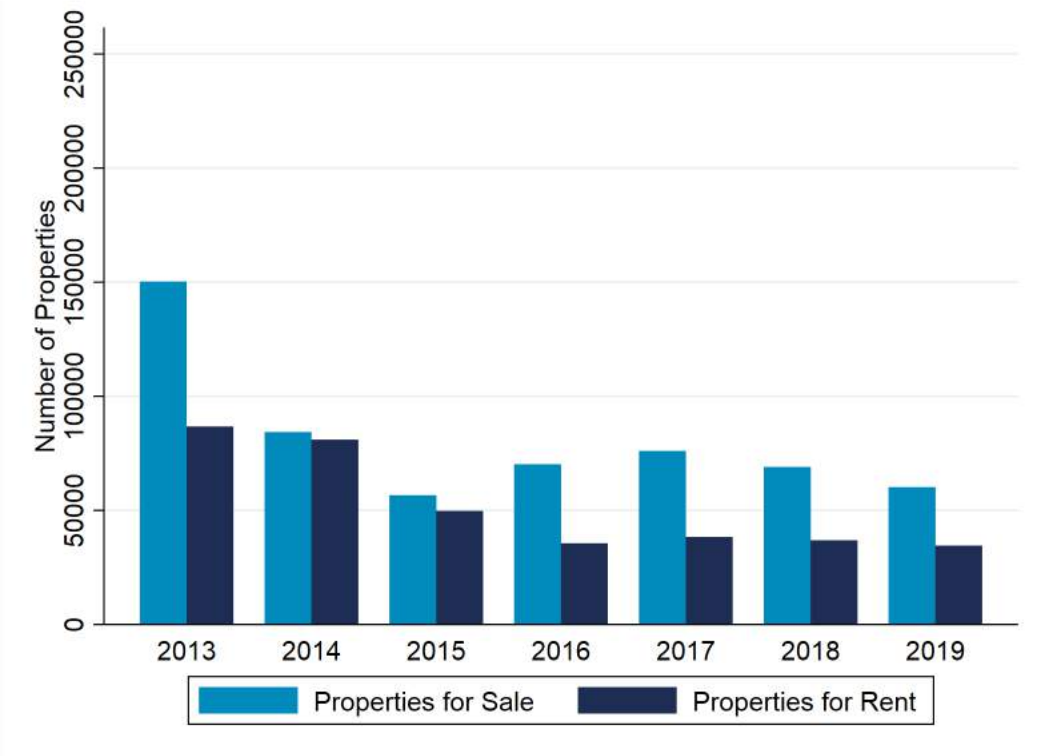


Figure 17: Sample Distribution over Time for 30 Mbit/s Broadband

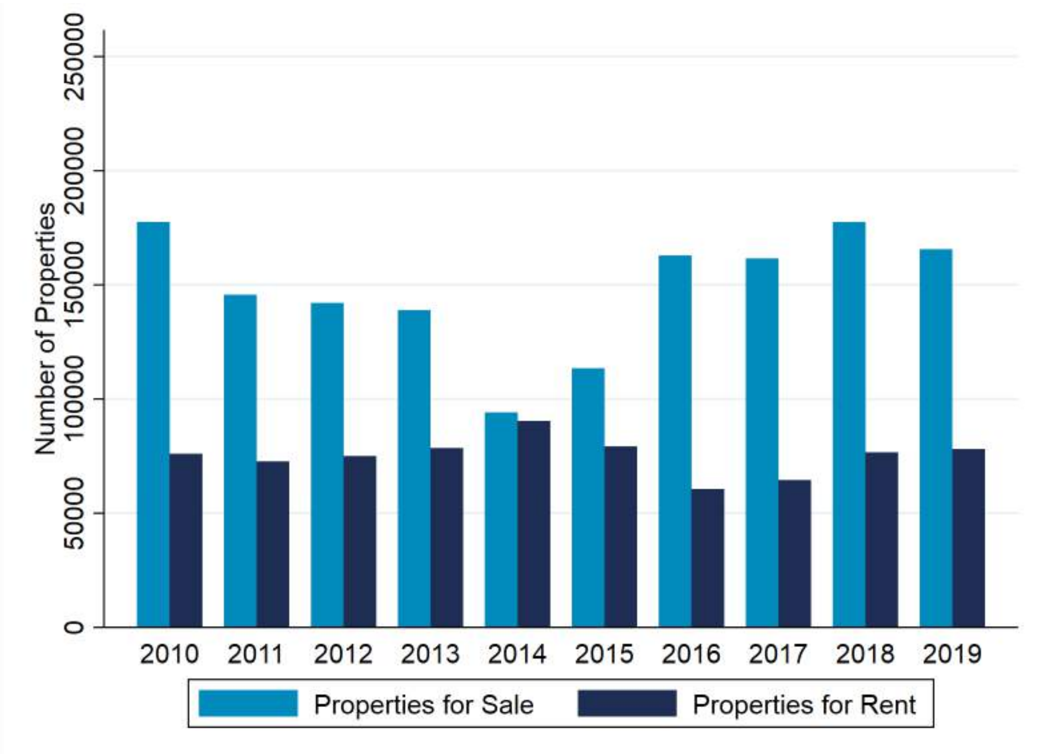


Figure 18: Sample Distribution over Time for 50 Mbit/s Broadband

B.2.3 Sample Distribution in Distance to Border

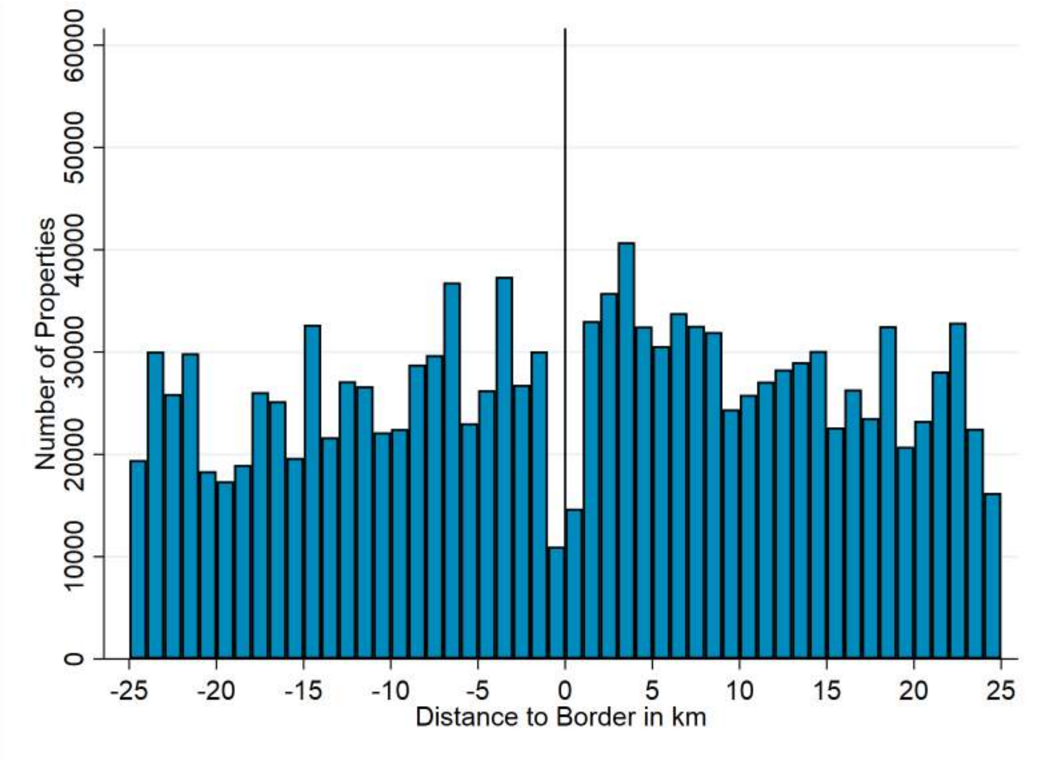


Figure 19: Sample Distribution in Distance to Border for 16 Mbit/s Broadband

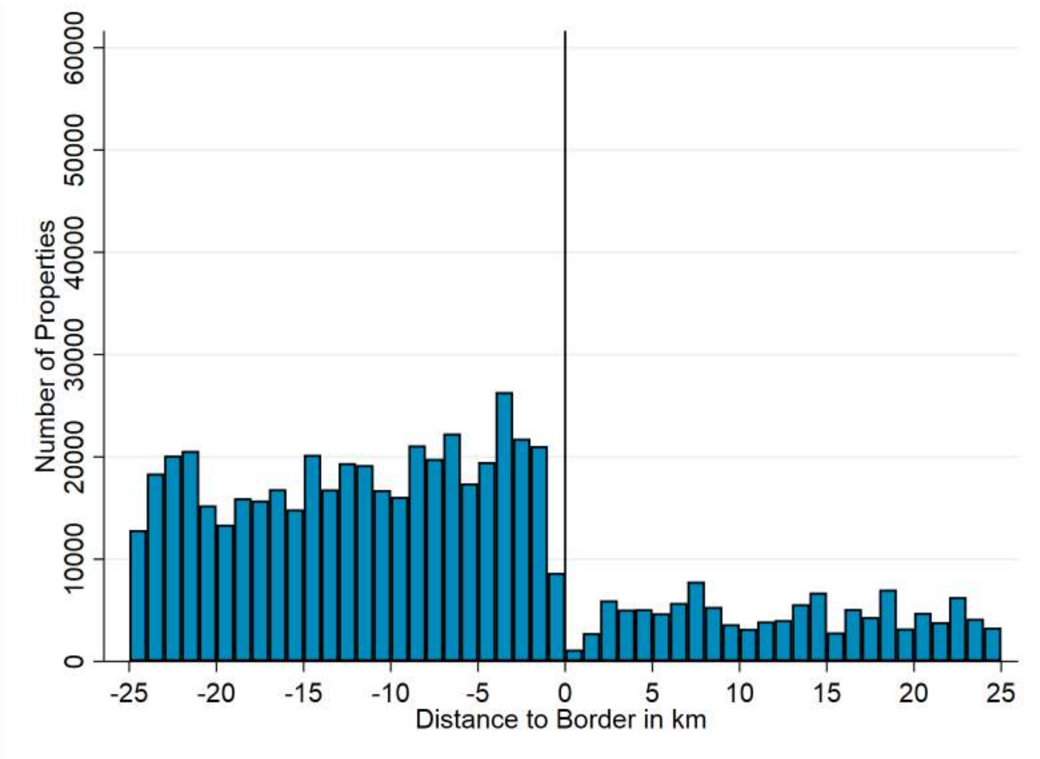


Figure 20: Sample Distribution in Distance to Border for 30 Mbit/s Broadband

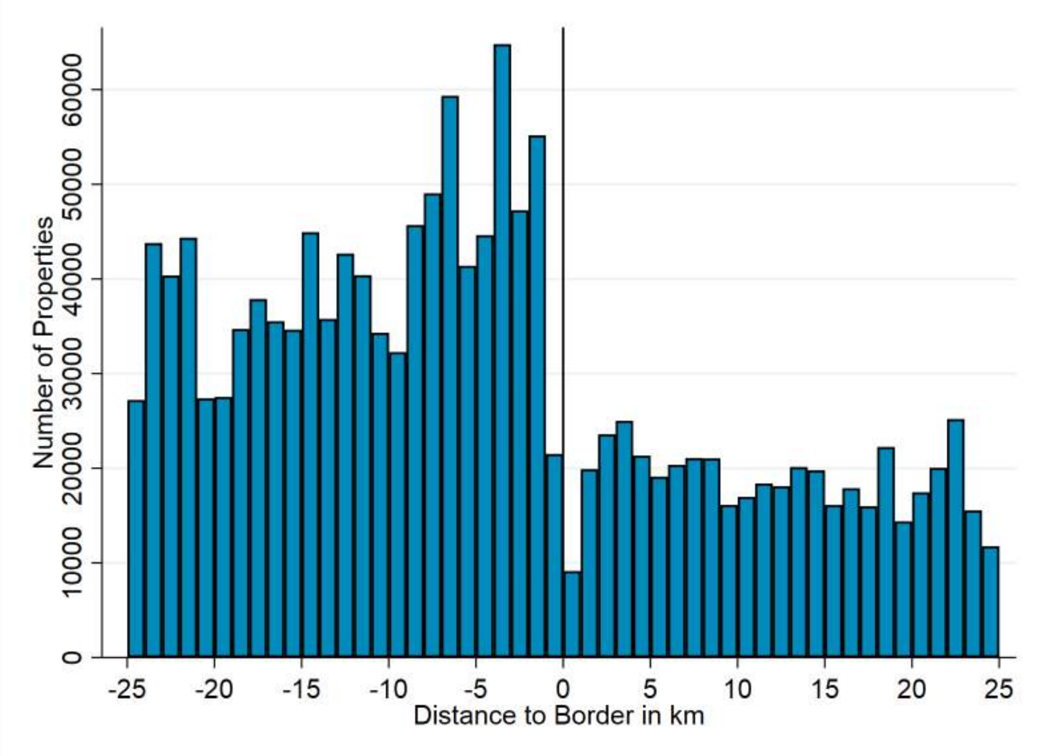


Figure 21: Sample Distribution in Distance to Border for 50 Mbit/s Broadband

B.2.4 Germany's Broadband Connections and Speed Distribution

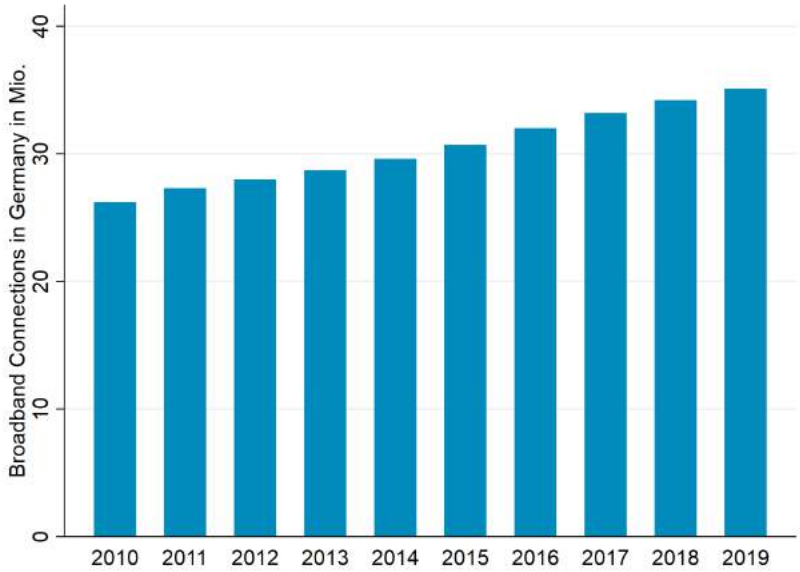


Figure 22: Number of Broadband Connections in Germany

Note: The graph depicts the annual number of registered broadband connections in Germany based on administrative data. Source: Bundesnetzagentur, 2010-2020.

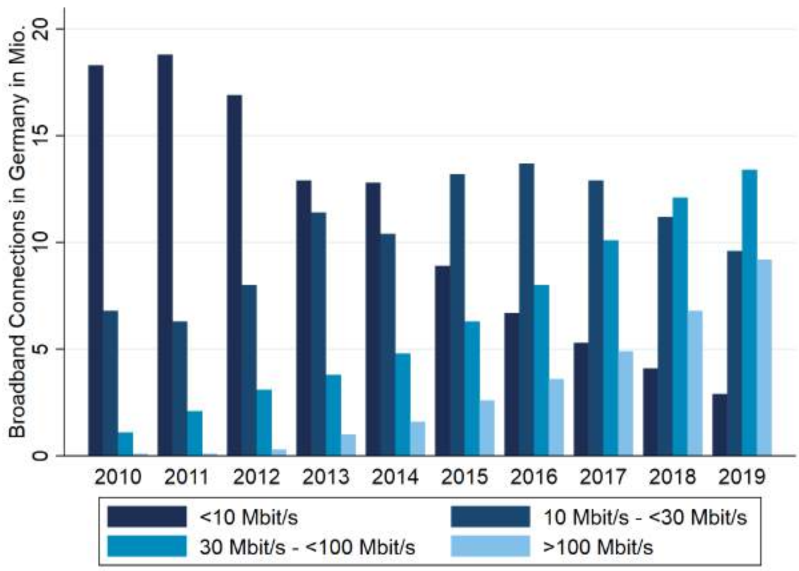


Figure 23: Speed Distribution of Broadband Connections in Germany

Note: The graph depicts the annual distribution by Internet speed of the registered broadband connections in Germany based on administrative data. Source: Bundesnetzagentur, 2010-2020.

C Main Results

C.1 Effect Size Heterogeneity

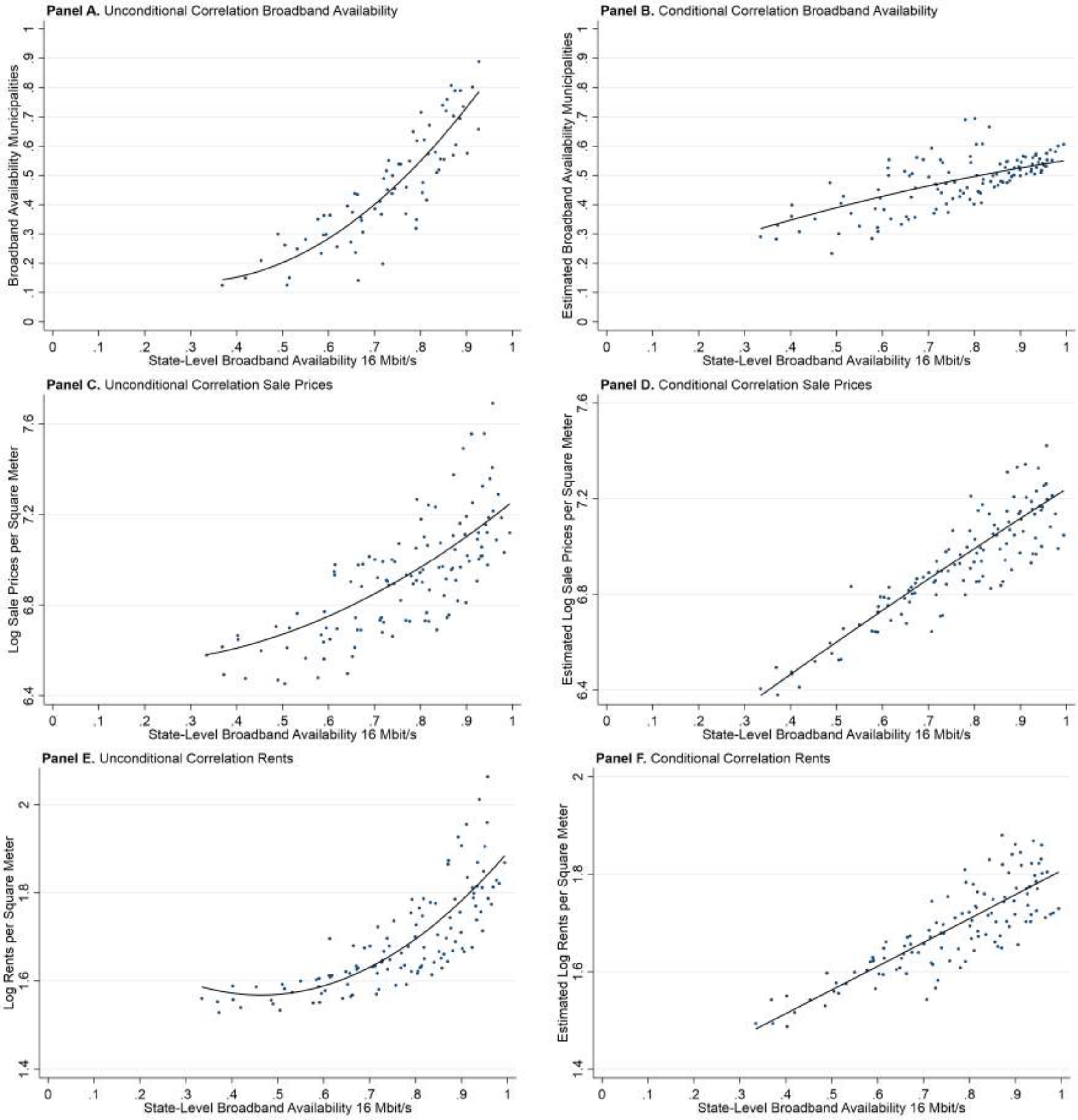


Figure 24: Correlations of State-Level Broadband Availability with Broadband Availability in Municipalities, Property Sale Prices, and Rents

Note: This figure illustrates the correlations between the state-level broadband availability on the x-axis, which is the determinant of "high" broadband states with the threshold of providing 75 percent of households with fast Internet, and the three main outcome variables on the y-axis, broadband availability in municipalities (Panels A and B), property sale prices (Panels C and D), and rents (Panels E and F). The left-hand panels A, C, and E display the unconditional correlations of the raw data, whereas