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From Upgrade to Uptake - The Effect of Mobile Internet Infrastructure on Usage of Local Online Services*

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PRELIMINARY DRAFT

Abstract

This paper provides evidence that superior mobile Internet infrastructure increases take-up of location-based online services. Using data from the largest German online platform for restaurant reviews, I find that upgrading the 2G network to 3G increases the number of restaurant reviews and the share of reviews written on smartphones. To identify the causal effect of the network upgrade, I exploit the geographic location of restaurants relative to cellular network antennas and the terrain around them. Since the 3G signal is much more dependent on a clear line-of-sight than the 2G signal, some restaurants that were previously well covered by 2G are blocked from 3G reception due to geographic obstacles such as hills and forests.

JEL classification: L86, R42, H54

Keywords: Mobile Internet, infrastructure upgrade, broadband

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1 Introduction

Policymakers call for more investment in broadband Internet infrastructure. Network providers, however, are reluctant to upgrade their network unless demand justifies the additional investment. For this reason, many regulators subsidize Internet infrastructure investment in areas with low demand. In the United States, for example, the Federal Communications Commission (FCC) created the Connect America Fund, which subsidizes broadband deployment in rural areas with up to \$4.5 billion per year (FCC, 2011). A portion of this fund is specifically targeted at expanding mobile broadband infrastructure. In Germany, the regulator forced winners of the latest spectrum auction to roll out their new network in rural areas first. Despite these regulatory efforts, the empirical evidence on the effect of infrastructure upgrades that are not driven by demand is anything but conclusive. Returns are likely to be small if the new infrastructure is either not used at all or used in the same fashion as the older infrastructure. It is therefore important to determine how an upgrade affects usage.

This paper shows that upgrading the mobile Internet infrastructure in Germany from a second-generation network (GSM) to a third-generation network (UMTS) had a positive effect on the usage of local online services. While mobile Internet is useful for a wide variety of applications, such as searches or social networks, it is indispensable for local online services that offer information based on the user's location. It is thus not surprising that travel and navigation apps are among the most frequently used smartphone applications.¹ Some of the most popular local online services allow users to find restaurants or other businesses based on ratings and reviews by previous customers. The importance of these reviews for restaurants is underlined by Anderson and Magruder (2012) who uses a regression discontinuity design to show that a better rating on the review platform Yelp leads to a significant increase in bookings.

Combining rich data on restaurants from Europe's largest review platform Qype², a unique dataset of all cellular antennas in Germany, and a fine-grained digital surface model (DSM), I find that in areas where 3G was available early on, restaurants received more reviews and a larger share of these reviews were written on a smartphone. To identify the causal effect of 3G availability, I exploit a technical particularity that distinguishes 2G and 3G signals. In Germany, like in most other countries, 3G uses higher frequency bands than 2G and so its signal is much more dependent on a clear line-of-sight between the mobile phone and a cellular antenna. Given the distance of a phone to the next antenna, 3G signal quality is mainly determined by the presence of obstacles such as hills, forests, and buildings.

The identification strategy of this paper relies on the relationship between the frequency of cellular signals and their sensitivity to other objects. Every signal that travels along the ground is to some extent absorbed by the terrain. The characteristics of the terrain influence the degree of absorption. For this reason, Strömberg (2004) uses a county's share of woodland as an instrument for the

¹A recent study by Nielsen (2012) found that after social networks and search, travel apps are the third most popular app category.

²Qype was acquired by Yelp in October 2012

share of households with radios. His underlying reasoning is that the radio signal is highly absorbed by the woodland and thus people in woody areas are less likely to have radio reception. Similarly, Nolen and Klonner (2010) uses terrain ruggedness as an instrument for the rollout of a cellular network in South Africa. However, not all signals are equally sensitive to the terrain. The degree of absorption increases proportionally with the frequency of the signal (Klemens, 2010, p. 25). Also, the probability that an object completely absorbs a signal is dependent on the frequency of the signal. For example, it is much harder to see around objects than to hear around objects. This is because the frequency of light is much higher than the frequency of sound. In a similar way, a 3G signal on a high-frequency band has a harder time traveling around objects than does a 2G signal on a lower frequency band.