the right-hand panels B, D, and F show the conditional correlations that are the result of regressions with control variables for property and regional characteristics as well as include border-region-by-year fixed effects. Property sale prices and rents are log values in order to facilitate better comparability of the estimates. The plots were generated by an evenly spaced number of bins, representing the sample average within each bin, and show the quadratic fitted regression lines.

C.2 Estimation of the Spatial RDD Using OLS

Spatial RDD Estimates	**Real Estate Sale Prices per sqm**	**Real Estate Rents per sqm**
	(1)	**(2)**
Panel A: RDD Polynomials in Distance to Border		
Linear	0.1030***	0.0800***
	(0.0017)	(0.0011)
Quadratic	0.1057***	0.0812***
	(0.0017)	(0.0011)
Linear Interacted	0.1030***	0.0799***
	(0.0017)	(0.0011)
Panel B: RDD Polynomials in Longitude and Latitude		
Linear	0.1041***	0.0782***
	(0.0017)	(0.0011)
Quadratic	0.1068***	0.0796***
	(0.0017)	(0.0011)
Cubic	0.1067***	0.0795***
	(0.0017)	(0.0011)
Quartic	0.1058***	0.0786***
	(0.0017)	(0.0011)
Border Region by Year FE	✓	✓
Regional Socioeconomic Controls	✓	✓
Individual Property Controls	✓	✓
Observations	792,799	428,171
Municipalities	4,897	4,570
Data Availability Period	2011-2016	2011-2016

Note: Shown are the coefficients and standard errors for regressions of log sale prices and rents on broadband broadband availability in municipalities under different specifications of the RDD polynomials, with each cell in the table reporting the result of a separate regression. Panel A displays estimates for linear, quadratic, and linear interacted RDD polynomials in distance to border, whereas Panel B presents the results for linear, quadratic, cubic, and quartic RDD specifications in longitude and latitude. Property sale prices and rents are log values in order to facilitate better comparability of the estimates. Standard errors are robust against heteroskedasticity. *p<0.1; **p<0.05; ***p<0.01.