When the 2G infrastructure was built in the early 1990s, every network provider chose its own antenna locations with the aim of maximizing coverage across the country.³ In the early 2000s, most of Germany was covered by the 2G network. When the 3G infrastructure was rolled out, network providers began to upgrade their existing antenna locations with new 3G antennas. Of course, the rollout itself was not random and urban areas had priority over rural areas. Nevertheless, there were many areas that had good 2G reception, but even when 3G antennas were installed at their closest antenna mast, they were not covered by the 3G signal due to characteristics of the terrain around them. Other areas with equal distance to the next antenna mast, however, were able to benefit from 3G because there were no hills or forests blocking the signal.

Using a difference-in-difference approach, I compare areas with 3G coverage to areas that are equally far away from the next antenna mast but that cannot receive 3G due to the terrain around them. 3G coverage is approximated by measuring whether there is a clear line-of-sight to an antenna. If hills, forests, large buildings, or other obstacles are between a specific location and the next antenna masts, 3G reception drops considerably.

The location-based service I analyze in this study, Qype, is especially useful when looking for restaurants close to the user's current location. When a tourist, for example, visits a new city, he can open the Qype app on his smartphone and search for nearby restaurants that have received good reviews from previous customers. If he enjoys the food at a chosen restaurant, he can use the same application to rate the restaurant himself and write a review. By testing whether there is a clear line of sight between a restaurant's immediate surroundings and any antenna within a given radius, I can determine whether the area surrounding the restaurant is likely to be covered by 3G or not. In the difference-in-difference setting, I then compare restaurants with and without 3G coverage before and after the diffusion of 3G networks.

This paper contributes to the literature on the effect of infrastructure upgrades, specifically on the upgrade of telecommunication infrastructure. Waverman and Röller (2001) were some of the first to estimate the causal effect of telecommunication infrastructure investment on growth. Using data for 21 OECD countries for the period from 1970 to 1990 and estimating a structural model, they find

³In Germany, the largest network provider at that time was the state-owned Deutsche Bundespost, which had universal service as its motivating force.

a significant positive effect that is especially strong when there is a high penetration of the technology. Czernich et al. (2011) also use data from OECD countries, but analyze them for the period from 1996 to 2007. Using an instrumental variable approach, they find that a 10 percentage point increase in broadband Internet penetration has a positive effect of up to 1.5 percentage points in annual per capita growth.

However, not all infrastructure investments have such positive outcomes. While Aschauer (1989) finds huge returns to public infrastructure investments, his study also initiated serious discussion of the problems of common time trends and reverse causality when estimating their effect on growth. Later studies show that when these issues are accounted for, the positive effect found by Aschauer almost vanishes.⁴ Therefore, policymakers must take care in deciding which infrastructure investments to subsidize. For example, when should we let the market take its course and let investments be channeled to areas with the highest demand? Alternatively, for what type of infrastructure are public returns credibly expected to be high enough to justify investment subsidies? Fogel (1962) famously argues that the century-old river network in the United States was more effective for economic development than the more modern railroad network that was heavily supported by the government. Fernald (1999) finds that large road infrastructure investments in the United States led to an one-time productivity boost in the 1950s and 1960s. On the margin, however, he does not find that road infrastructure investments are especially productive. In a recent study, Banerjee et al. (2012) find that new transportation infrastructure in China had no effect on per capita GDP growth for regions that were quasi-randomly connected to the transportation network.

While Fernald (1999) raises the important question of whether an upgrade in infrastructure has effects comparable to a first build-up of the same infrastructure, Banerjee et al. (2012) cast doubt on the notion that new infrastructure is beneficial even in areas where there is no immediate demand. By using spatially fine-grained data, this paper finds that an upgrade in mobile Internet infrastructure led to a change in usage of the infrastructure. This can be seen as the basic condition for the infrastructure to have an economic effect, even in areas where there was low initial demand.