Table 11: Estimation of the Spatial RDD Using OLS

D Heterogeneities

D.1 Heterogeneity by Property Types

Spatial RDD Estimates	Sale Prices		Rents	
	Houses	Apartments	Houses	Apartments
	(1)	(2)	(3)	(4)
Panel A: RDD Polynomials in Distance to Border				
Linear	0.0712***	0.0558***	0.0753***	0.0524***
	(0.0023)	(0.0036)	(0.0046)	(0.0014)
Quadratic	0.0840***	0.0400***	0.0638***	0.0433***
	(0.0018)	(0.0028)	(0.0034)	(0.0010)
Linear Interacted	0.0626***	0.0397***	0.0696***	0.0431***
	(0.0021)	(0.0033)	(0.0042)	(0.0013)
Panel B: RDD Polynomials in Longitude and Latitude				
Linear	0.0834***	0.0407***	0.0616***	0.0419***
	(0.0018)	(0.0028)	(0.0034)	(0.0010)
Quadratic	0.0885***	0.0606***	0.0652***	0.0480***
	(0.0018)	(0.0028)	(0.0034)	(0.0010)
Cubic	0.0852***	0.0575***	0.0611***	0.0428***
	(0.0018)	(0.0029)	(0.0035)	(0.0011)
Quartic	0.0881***	0.0628***	0.0536***	0.0453***
	(0.0019)	(0.0030)	(0.0037)	(0.0011)
Border Region by Year FE	✓	✓	✓	✓
Regional Socioeconomic Controls	✓	✓	✓	✓
Individual Property Controls	✓	✓	✓	✓
Observations	950,633	382,965	66,338	582,320
Municipalities	4,891	4,542	3,858	4,454
Data Availability Period	2010-2019	2010-2019	2010-2019	2010-2019

Note: Shown are the coefficients and standard errors for "high broadband state" under different specifications of the RDD polynomials, with each cell in the table reporting the result of a separate regression. Panel A displays estimates for linear, quadratic, and linear interacted RDD polynomials in distance to border, whereas Panel B presents the results for linear, quadratic, cubic, and quartic RDD specifications in longitude and latitude. Property sale prices and rents are log values in order to facilitate better comparability of the estimates. Standard errors are robust against heteroskedasticity. *p<0.1; **p<0.05; ***p<0.01.

Table 12: Heterogeneity by Property Types: Results of the Two-Stage Spatial RDD for 16 Mbit/s Broadband

D.2 Heterogeneity by Municipality Types

Spatial RDD Estimates	Sale Prices		Rents	
	Very Rural Municipalities	Very Small Towns	Very Rural Municipalities	Very Small Towns
	(1)	(2)	(3)	(4)
Panel A: RDD Polynomials in Distance to Border				
Linear	0.0244***	0.0616***	0.0113***	0.0804***
	(0.0028)	(0.0033)	(0.0020)	(0.0020)
Quadratic	0.0215***	0.0738***	0.0116***	0.0596***
	(0.0023)	(0.0027)	(0.0016)	(0.0016)
Linear Interacted	0.0085***	0.0582***	0.0158***	0.0595***
	(0.0026)	(0.0030)	(0.0019)	(0.0018)
Panel B: RDD Polynomials in Longitude and Latitude				
Linear	0.0162***	0.0806***	0.0082***	0.0583***
	(0.0023)	(0.0028)	(0.0016)	(0.0016)
Quadratic	0.0242***	0.0947***	0.0138***	0.0627***
	(0.0023)	(0.0028)	(0.0016)	(0.0016)
Cubic	0.0092***	0.0929***	0.0045***	0.0608***
	(0.0023)	(0.0028)	(0.0016)	(0.0016)
Quartic	0.0232***	0.0813***	0.0106***	0.0592***
	(0.0024)	(0.0030)	(0.0016)	(0.0017)
Border Region by Year FE	✓	✓	✓	✓
Regional Socioeconomic Controls	✓	✓	✓	✓
Individual Property Controls	✓	✓	✓	✓
Observations	853,771	479,827	351,836	296,822
Municipalities	4,343	554	4,019	551
Data Availability Period	2010-2019	2010-2019	2010-2019	2010-2019

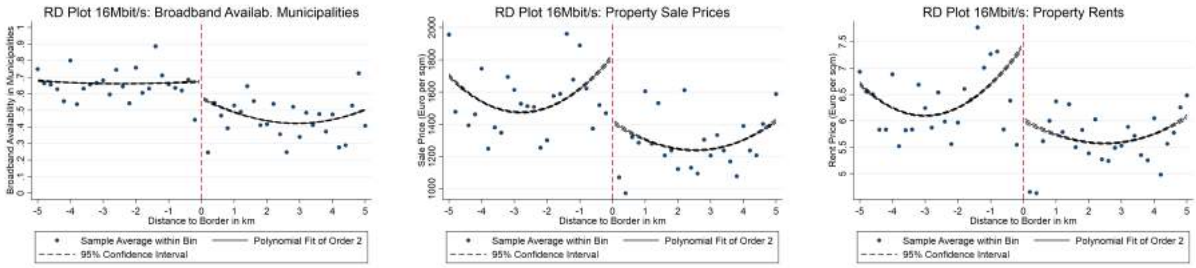
Note: Shown are the coefficients and standard errors for "high broadband state" under different specifications of the RDD polynomials, with each cell in the table reporting the result of a separate regression. Panel A displays estimates for linear, quadratic, and linear interacted RDD polynomials in distance to border, whereas Panel B presents the results for linear, quadratic, cubic, and quartic RDD specifications in longitude and latitude. Property sale prices and rents are log values in order to facilitate better comparability of the estimates. Standard errors are robust against heteroskedasticity. *p<0.1; **p<0.05; ***p<0.01.

Table 13: Heterogeneity by Municipality Types: Results of the Two-Stage Spatial RDD for 16 Mbit/s Broadband

E Specification Checks

E.1 Graphical Evidence

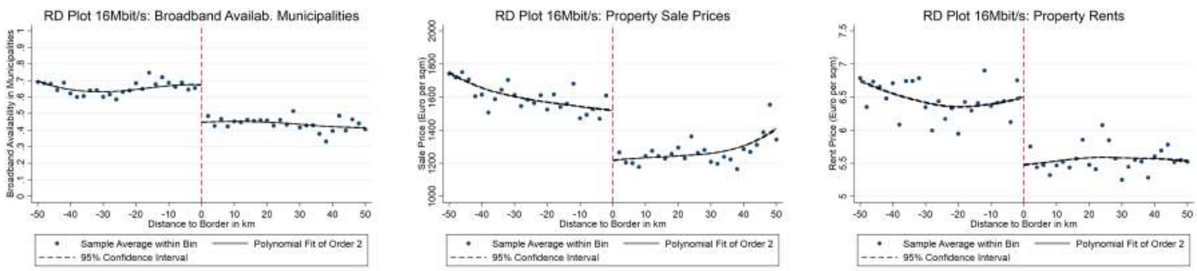
E.1.1 RD Plots of Main Outcomes for 5km Bandwidth



(a) *RD Plots for 16 Mbit/s*

Figure 25: RD Plots of the Two-Stage Spatial RDD for Broadband Availability in Municipalities, Property Sale Prices, and Property Rents

E.1.2 RD Plots of Main Outcomes for 50km Bandwidth



(a) *RD Plots for 16 Mbit/s*

Figure 26: RD Plots of the Two-Stage Spatial RDD for Broadband Availability in Municipalities, Property Sale Prices, and Property Rents

E.2 Tables

E.2.1 Sensitivity of Spatial RDD Results to Different Bandwidths Around the Interstate Borders

Spatial RDD Estimates	Broadband Availability			Sale Prices			Rents		
Bandwidth Around State Borders	**5 km**	**25 km**	**50 km**	**5 km**	**25 km**	**50 km**	**5 km**	**25 km**	**50 km**
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**	**(9)**
Panel A: RDD Polynomials in Distance to Border									
Linear	0.0729	0.0999***	0.0811***	0.0248***	0.0602***	0.0435***	0.0321***	0.0525***	0.0055***
	(0.0567)	(0.0234)	(0.0195)	(0.0049)	(0.0020)	(0.0017)	(0.0034)	(0.0013)	(0.0011)
Quadratic	0.1067***	0.0990***	0.0667***	0.0191***	0.0635***	0.0348***	0.0091***	0.0439***	0.0085***
	(0.0378)	(0.0174)	(0.0160)	(0.0035)	(0.0015)	(0.0014)	(0.0025)	(0.0010)	(0.0009)
Linear Interacted	0.1038**	0.1086***	0.0874***	0.0161***	0.0483***	0.0148***	0.0105***	0.0429***	-0.0078***
	(0.0453)	(0.0202)	(0.0174)	(0.0042)	(0.0018)	(0.0016)	(0.0029)	(0.0012)	(0.0011)
Panel B: RDD Polynomials in Longitude and Latitude									
Linear	0.1041***	0.0970***	0.0668***	0.0234***	0.0644***	0.0330***	0.0112***	0.0425***	0.0070***
	(0.0376)	(0.0174)	(0.0159)	(0.0034)	(0.0015)	(0.0014)	(0.0025)	(0.0010)	(0.0009)
Quadratic	0.0967***	0.0979***	0.0643***	0.0354***	0.0743***	0.0400***	0.0202***	0.0483***	0.0104***
	(0.0374)	(0.0172)	(0.0159)	(0.0034)	(0.0015)	(0.0014)	(0.0025)	(0.0010)	(0.0009)
Cubic	0.0944**	0.0931***	0.0534***	0.0240***	0.0701***	0.0487***	0.0092***	0.0435***	0.0196***
	(0.0369)	(0.0174)	(0.0163)	(0.0034)	(0.0015)	(0.0014)	(0.0024)	(0.0010)	(0.0009)
Quartic	0.0945***	0.1023***	0.1022***	0.0344***	0.0743***	0.0557***	0.0132***	0.0449***	0.0192***
	(0.0363)	(0.0172)	(0.0162)	(0.0034)	(0.0016)	(0.0015)	(0.0024)	(0.0011)	(0.0010)
Border Region by Year FE	✓	✓	✓	✓	✓	✓	✓	✓	✓
Regional Socioeconomic Controls	✓	✓	✓	✓	✓	✓	✓	✓	✓
Individual Property Controls				✓	✓	✓	✓	✓	✓
Observations				321,677	1,333,598	1,891,133	163,739	648,658	968,683
Municipalities	1,084	4,897	6,804	1,084	4,897	6,804	1,018	4,570	6,416
Data Availability Period	2011-2016	2011-2016	2011-2016	2010-2019	2010-2019	2010-2019	2010-2019	2010-2019	2010-2019

Note: Shown are the coefficients and standard errors for "high broadband state" under different specifications of the RDD polynomials, with each cell in the table reporting the result of a separate regression. Panel A displays estimates for linear, quadratic, and linear interacted RDD polynomials in distance to border, whereas Panel B presents the results for linear, quadratic, cubic, and quartic RDD specifications in longitude and latitude. Property sale prices and rents are log values in order to facilitate better comparability of the estimates. Standard errors are robust against heteroskedasticity and clustered at the municipality-level for municipal broadband access. *p<0.1; **p<0.05; ***p<0.01.