⁴For an overview of the discussion see Munnell (1992)

2 Data

To estimate the effect of the upgrade from 2G to 3G on usage of the local online service Qype, I use data from five different sources. First, I use a dataset of 105,954 restaurants in Germany that are listed on Qype. Qype was founded in 2006 and describes itself as Europe’s largest user-generated reviews platform.⁵ According to the company, the platform is used by 25 million unique users every month and more than 2 million users actively contribute by writing reviews.⁶ The Qype app for the iPhone is consistently ranked as one of the top apps in the travel category of the Apple Appstore⁷ in Germany. In October 2012, Qype was acquired by its larger US competitor Yelp.⁸

To get a sense of how location-based review platforms like Qype work, it is useful to take a look at how users experience them on mobile devices. Figure 1 shows screenshots from the Qype iPhone app. Apps for other operating systems, such as Android or Blackberry, work in a very similar way. In a first step, the user chooses what to search for. In addition to restaurant reviews, Qype offers customer reviews of all sorts of businesses, including hotels, hairdressers, and doctors. In the first screenshot of Figure 1, the blue dot represents the user’s current position and the red pins represent restaurants near to the user. When one of the red pins is tapped, the name of the respective restaurant is shown. When it is tapped again, the app presents the second screenshot in Figure 1. From here, the user can access detailed information such as photos, the restaurant’s address, its average user rating, its phone number, and its web address. The third screenshot of Figure 1 shows all restaurant reviews that were written by previous customers. In addition to the text of the review, the app displays the star rating received by the restaurant from the review’s author.

In addition to the information from the screenshots, I use many other restaurant characteristics, such as type of cuisine, possibility of booking a table online, and whether the restaurant actively promotes itself on Qype. Since every restaurant needs to be geocoded, I remove 1,778 restaurants with invalid addresses from the sample. Figure 2 shows the spatial distribution of the sample of restaurants. It is not surprising that there are fewer restaurants in the less densely populated eastern part of Germany, and there is, of course, a certain amount of clustering of restaurants in cities.

I combine this restaurant dataset with a database of 516,716 Qype customer reviews for all restaurants in Germany. Out of the 104,176 restaurants with valid addresses, 67,693 received at least one review on Qype. On average, every restaurant in the sample received 4.96 reviews. Of those restaurants that received at least one review, the average is 7.63 reviews. As there is still a great deal of heterogeneity between the restaurants in the sample, I restrict the sample to those restaurants that had at least one review in 2008. This restriction is very important as the year 2008 marked the beginning of the smartphone app and mobile Internet hype. Apple’s Appstore for the iPhone was introduced in July

⁵<http://www.qype.co.uk/impressum>

⁶<http://de.press.qype.com/2012/09/10/eine-neue-dimension-fur-unternehmen-auf-qype/>

⁷<http://www.appannie.com/app/ios/299229792/ranking>

⁸<http://officialblog.yelp.com/2012/10/welcoming-qype-to-the-team.html>

2008⁹ and the first phone with the Android operating system was introduced three months later.¹⁰ Before 2008, third-party apps were available for very few mobile phones and their installation was quite complicated. By restricting the sample to restaurants that had at least one review in 2008, I ensure that all 25,340 restaurants in the sample had customers who were using Qype in the early days of the service. Restaurants that are only frequented by non-adopters are not considered in the remainder of my analysis.

I also merge the dataset of restaurants with some additional municipal-level data. From the Breitbandatlas Deutschland, I merge information on the diffusion of several Internet access technologies. The Breitbandatlas is an annual survey conducted by the German Ministry of Economics and Technology. All German mobile and fixed-line Internet providers are asked how much of the population in a specific municipality they cover with different broadband Internet technologies. The information from all Internet providers is then aggregated and the resulting dataset informs about the share of inhabitants in a municipality that has access to a certain Internet access technology. For this study, I am interested in DSL coverage as well as 3G in the year 2008. I also merge information from the German Federal Statistical Office on the population and the area of every municipality.