Table 14: Sensitivity of Spatial RDD Results to Different Bandwidths Around the Interstate Borders

E.2.2 Sensitivity of Spatial RDD Results to Observations near the Interstate Borders ("Donut Hole Approach")

Spatial RDD Estimates	Broadband Availability			Sale Prices			Rents		
"Donut Hole" Size	2 km	5 km	10 km	2 km	5 km	10 km	2 km	5 km	10 km
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Panel A: RDD Polynomials in Distance to Border									
Linear	0.1199***	0.1251***	0.1348***	0.0638***	0.0878***	0.1109***	0.0578***	0.0865***	0.0836***
	(0.0251)	(0.0310)	(0.0521)	(0.0021)	(0.0027)	(0.0046)	(0.0014)	(0.0018)	(0.0029)
Quadratic	0.1052***	0.1046***	0.1053***	0.0660***	0.0741***	0.0672***	0.0460***	0.0571***	0.0511***
	(0.0180)	(0.0189)	(0.0229)	(0.0016)	(0.0017)	(0.0021)	(0.0010)	(0.0011)	(0.0014)
Linear Interacted	0.1248***	0.1488***	0.1975***	0.0484***	0.0585***	0.0792***	0.0429***	0.0631***	0.0702***
	(0.0216)	(0.0259)	(0.0429)	(0.0019)	(0.0023)	(0.0036)	(0.0013)	(0.0016)	(0.0025)
Panel B: RDD Polynomials in Longitude and Latitude									
Linear	0.1033***	0.1023***	0.1027***	0.0674***	0.0748***	0.0668***	0.0450***	0.0562***	0.0484***
	(0.0180)	(0.0189)	(0.0229)	(0.0016)	(0.0017)	(0.0021)	(0.0010)	(0.0011)	(0.0014)
Quadratic	0.1047***	0.1014***	0.0988***	0.0770***	0.0832***	0.0762***	0.0499***	0.0585***	0.0514***
	(0.0178)	(0.0188)	(0.0226)	(0.0016)	(0.0017)	(0.0021)	(0.0010)	(0.0011)	(0.0014)
Cubic	0.0995***	0.0952***	0.0964***	0.0738***	0.0813***	0.0754***	0.0460***	0.0568***	0.0495***
	(0.0178)	(0.0188)	(0.0225)	(0.0016)	(0.0018)	(0.0021)	(0.0010)	(0.0011)	(0.0014)
Quartic	0.1090***	0.1052***	0.1059***	0.0805***	0.0899***	0.0873***	0.0486***	0.0602***	0.0564***
	(0.0177)	(0.0187)	(0.0223)	(0.0017)	(0.0019)	(0.0024)	(0.0011)	(0.0012)	(0.0015)
Border Region by Year FE	✓	✓	✓	✓	✓	✓	✓	✓	✓
Regional Socioeconomic Controls	✓	✓	✓	✓	✓	✓	✓	✓	✓
Individual Property Controls				✓	✓	✓	✓	✓	✓
Observations	1,244,581	1,044,944	750,323	1,244,581	1,044,944	750,323	606,139	503,561	368,529
Municipalities	4,712	4,148	3,080	4,712	4,148	3,080	4,383	3,845	2,854
Data Availability Period	2011-2016	2011-2016	2011-2016	2010-2019	2010-2019	2010-2019	2010-2019	2010-2019	2010-2019

Note: Shown are the coefficients and standard errors for "high broadband state" under different specifications of the RDD polynomials, with each cell in the table reporting the result of a separate regression. Panel A displays estimates for linear, quadratic, and linear interacted RDD polynomials in distance to border, whereas Panel B presents the results for linear, quadratic, cubic, and quartic RDD specifications in longitude and latitude. Property sale prices and rents are log values in order to facilitate better comparability of the estimates. Standard errors are robust against heteroskedasticity and clustered at the municipality-level for municipal broadband access. *p<0.1; **p<0.05; ***p<0.01.

Table 15: Sensitivity of Spatial RDD Results to Observations near the Interstate Borders ("Donut Hole Approach")

E.2.3 Sensitivity of Spatial RDD Results to the Subsequent Addition of Fixed Effects and Control Variables

Spatial RDD Estimates	Broadband Availability			Sale Prices			Rents		
Regression Specification	**Plain**	**+ FE**	**+FE +controls**	**Plain**	**+ FE**	**+FE +controls**	**Plain**	**+ FE**	**+FE +controls**
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**	**(9)**
Panel A: RDD Polynomials in Distance to Border									
Linear	0.2319***	0.1124***	0.0999***	0.2145***	0.0954***	0.0602***	0.2145***	0.0954***	0.0605***
	(0.0204)	(0.0230)	(0.0234)	(0.0019)	(0.0021)	(0.0020)	(0.0019)	(0.0021)	(0.0020)
Quadratic	0.2361***	0.1155***	0.0990***	0.2205***	0.0976***	0.0635***	0.2205***	0.0976***	0.0641***
	(0.0103)	(0.0165)	(0.0174)	(0.0010)	(0.0015)	(0.0015)	(0.0010)	(0.0015)	(0.0015)
Linear Interacted	0.2432***	0.1218***	0.1086***	0.1847***	0.0652***	0.0483***	0.1847***	0.0652***	0.0487***
	(0.0174)	(0.0199)	(0.0202)	(0.0016)	(0.0019)	(0.0018)	(0.0016)	(0.0019)	(0.0018)
Panel B: RDD Polynomials in Longitude and Latitude									
Linear	0.2265***	0.1129***	0.0970***	0.2127***	0.0912***	0.0644***	0.2127***	0.0912***	0.0650***
	(0.0107)	(0.0165)	(0.0174)	(0.0010)	(0.0015)	(0.0015)	(0.0010)	(0.0015)	(0.0015)
Quadratic	0.2181***	0.1144***	0.0979***	0.1943***	0.0909***	0.0743***	0.1943***	0.0909***	0.0748***
	(0.0100)	(0.0162)	(0.0172)	(0.0009)	(0.0015)	(0.0015)	(0.0009)	(0.0015)	(0.0015)
Cubic	0.2109***	0.1086***	0.0931***	0.1818***	0.0854***	0.0701***	0.1818***	0.0854***	0.0703***
	(0.0100)	(0.0164)	(0.0174)	(0.0009)	(0.0015)	(0.0015)	(0.0009)	(0.0015)	(0.0015)
Quartic	0.2221***	0.1130***	0.1023***	0.1738***	0.0833***	0.0743***	0.1738***	0.0833***	0.0744***
	(0.0099)	(0.0164)	(0.0172)	(0.0009)	(0.0017)	(0.0016)	(0.0009)	(0.0017)	(0.0016)
Border Region by Year FE		✓	✓		✓	✓		✓	✓
Regional Socioeconomic Controls			✓			✓			✓
Individual Property Controls						✓			✓
Observations				1,333,193	1,333,193	1,333,193	648,519	648,519	648,519
Municipalities	4,897	4,897	4,897	4,897	4,897	4,897	4,570	4,570	4,570
Data Availability Period	2011-2016	2011-2016	2011-2016	2010-2019	2010-2019	2010-2019	2010-2019	2010-2019	2010-2019

Note: Shown are the coefficients and standard errors for "high broadband state" under different specifications of the RDD polynomials, with each cell in the table reporting the result of a separate regression. Panel A displays estimates for linear, quadratic, and linear interacted RDD polynomials in distance to border, whereas Panel B presents the results for linear, quadratic, cubic, and quartic RDD specifications in longitude and latitude. Property sale prices and rents are log values in order to facilitate better comparability of the estimates. Standard errors are robust against heteroskedasticity and clustered at the municipality-level for municipal broadband access. *p<0.1; **p<0.05; ***p<0.01.

Table 16: Sensitivity of Spatial RDD Results to the Subsequent Addition of Fixed Effects and Control Variables

E.2.4 Sensitivity of Spatial RDD Results to Estimations in Levels (Prices per Square Meter)

Spatial RDD Estimates	**Broadband Availability in Municipalities**	**Real Estate Sale Prices per sqm**	**Real Estate Rents per sqm**
	(1)	**(2)**	**(3)**
Panel A: RDD Polynomials in Distance to Border			
Linear	0.0999***	79.5038***	0.3724***
	(0.0234)	(2.6977)	(0.0090)
Quadratic	0.0990***	83.8841***	0.3036***
	(0.0174)	(2.1065)	(0.0068)
Linear Interacted	0.1086***	71.5816***	0.3053***
	(0.0202)	(2.5187)	(0.0085)
Panel B: RDD Polynomials in Longitude and Latitude			
Linear	0.0970***	83.8233***	0.2917***
	(0.0174)	(2.1169)	(0.0069)
Quadratic	0.0979***	105.5522***	0.3332***
	(0.0172)	(2.0940)	(0.0069)
Cubic	0.0931***	100.2879***	0.2954***
	(0.0174)	(2.0922)	(0.0069)
Quartic	0.1023***	89.3098***	0.2884***
	(0.0172)	(2.2000)	(0.0072)
Border Region by Year FE	✓	✓	✓
Regional Socioeconomic Controls	✓	✓	✓
Individual Property Controls		✓	✓
Observations		1,333,599	648,501
Municipalities	4,897	4,897	4,570
Data Availability Period	2011-2016	2010-2019	2010-2019

Note: Shown are the coefficients and standard errors for "high broadband state" under different specifications of the RDD polynomials, with each cell in the table reporting the result of a separate regression. Panel A displays estimates for linear, quadratic, and linear interacted RDD polynomials in distance to border, whereas Panel B presents the results for linear, quadratic, cubic, and quartic RDD specifications in longitude and latitude. Property sale prices and rents are log values in order to facilitate better comparability of the estimates. Standard errors are robust against heteroskedasticity and clustered at the municipality-level for municipal broadband access. *p<0.1; **p<0.05; ***p<0.01.

Table 17: Sensitivity of RDD Spatial Results to Estimations in Levels (Prices per Square Meter)

E.2.5 Sensitivity of Spatial RDD Results to Estimations in Levels (Total Prices)

Spatial RDD Estimates	Broadband Availability in Municipalities	Real Estate Sale Prices per sqm	Real Estate Rents per sqm
	(1)	(2)	(3)
Panel A: RDD Polynomials in Distance to Border			
Linear	0.0999***	9,961.0107***	30.7962***
	(0.0234)	(429.0032)	(0.8333)
Quadratic	0.0990***	11,645.5483***	25.1453***
	(0.0174)	(324.3605)	(0.6161)
Linear Interacted	0.1086***	8,751.1269***	25.5521***
	(0.0202)	(394.1785)	(0.7713)
Panel B: RDD Polynomials in Longitude and Latitude			
Linear	0.0970***	11,686.7213***	23.7885***
	(0.0174)	(325.1242)	(0.6159)
Quadratic	0.0979***	13,575.3953***	27.7219***
	(0.0172)	(326.8030)	(0.6190)
Cubic	0.0931***	12,833.1967***	24.6041***
	(0.0174)	(328.2698)	(0.6283)
Quartic	0.1023***	11,258.3430***	22.5527***
	(0.0172)	(350.3560)	(0.6554)
Border Region by Year FE	✓	✓	✓
Regional Socioeconomic Controls	✓	✓	✓
Individual Property Controls		✓	✓
Observations		1,333,599	648,501
Municipalities	4,897	4,897	4,570
Data Availability Period	2011-2016	2010-2019	2010-2019

Note: Shown are the coefficients and standard errors for “high broadband state” under different specifications of the RDD polynomials, with each cell in the table reporting the result of a separate regression. Panel A displays estimates for linear, quadratic, and linear interacted RDD polynomials in distance to border, whereas Panel B presents the results for linear, quadratic, cubic, and quartic RDD specifications in longitude and latitude. Property sale prices and rents are log values in order to facilitate better comparability of the estimates. Standard errors are robust against heteroskedasticity and clustered at the municipality-level for municipal broadband access. *p<0.1; **p<0.05; ***p<0.01.

Table 18: Sensitivity of Spatial RDD Results to Estimations in Levels (Total Prices)

F Robustness Checks

F.1 Robustness Checks on Sample

F.1.1 Spatial Robustness Checks of the Two-Stage Spatial RDD: Leaving One Border Region Out

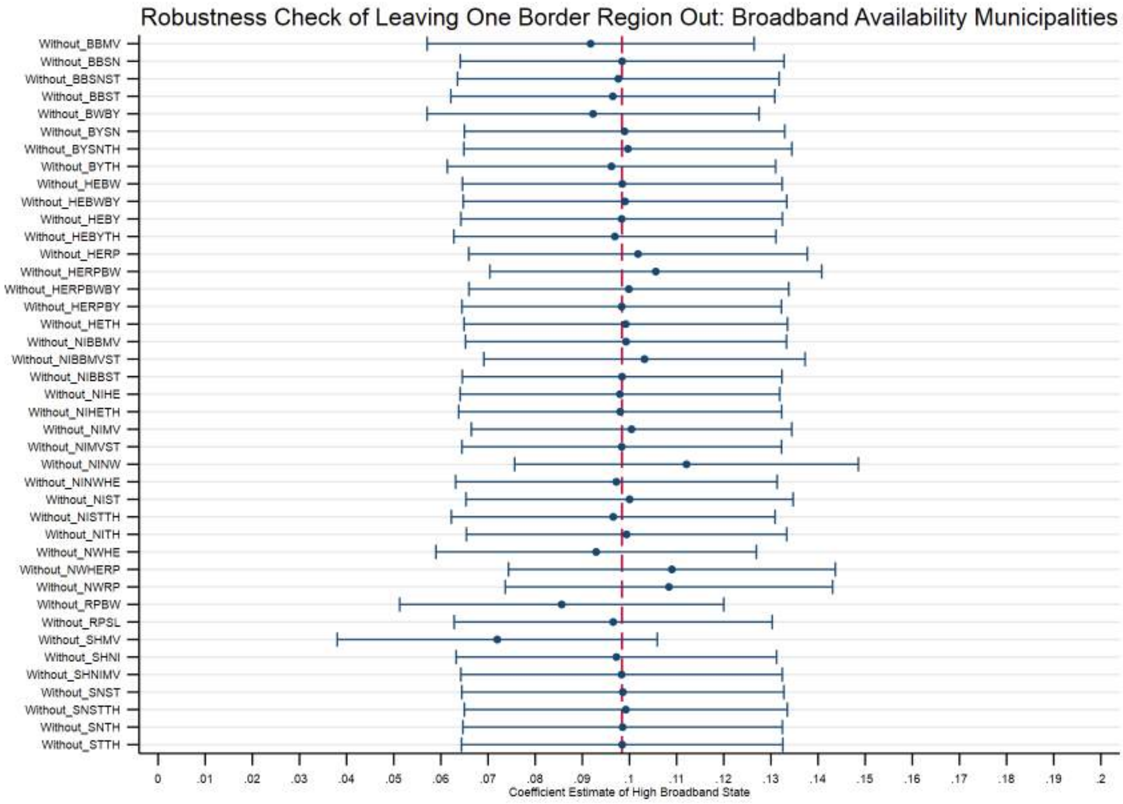


Figure 27: Leaving One Border Region Out: Broadband Availability in Municipalities

Note: This coefficient plot presents the coefficients and standard errors for the effect of "high broadband state" on broadband availability in municipalities using the preferred RDD specification with quadratic polynomials in longitude and latitude, with each row reporting the result of a separate regression that leaves out one distinct border region at a time.

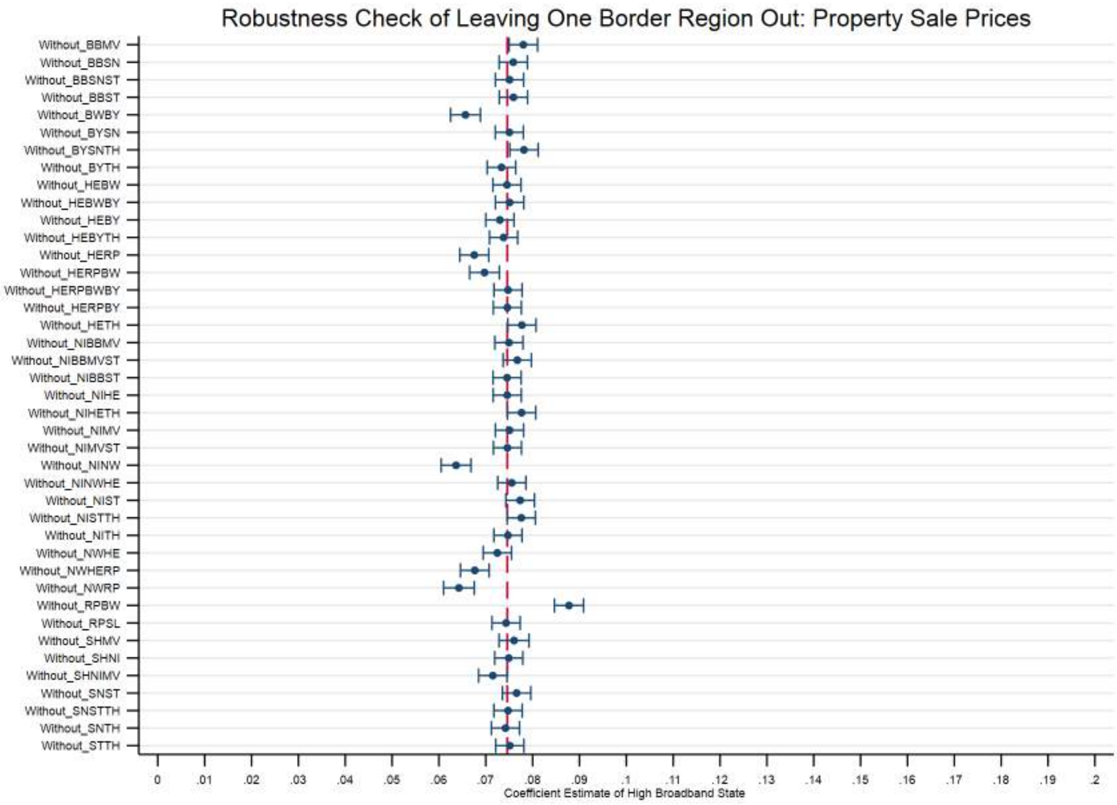


Figure 28: Leaving One Border Region Out: Property Sale Prices

Note: This coefficient plot presents the coefficients and standard errors for the effect of "high broadband state" on property sale prices using the preferred RDD specification with quadratic polynomials in longitude and latitude, with each row reporting the result of a separate regression that leaves out one distinct border region at a time.

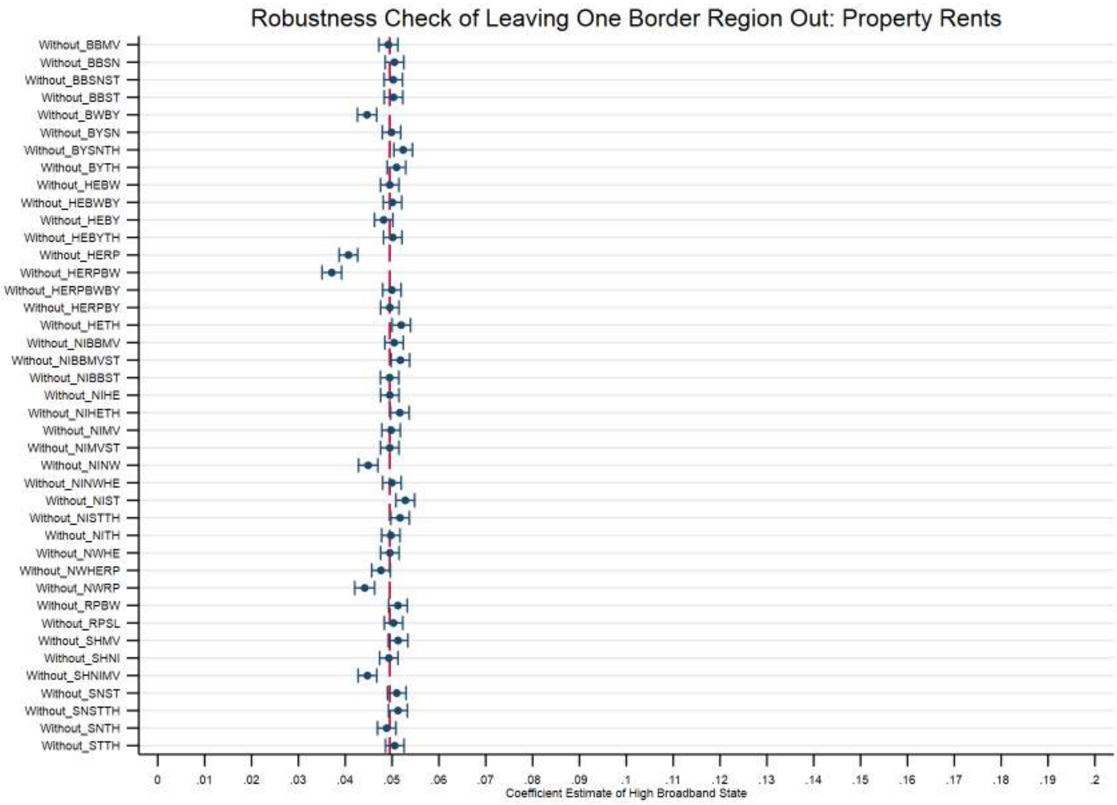


Figure 29: Leaving One Border Region Out: Property Rents

Note: This coefficient plot presents the coefficients and standard errors for the effect of "high broadband state" on property rents using the preferred RDD specification with quadratic polynomials in longitude and latitude, with each row reporting the result of a separate regression that leaves out one distinct border region at a time.