To obtain information about 3G coverage at a specific location, I use a unique dataset of all cellular antennas in Germany. This dataset includes 510,210 antennas on 73,291 antenna masts. Every antenna mast has several antennas, even if there is only one technology installed by one provider. For example, in order to cover a specific area with 3G, a network provider would need to install several antennas aimed in different directions on the same mast so that a large area is covered by the signal. In Germany, most network providers use their own masts. In fact, until a few years ago, the German regulator did not allow network providers to share an antenna mast. But even today, collocation of several providers on the same antenna mast is more the exception than the rule. Figure 3 shows the spatial distribution of all antenna locations in Germany. As expected, antenna density is highest in large cities, but because network providers need to cover even very remote areas, there is virtually no region without antennas.

As the variation I am going to exploit for identifying the causal effect of 3G coverage is based on absorption of the 3G signal by obstacles like hills or forests, I also use a digital surface model (DSM). A surface model is a digital representation of the world's surface, including all objects on it. With the help of a DSM it is possible to determine the height of the surface at any point on the globe. One of the most advanced DSMs is the Shuttle Radar Topography Mission (SRTM), which dates back to a space mission in 2000. The mission was a joint project by NASA, the National Geospatial-Intelligence Agency, and the German and Italian Space Agencies. During the mission, the Space Shuttle Endeavour used a 60-meter-long mast and two special radar systems to scan the whole world from space (Farr et al., 2007). For every arcsecond, which corresponds to an area of 30 square meters, the radar determined the height of the surface. As the raw data contain some voids and some empty cells, I use the SRTM data pre-

⁹<http://pogue.blogs.nytimes.com/2008/07/11/a-first-look-at-the-iphone-apps-store/>

¹⁰http://www.gsmarena.com/t_mobile_g1-2533.php

pared by the CGIAR Consortium for Spatial Information (Jarvis et al., 2008). The data has a resolution of 3 arcseconds which corresponds to cells of approximately 90 square meters. Figure 4 shows a map section of the SRTM data for an area in southern Germany. The heights of the surface are visualized in a three-dimensional way. On the map, antenna locations are marked with red dots.

A special focus of this paper is on the effect of an upgrade to 3G in rural areas. Using administrative data at the county or municipality level to determine the rurality of a location would be problematic for this study. Larger counties with densely populated centers but vast areas of underpopulated land are bound to be misleadingly classified when administrative borders are used as a reference system. Therefore, I use a much more finely-grained population density measure. To determine whether a restaurant is located in a populated area, which might also be the center of a less densely populated municipality, I use data from a detailed population density grid created by the Joint Research Center (JRC) of the European Commission. The grid was created by desegregating administrative population data at the municipality level with the help of the CORINE Land Cover map, which provides information on whether a given square kilometer of the surface is populated or not (Gallego, 2010). By interpolation, the population density of a municipality is then broken down into a 1-hectare grid. Figure 5 depicts the population density in the area surrounding Munich. I define areas with a population density of less than 2,500 inhabitants per square kilometer as rural. These areas are marked as dark and grass green in Figure 5. Areas that are marked in shades of red, orange, and yellow are defined as urban.

As figure 5 shows, many areas commonly classified as rural according to administrative data have relatively densely populated centers that fall into the urban classification used in this paper. This is the case because administrative boundaries are wider in rural areas and when the population is averaged across a large area of land, its density is considerably underestimated in the center. For mobile network operators, these urban centers of rural areas can be profitable since the installation cost per user can be as low as in cities if one antenna mast covers enough of the population. Conversely, the outskirts of cities are often classified as highly urban according to administrative data, but are more likely to be classified as rural according to the definition used in this paper. For mobile network operators, antenna locations are chosen based on the population that can be reached in the immediate surroundings of the antenna. If few people live on the outskirts and the city center is already well covered by other antennas, operators may find it less profitable to install antennas in the outskirt area. The fine-grained population density data are therefore appropriate for the analyses in this paper.