F.1.2 Estimation of the Two-Stage Spatial RDD of Former West Germany Only

Spatial RDD Estimates	Broadband Availability in Municipalities	Real Estate Sale Prices per sqm	Real Estate Rents per sqm
	(1)	(2)	(3)
Panel A: RDD Polynomials in Distance to Border			
Linear	0.0547*	0.0835***	0.0931***
	(0.0302)	(0.0024)	(0.0018)
Quadratic	0.0650***	0.0935***	0.0913***
	(0.0242)	(0.0020)	(0.0015)
Linear Interacted	0.0767***	0.0863***	0.0961***
	(0.0257)	(0.0022)	(0.0017)
Panel B: RDD Polynomials in Longitude and Latitude			
Linear	0.0527**	0.1114***	0.0939***
	(0.0244)	(0.0020)	(0.0015)
Quadratic	0.0515**	0.1206***	0.1009***
	(0.0244)	(0.0020)	(0.0015)
Cubic	0.0620**	0.0942***	0.0754***
	(0.0245)	(0.0021)	(0.0016)
Quartic	0.0806***	0.0580***	0.0453***
	(0.0253)	(0.0022)	(0.0017)
Border Region by Year FE	✓	✓	✓
Regional Socioeconomic Controls	✓	✓	✓
Individual Property Controls		✓	✓
Observations		1,054,234	433,724
Municipalities	3,438	3,438	3,290
Data Availability Period	2011-2016	2010-2019	2010-2019

Note: Shown are the coefficients and standard errors for "high broadband state" under different specifications of the RDD polynomials, with each cell in the table reporting the result of a separate regression. Panel A displays estimates for linear, quadratic, and linear interacted RDD polynomials in distance to border, whereas Panel B presents the results for linear, quadratic, cubic, and quartic RDD specifications in longitude and latitude. Property sale prices and rents are log values in order to facilitate better comparability of the estimates. Standard errors are robust against heteroskedasticity and clustered at the municipality-level for municipal broadband access. *p<0.1; **p<0.05; ***p<0.01.

Table 19: Estimation of the Two-Stage Spatial RDD of Former West Germany Only

F.1.3 Estimation of the Two-Stage Spatial RDD of Former East Germany Only

Spatial RDD Estimates	Broadband Availability in Municipalities	Real Estate Sale Prices per sqm	Real Estate Rents per sqm
	(1)	(2)	(3)
Panel B: RDD Polynomials in Longitude and Latitude			
Linear	0.2438***	0.0968***	0.0362***
	(0.0409)	(0.0067)	(0.0026)
Quadratic	0.1747***	0.0737***	0.0134***
	(0.0297)	(0.0057)	(0.0023)
Linear Interacted	0.1408***	0.0047	-0.0068**
	(0.0391)	(0.0066)	(0.0026)
Panel B: RDD Polynomials in Longitude and Latitude			
Linear	0.1504***	0.0749***	0.0192***
	(0.0300)	(0.0058)	(0.0024)
Quadratic	0.1588***	0.0818***	0.0176***
	(0.0313)	(0.0058)	(0.0024)
Cubic	0.1654***	0.0766***	0.0262***
	(0.0312)	(0.0058)	(0.0024)
Quartic	0.1619***	0.0599***	0.0227***
	(0.0309)	(0.0059)	(0.0024)
Border Region by Year FE	✓	✓	✓
Regional Socioeconomic Controls	✓	✓	✓
Individual Property Controls		✓	✓
Observations		279,094	214,349
Municipalities	1,459	1,459	1,280
Data Availability Period	2011-2016	2010-2019	2010-2019

Note: Shown are the coefficients and standard errors for "high broadband state" under different specifications of the RDD polynomials, with each cell in the table reporting the result of a separate regression. Panel A displays estimates for linear, quadratic, and linear interacted RDD polynomials in distance to border, whereas Panel B presents the results for linear, quadratic, cubic, and quartic RDD specifications in longitude and latitude. Property sale prices and rents are log values in order to facilitate better comparability of the estimates. Standard errors are robust against heteroskedasticity and clustered at the municipality-level for municipal broadband access. *p<0.1; **p<0.05; ***p<0.01.

Table 20: Estimation of the Two-Stage Spatial RDD of Former East Germany Only

F.1.4 Estimation of the Two-Stage Spatial RDD Without Bavaria in 2018 and 2019

Spatial RDD Estimates	**Broadband Availability in Municipalities**	**Real Estate Sale Prices per sqm**	**Real Estate Rents per sqm**
	(1)	**(2)**	**(3)**
Panel A: RDD Polynomials in Distance to Border			
Linear	0.0999***	0.0577***	0.0516***
	(0.0234)	(0.0020)	(0.0013)
Quadratic	0.0990***	0.0625***	0.0437***
	(0.0174)	(0.0015)	(0.0010)
Linear Interacted	0.1086***	0.0454***	0.0418***
	(0.0202)	(0.0018)	(0.0012)
Panel B: RDD Polynomials in Longitude and Latitude			
Linear	0.0970***	0.0634***	0.0422***
	(0.0174)	(0.0015)	(0.0010)
Quadratic	0.0979***	0.0732***	0.0479***
	(0.0172)	(0.0015)	(0.0010)
Cubic	0.0931***	0.0691***	0.0432***
	(0.0174)	(0.0015)	(0.0010)
Quartic	0.1023***	0.0730***	0.0443***
	(0.0172)	(0.0016)	(0.0011)
Border Region by Year FE	✓	✓	✓
Regional Socioeconomic Controls	✓	✓	✓
Individual Property Controls		✓	✓
Observations		1,318,618	644,127
Municipalities	4,897	4,897	4,569
Data Availability Period	2011-2016	2010-2019	2010-2019

Note: Shown are the coefficients and standard errors for "high broadband state" under different specifications of the RDD polynomials, with each cell in the table reporting the result of a separate regression. Panel A displays estimates for linear, quadratic, and linear interacted RDD polynomials in distance to border, whereas Panel B presents the results for linear, quadratic, cubic, and quartic RDD specifications in longitude and latitude. Property sale prices and rents are log values in order to facilitate better comparability of the estimates. Standard errors are robust against heteroskedasticity and clustered at the municipality-level for municipal broadband access. *p<0.1; **p<0.05; ***p<0.01.

Table 21: Estimation of the Two-Stage Spatial RDD Without Bavaria in 2018 and 2019

F.1.5 Estimation of the Two-Stage Spatial RDD Without Rhineland-Palatinate

Spatial RDD Estimates	Broadband Availability in Municipalities	Real Estate Sale Prices per sqm	Real Estate Rents per sqm
	(1)	(2)	(3)
Panel A: RDD Polynomials in Distance to Border			
Linear	0.1417***	0.0537***	0.0346***
	(0.0267)	(0.0024)	(0.0015)
Quadratic	0.1263***	0.0501***	0.0169***
	(0.0207)	(0.0020)	(0.0012)
Linear Interacted	0.1487***	0.0295***	0.0080***
	(0.0240)	(0.0022)	(0.0014)
Panel B: RDD Polynomials in Longitude and Latitude			
Linear	0.1297***	0.0339***	0.0080***
	(0.0200)	(0.0020)	(0.0012)
Quadratic	0.1268***	0.0445***	0.0135***
	(0.0200)	(0.0020)	(0.0012)
Cubic	0.1227***	0.0312***	0.0008
	(0.0200)	(0.0020)	(0.0012)
Quartic	0.1232***	0.0457***	0.0121***
	(0.0195)	(0.0021)	(0.0013)
Border Region by Year FE	✓	✓	✓
Regional Socioeconomic Controls	✓	✓	✓
Individual Property Controls		✓	✓
Observations		1,049,350	538,677
Municipalities	3,271	3,271	3,047
Data Availability Period	2011-2016	2010-2019	2010-2019

Note: Shown are the coefficients and standard errors for "high broadband state" under different specifications of the RDD polynomials, with each cell in the table reporting the result of a separate regression. Panel A displays estimates for linear, quadratic, and linear interacted RDD polynomials in distance to border, whereas Panel B presents the results for linear, quadratic, cubic, and quartic RDD specifications in longitude and latitude. Property sale prices and rents are log values in order to facilitate better comparability of the estimates. Standard errors are robust against heteroskedasticity and clustered at the municipality-level for municipal broadband access. *p<0.1; **p<0.05; ***p<0.01.

Table 22: Estimation of the Two-Stage Spatial RDD Without Rhineland-Palatinate

F.1.6 Estimation of the Two-Stage Spatial RDD With Sample Including Bigger Cities

Spatial RDD Estimates	**Broadband Availability in Municipalities**	**Real Estate Sale Prices per sqm**	**Real Estate Rents per sqm**
	(1)	**(2)**	**(3)**
Panel A: RDD Polynomials in Distance to Border			
Linear	0.1376***	0.0974***	0.0754***
	(0.0288)	(0.0015)	(0.0009)
Quadratic	0.1240***	0.1084***	0.0863***
	(0.0209)	(0.0011)	(0.0007)
Linear Interacted	0.1337***	0.0706***	0.0591***
	(0.0259)	(0.0013)	(0.0008)
Panel B: RDD Polynomials in Longitude and Latitude			
Linear	0.1215***	0.1083***	0.0856***
	(0.0209)	(0.0011)	(0.0007)
Quadratic	0.1249***	0.1211***	0.0910***
	(0.0207)	(0.0012)	(0.0007)
Cubic	0.1193***	0.1192***	0.0888***
	(0.0209)	(0.0012)	(0.0007)
Quartic	0.1310***	0.1204***	0.0884***
	(0.0214)	(0.0012)	(0.0007)
Border Region by Year FE	✓	✓	✓
Regional Socioeconomic Controls	✓	✓	✓
Individual Property Controls		✓	✓
Observations		2,306,728	2,051,393
Municipalities	5,248	5,248	4,920
Data Availability Period	2011-2016	2010-2019	2010-2019

Note: Shown are the coefficients and standard errors for "high broadband state" under different specifications of the RDD polynomials, with each cell in the table reporting the result of a separate regression. Panel A displays estimates for linear, quadratic, and linear interacted RDD polynomials in distance to border, whereas Panel B presents the results for linear, quadratic, cubic, and quartic RDD specifications in longitude and latitude. Property sale prices and rents are log values in order to facilitate better comparability of the estimates. Standard errors are robust against heteroskedasticity and clustered at the municipality-level for municipal broadband access. *p<0.1; **p<0.05; ***p<0.01.

Table 23: Estimation of the Two-Stage Spatial RDD With Sample Including Bigger Cities

F.2 Estimation of the Two-Stage Spatial RDD With Additional Control Variables

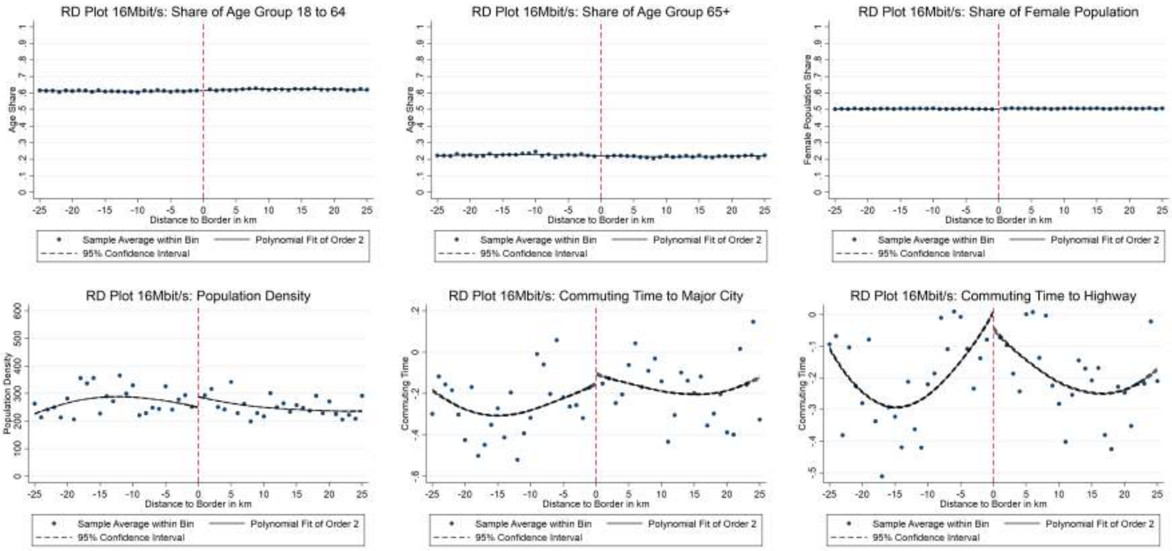


Figure 30: Graphical Evidence of Balanced Additional Controls Around Interstate Borders

Note: This combined figure of RD plots shows additional regional socioeconomic characteristics around the interstate borders that are used as the boundary discontinuity in the main analysis. The outcome variables are plotted in levels on the y-axis and distance to border is displayed on the x-axis. The graphs additionally display solid lines for the quadratic fit and dotted lines for the 95 percent confidence intervals. The variables are the share of age group 18-64; the share of age group 65+; the share of female population; the population density; the commuting time to the nearest major city; the commuting time to the nearest highway. While the corresponding robustness check controls for all of these regional characteristics, it is notable that no major other discontinuities around the interstate borders are visible.

Spatial RDD Estimates	Broadband Availability in Municipalities	Real Estate Sale Prices per sqm	Real Estate Rents per sqm
	(1)	(2)	(3)
Panel A: RDD Polynomials in Distance to Border			
Linear	0.0764***	0.0380***	0.0309***
	(0.0208)	(0.0020)	(0.0013)
Quadratic	0.0711***	0.0310***	0.0218***
	(0.0156)	(0.0015)	(0.0010)
Linear Interacted	0.0820***	0.0202***	0.0200***
	(0.0181)	(0.0018)	(0.0012)
Panel B: RDD Polynomials in Longitude and Latitude			
Linear	0.0710***	0.0338***	0.0223***
	(0.0156)	(0.0015)	(0.0010)
Quadratic	0.0697***	0.0424***	0.0255***
	(0.0156)	(0.0015)	(0.0010)
Cubic	0.0702***	0.0411***	0.0272***
	(0.0158)	(0.0016)	(0.0010)
Quartic	0.0821***	0.0584***	0.0319***
	(0.0155)	(0.0016)	(0.0010)
Border Region by Year FE	✓	✓	✓
Regional Socioeconomic Controls	✓	✓	✓
Individual Property Controls		✓	✓
Observations		1,331,309	647,897
Municipalities	4,897	4,897	4,570
Data Availability Period	2011-2016	2010-2019	2010-2019

Note: Shown are the coefficients and standard errors for "high broadband state" under different specifications of the RDD polynomials, with each cell in the table reporting the result of a separate regression. Additional control variables for population density, female population share, age 18-64 share, age 65+ share, and commuting times are included. Panel A displays estimates for linear, quadratic, and linear interacted RDD polynomials in distance to border, whereas Panel B presents the results for linear, quadratic, cubic, and quartic RDD specifications in longitude and latitude. Property sale prices and rents are log values in order to facilitate better comparability of the estimates. Standard errors are robust against heteroskedasticity and clustered at the municipality-level for municipal broadband access. *p<0.1; **p<0.05; ***p<0.01.

Table 24: Estimation of the Two-Stage Spatial RDD With Additional Control Variables

F.3 Alternative Cutoffs for State Classification

F.3.1 Estimation of the Two-Stage Spatial RDD Using Alternative "High Broadband State" Cutoff of 65% Covered Households

Spatial RDD Estimates	**Broadband Availability in Municipalities**	**Real Estate Sale Prices per sqm**	**Real Estate Rents per sqm**
	(1)	**(2)**	**(3)**
Panel A: RDD Polynomials in Distance to Border			
Linear	0.0818***	0.0330***	0.0261***
	(0.0199)	(0.0022)	(0.0015)
Quadratic	0.0825***	0.0363***	0.0282***
	(0.0203)	(0.0021)	(0.0015)
Linear Interacted	0.0826***	0.0254***	0.0228***
	(0.0203)	(0.0022)	(0.0015)
Panel B: RDD Polynomials in Longitude and Latitude			
Linear	0.0833***	0.0374***	0.0287***
	(0.0203)	(0.0021)	(0.0015)
Quadratic	0.0868***	0.0423***	0.0329***
	(0.0202)	(0.0021)	(0.0015)
Cubic	0.0854***	0.0343***	0.0290***
	(0.0201)	(0.0022)	(0.0015)
Quartic	0.0911***	0.0413***	0.0316***
	(0.0203)	(0.0022)	(0.0015)
Border Region by Year FE	✓	✓	✓
Regional Socioeconomic Controls	✓	✓	✓
Individual Property Controls		✓	✓
Observations		722,102	323,451
Municipalities	4,783	4,783	4,231
Data Availability Period	2011-2016	2010-2019	2010-2019

Note: Shown are the coefficients and standard errors for "high broadband state" under different specifications of the RDD polynomials, with each cell in the table reporting the result of a separate regression. Panel A displays estimates for linear, quadratic, and linear interacted RDD polynomials in distance to border, whereas Panel B presents the results for linear, quadratic, cubic, and quartic RDD specifications in longitude and latitude. Property sale prices and rents are log values in order to facilitate better comparability of the estimates. Standard errors are robust against heteroskedasticity and clustered at the municipality-level for municipal broadband access. *p<0.1; **p<0.05; ***p<0.01.

Table 25: Estimation of the Two-Stage Spatial RDD Using Alternative "High Broadband State" Cutoff of 65% Covered Households

F.3.2 Estimation of the Two-Stage Spatial RDD Using Alternative "High Broadband State" Cutoff of 85% Covered Households

Spatial RDD Estimates	Broadband Availability in Municipalities	Real Estate Sale Prices per sqm	Real Estate Rents per sqm
	(1)	(2)	(3)
Panel A: RDD Polynomials in Distance to Border			
Linear	0.0380***	0.0443***	0.0414***
	(0.0144)	(0.0025)	(0.0015)
Quadratic	0.0453***	0.0514***	0.0443***
	(0.0153)	(0.0025)	(0.0015)
Linear Interacted	0.0423***	0.0460***	0.0418***
	(0.0148)	(0.0025)	(0.0015)
Panel B: RDD Polynomials in Longitude and Latitude			
Linear	0.0421***	0.0521***	0.0435***
	(0.0153)	(0.0025)	(0.0015)
Quadratic	0.0394***	0.0609***	0.0517***
	(0.0151)	(0.0025)	(0.0015)
Cubic	0.0404***	0.0554***	0.0433***
	(0.0150)	(0.0025)	(0.0015)
Quartic	0.0490***	0.0732***	0.0624***
	(0.0146)	(0.0025)	(0.0016)
Border Region by Year FE	✓	✓	✓
Regional Socioeconomic Controls	✓	✓	✓
Individual Property Controls		✓	✓
Observations		1,459,128	740,435
Municipalities	4,902	4,902	4,595
Data Availability Period	2011-2016	2010-2019	2010-2019

Note: Shown are the coefficients and standard errors for "high broadband state" under different specifications of the RDD polynomials, with each cell in the table reporting the result of a separate regression. Panel A displays estimates for linear, quadratic, and linear interacted RDD polynomials in distance to border, whereas Panel B presents the results for linear, quadratic, cubic, and quartic RDD specifications in longitude and latitude. Property sale prices and rents are log values in order to facilitate better comparability of the estimates. Standard errors are robust against heteroskedasticity and clustered at the municipality-level for municipal broadband access. *p<0.1; **p<0.05; ***p<0.01.

Table 26: Estimation of the Two-Stage Spatial RDD Using Alternative "High Broadband State" Cutoff of 85% Covered Households

F.4 Instrument Validity

Mean Broadband Availability 16 Mbit/s in "High" and "Low" Broadband States 2011-2016

Year	High Broadband States	Low Broadband States
2011	81%	63%
2012	82%	69%
2013	78%	68%
2014	81%	65%
2015	87%	71%
2016	88%	70%

Note: The population-weighted broadband availability is calculated for the entire states (not only small municipalities).

Table 27:

Year	High Broadband States		Low Broadband States	
	Sample Municipalities	Non-Sample Municipalities	Sample Municipalities	Non-Sample Municipalities
2011	52%	56%	47%	45%
2012	58%	59%	53%	52%
2013	64%	63%	55%	53%
2014	70%	68%	46%	49%
2015	76%	75%	56%	57%
2016	80%	79%	52%	60%

Note: The yearly population-weighted broadband availability is calculated within high and low broadband states only for small municipalities that either belong to the border sample or not.

Table 28: Mean Broadband Availability 16 Mbit/s 2011-2016 in the Sample and Non-Sample Small Municipalities

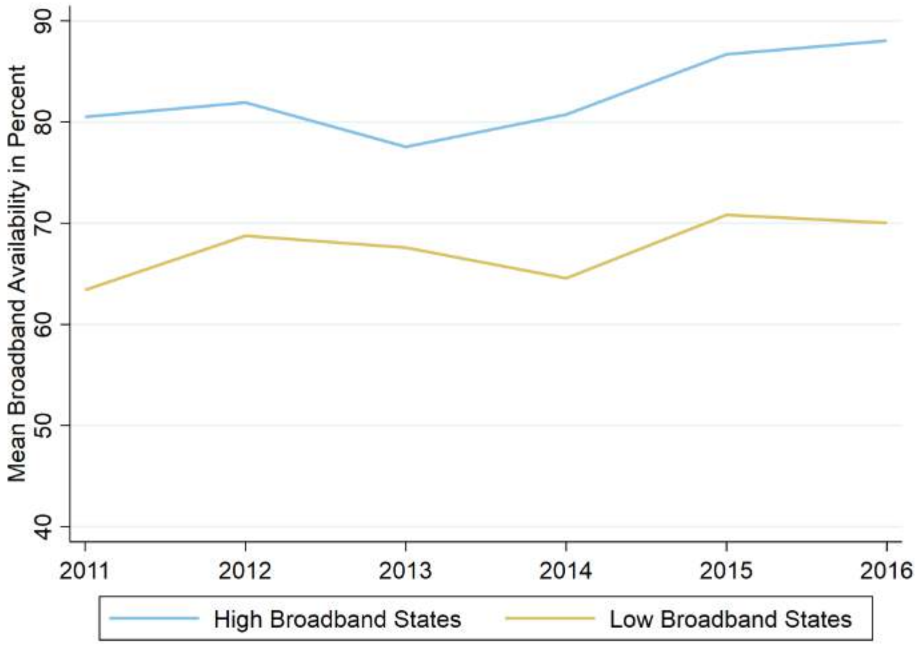


Figure 31: Mean Broadband Availability in States in Percent

Note: This graph portrays the development of the population-weighted broadband availability in high and low broadband states between 2011 and 2016. This calculation uses administrative data on broadband availability and population in municipalities to validate the official numbers for the entire states.