Table 1 presents some descriptive statistics for the restaurant data. The first variable indicates the number of antenna masts within 10 kilometers of a restaurant. This variable is important as it ensures that it is not the density of the network that drives the clear line of sight to an antenna. The high mean of over 422 masts indicates that usually antenna masts are located quite close to each other. Practically speaking, beyond 10 kilometers, cellular reception is very unlikely. The second variable indicates the distance to the closest antenna mast in kilometers. Like the first variable, this one serves as an important control

for the antenna network. It also captures the centrality of a restaurant if we assume that antennas are located in central locations. The next few variables come from the Federal Statistical Office and the Breitbandatlas, as described above. Note that DSL and 3G coverage are expressed as percentage values that relate to the population in a municipality rather than the geographic area of a municipality. All the other variables are restaurant characteristics obtained from Qype. The web variable indicates whether there is an url for a restaurant website on Qype. The rank variable refers to the rank of a restaurant based on its rating compared to other restaurants in the same city. The booking variable indicates whether it is possible to book a table at the restaurant online. Author experience denotes the cumulated number of reviews that authors who reviewed the restaurant wrote. If the number is high relative to the number of reviews for a restaurant, this could indicate that the restaurant is more frequently visited by experienced Qype users. The last variable denotes the year that the restaurant received its first review on Qype. Since the sample is restricted to restaurants that had at least one review in 2008, it is not surprising that the average restaurant in the sample received its first review almost a year prior to that date.

3 Empirical Model and Results

This paper investigates the relationship between an upgrade in the mobile Internet infrastructure and usage of the local online service Qype. In a first step, I investigate whether restaurants located in areas with 3G coverage receive more customer reviews than restaurants in areas without 3G reception. As a proxy for 3G coverage, I use a dummy that indicates whether there is a clear line of sight between the immediate surroundings of a restaurant and a mobile network antenna. Due to its frequency, the 3G signal is very sensitive to being blocked by obstacles. If there is no clear line-of-sight due to hills, forests, or large buildings, chances of a reasonably good 3G reception drop significantly.

I estimate the following model:

$$y_i = \beta_0 + \beta_1 visibility_i + \beta_2 X_i + \beta_3 R_i + \beta_4 type_i + \beta_5 county_i + \epsilon_i$$

where y_i is the number of reviews that a restaurant i received. $visibility_i$ represents the aforementioned dummy and takes the value 1 when there is a clear line-of-sight between the area surrounding a restaurant and any antenna mast within a radius of 10 km. Antennas at a distance of more than 10 km are highly unlikely to provide a strong enough 3G signal. Vector X_i includes a set of characteristics of restaurant i , namely dummies that indicate whether the restaurant actively uses Qype for promotional purposes, whether there are photos of the restaurant available on Qype, whether it is possible to book a table at the restaurant online, whether there is a link on Qype to the restaurant's website, and whether there is a phone number for the restaurant available on Qype. X_i also includes the average star rating of restaurant i , its Qype ranking within its municipality, the year in which the restaurant received its first review, and the accumulated experience of all authors who wrote reviews for the

restaurant. The latter is measured by the sum of all reviews that were written by the respective author. Vector R_i includes regional characteristics such as the population and area of the municipality in which restaurant i is located. $type_i$ is a set of more than 80 dummies that indicate the kind of cuisine or if cuisine is not applicable, the kind of establishment, for example, a snack bar or a fast food restaurant.