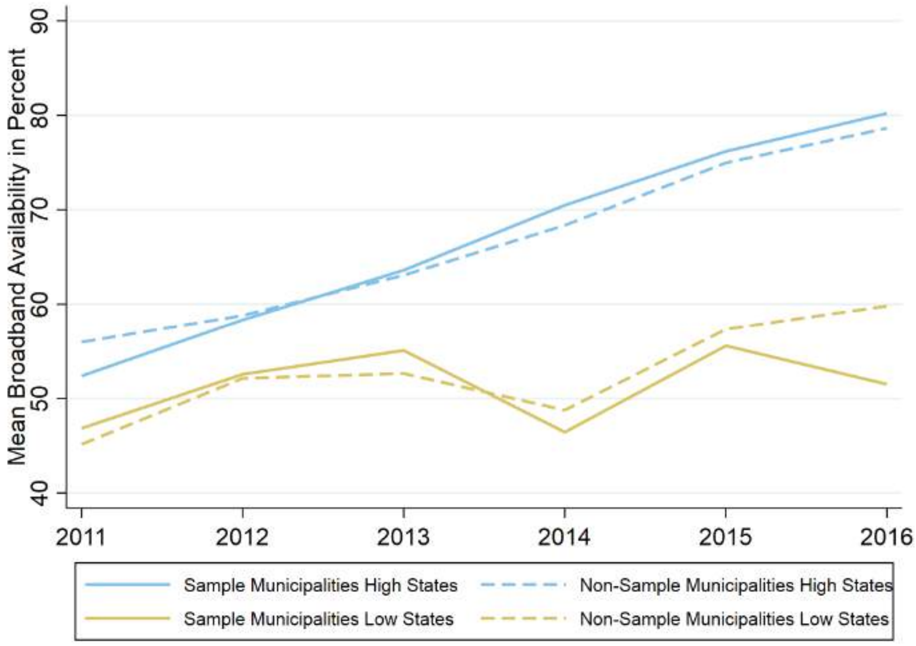


Figure 32: Mean Broadband Availability in Municipalities in Percent

Note: This graph portrays the development of the population-weighted broadband availability in high and low broadband states between 2011 and 2016, with a differentiation between small municipalities belonging to the border sample (solid lines) and other small municipalities in the rest of the states (dashed lines). The similar trend for both sample and non-sample municipalities makes a strong case for our argument that different state preferences for broadband expansion in rural areas determined the level of broadband availability in small municipalities, regardless of whether they are located close to an interstate border or not.

F.5 Alternative Identification Strategy: Event Study

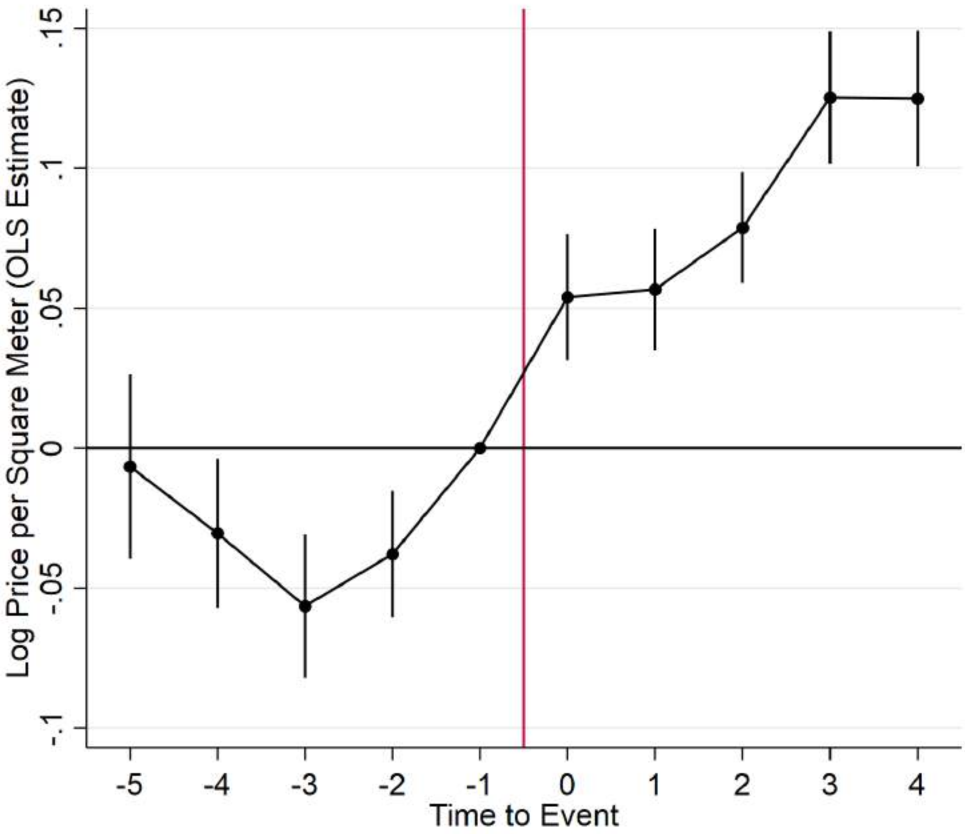


Figure 33: Event Study Estimates

Note: The figure plots event study estimates of property sale prices on the event of states surpassing the "high" broadband threshold. The dependent variable is the log property sale price to facilitate comparability with the main RDD estimates. Confidence intervals are drawn at the 95 percent level and standard errors are robust against heteroskedasticity. The regression specification is similar to the main RDD analyses and includes all property and socioeconomic controls as well as border-region-by-year fixed effects using. Contrary to the main analysis, the sample used are all municipalities located at state borders over time, whereas the main analysis was based only on the pairs of adjacent states where one is considered "high" and the other one "low." This results in a sample that is about three times the size of the main RD sample (3.9 compared with 1.3 million observations). For the event study, the reference period is normalized to the year -1 which is the first year in which a municipality reached the threshold of providing 75 percent of households with at least 16 Mbit/s broadband Internet.

G Placebo Tests

G.1 Tables

G.1.1 Estimation of the Two-Stage Spatial RDD with Individual Property Controls as Dependent Variables

Spatial RDD Estimates	Number of Rooms	Building Age	Garden	Fancy	Quiet Location
	(1)	(2)	(3)	(4)	(5)
Panel A: RDD Polynomials in Distance to Border					
Linear	-0.0094	-0.0958	-0.0030	-0.0003	-0.0045
	(0.0167)	(0.0615)	(0.0047)	(0.0018)	(0.0029)
Quadratic	-0.0148	-0.0360	-0.0019	-0.0010	-0.0021
	(0.0121)	(0.0441)	(0.0032)	(0.0014)	(0.0020)
Linear Interacted	-0.0094	-0.0100	-0.0049	-0.0006	-0.0008
	(0.0149)	(0.0538)	(0.0041)	(0.0018)	(0.0025)
Panel B: RDD Polynomials in Longitude and Latitude					
Linear	-0.0152	-0.0410	-0.0015	-0.0009	-0.0022
	(0.0120)	(0.0439)	(0.0032)	(0.0015)	(0.0020)
Quadratic	-0.0132	-0.0342	-0.0027	0.0000	-0.0019
	(0.0119)	(0.0437)	(0.0031)	(0.0013)	(0.0020)
Cubic	-0.0127	-0.0241	-0.0034	0.0007	-0.0026
	(0.0117)	(0.0430)	(0.0031)	(0.0012)	(0.0020)
Quartic	-0.0123	-0.0153	0.0026	0.0019	-0.0019
	(0.0115)	(0.0433)	(0.0029)	(0.0012)	(0.0020)
Border Region by Year FE	✓	✓	✓	✓	✓
Regional Controls	✓	✓	✓	✓	✓
Property Controls	✓	✓	✓	✓	✓
Observations	1,333,598	1,333,598	1,333,598	1,333,598	1,333,598
Municipalities	4,897	4,897	4,897	4,897	4,897
Data Availability Period	2010-2019	2010-2019	2010-2019	2010-2019	2010-2019

Note: Shown are the coefficients and standard errors for "high broadband state" under different specifications of the RDD polynomials, with each cell in the table reporting the result of a separate regression. Panel A displays estimates for linear, quadratic, and linear interacted RDD polynomials in distance to border, whereas Panel B presents the results for linear, quadratic, cubic, and quartic RDD specifications in longitude and latitude. Property sale prices and rents are log values in order to facilitate better comparability of the estimates. Standard errors are robust against heteroskedasticity and clustered at the municipality-level for municipal broadband access. *p<0.1; **p<0.05; ***p<0.01.

Table 29: Estimation of the Two-Stage Spatial RDD with Individual Property Controls as Dependent Variables

G.1.2 Estimation of the Two-Stage Spatial RDD with Regional Socioeconomic Controls as Dependent Variables

Spatial RDD Estimates	Municipality Growth	Housing Mkt. Region Type	School Quality	Crime Rate	Mobile Internet
	(1)	(2)	(3)	(4)	(5)
Panel A: RDD Polynomials in Distance to Border					
Linear	0.2575***	0.4453***	-0.2097***	-0.0002	-0.0377***
	(0.0881)	(0.0594)	(0.0256)	(0.0005)	(0.0020)
Quadratic	0.3373***	0.3853***	-0.2044***	-0.0004	-0.0364***
	(0.0752)	(0.0461)	(0.0215)	(0.0004)	(0.0019)
Linear Interacted	0.2828***	0.3205***	-0.2025***	-0.0005	-0.0363***
	(0.0892)	(0.0544)	(0.0262)	(0.0005)	(0.0020)
Panel B: RDD Polynomials in Longitude and Latitude					
Linear	0.3432***	0.3880***	-0.2060***	-0.0003	-0.0361***
	(0.0763)	(0.0470)	(0.0210)	(0.0004)	(0.0019)
Quadratic	0.3552***	0.3573***	-0.2233***	-0.0000	-0.0376***
	(0.0706)	(0.0455)	(0.0206)	(0.0004)	(0.0018)
Cubic	0.3435***	0.3907***	-0.2064***	0.0001	-0.0373***
	(0.0686)	(0.0440)	(0.0212)	(0.0004)	(0.0017)
Quartic	0.2983***	0.3483***	-0.1430***	0.0012***	-0.0363***
	(0.0670)	(0.0452)	(0.0229)	(0.0004)	(0.0017)
Border Region by Year FE	✓	✓	✓	✓	✓
Regional Controls	✓	✓	✓	✓	✓
Property Controls	✓	✓	✓	✓	✓
Observations	1,333,598	1,333,598	1,333,598	1,333,598	1,333,598
Municipalities	4,897	4,897	4,897	4,897	4,897
Data Availability Period	2010-2019	2010-2019	2010-2019	2010-2019	2010-2019

Note: Shown are the coefficients and standard errors for "high broadband state" under different specifications of the RDD polynomials, with each cell in the table reporting the result of a separate regression. Panel A displays estimates for linear, quadratic, and linear interacted RDD polynomials in distance to border, whereas Panel B presents the results for linear, quadratic, cubic, and quartic RDD specifications in longitude and latitude. Property sale prices and rents are log values in order to facilitate better comparability of the estimates. Standard errors are robust against heteroskedasticity and clustered at the municipality-level for municipal broadband access. *p<0.1; **p<0.05; ***p<0.01.

Table 30: Estimation of the Two-Stage Spatial RDD with Regional Socioeconomic Controls as Dependent Variables