Table 2 presents results of the multivariate regression described above. The first line reveals that the visibility of an antenna is strongly positively associated with the number of reviews. In itself, this is not too surprising as the probability of a clear line of sight increases with the number of antennas in an area. However, in Column 2 I control for the number of antennas within a radius of 10 km around the restaurant. This is a good proxy for the mobile network density in the area. In Column 3, I also control for the distance to the closest antenna. The negative coefficient shows that restaurants that are closer to the next antenna receive more reviews. Holding both the network density and the distance to the closest antenna constant, restaurants that do not have any obstacle between them and an antenna still receive significantly more reviews than restaurants with less favorable topographic conditions. The results remain robust to controlling for the population and size of the municipality. In the last column, I control for the share of the population that was covered by DSL and 3G in the municipality in 2008. The small size of the 3G coefficient, especially compared to the coefficient in the first row, shows that the visibility dummy captures a different, presumably more location-specific, variation than the 3G variable. Interestingly, the share of population with DSL availability is not significantly associated with the number of reviews received by a restaurant. This underlines the relevance of mobile Internet for usage of Qype.

Table 3 shows regressions with the same dependent variable as in table 2 but including a set of restaurant-specific controls. The second line shows that restaurants that advertise their Qype profile page and provide additional promotional information receive a greater number of reviews. This might, to some extent, be driven by selection, since restaurant owners who use Qype for advertising purposes may have different customers than restaurant owners who use other means of advertising. But it could also indicate that additional information provided by the restaurant owner increases the number of reviews the restaurant receives. The availability of at least one photo is also strongly associated with more reviews. Photos can be submitted either by the owner and/or by customers. Two out of three restaurants have photos on their Qype profile, but only about every fourth restaurant has additional information provided by the owner. It is surprising that the number of stars a restaurant is given is negatively associated with the number of reviews it receives. This means that receiving more reviews can result in a worse rating. One reason for this could be that dissatisfied customers have more of a tendency to write a review than do people who have had an enjoyable experience. Another explanation could be that the rating of restaurants with very few reviews is positively biased. Anderson and Magruder (2012) speculate about the incentives of restaurant owners to game online review platforms. They note that having fewer reviews makes it easier to influence the rating with a fraudulent review. As the number of legitimate reviews increases, more effort is needed to game the system. Since reviews can be submitted only by registered Qype users, it also becomes increasingly suspi-

cious if many reviews are submitted by reviewers with little experience. Wang (2012) describes how review platforms try to detect fraud by restaurant owners. Nevertheless, the negative association between the rating and the number of reviews is sizable and persistent across all estimations in this paper. In Column 4, more than 80 restaurant type dummies are added. This means that even if Japanese restaurants are only compared to other Japanese restaurants or snack bars are compared only to other snack bars, the association between reviews and visibility remains robust. This is also the case when including regional municipality-level characteristics as well as county-fixed effects in Columns 5 and 6. Having a clear line of sight between the restaurant and an antenna is associated with 0.4 more reviews per restaurant.

In table 2 and 3, the dependent variable is the total number of reviews submitted for each restaurant. However, Qype users can submit reviews not only via a smartphone app, but also through the website. One could argue that 3G coverage should affect only those reviews that were submitted via smartphone app, but there are several reasons why this may not be the case. First, some smartphone users might not want to install the app and so use the website instead. For users of tablets, such as the iPad, the website is actually the only option for submitting a review since Qype does not offer tablet apps. It is also likely that some people use their mobile devices to find a restaurant and then write a review of it on a desktop PC, perhaps due the latter's larger keyboard. Even if the reviews submitted via apps and the reviews posted on the website are both affected by 3G coverage, it makes sense to shift focus from all reviews to the share of reviews submitted via apps because by focusing on the share of mobile reviews, I am implicitly controlling for restaurant-specific Internet trends. Let us assume that a restaurant owner discovers the revenue-enhancing potential of the Internet, sets up a facebook page, and starts advertising on Google. This activity might induce some Internet users to visit the restaurant and subsequently leave a review on Qype. If owners of restaurants with 3G coverage are more likely to discover the potential of the Internet, this could bias my results concerning the total number of reviews. It should not, however, affect the share of reviews submitted via smartphones. The effect on reviews submitted via smartphone and the effect on reviews submitted through the website should be the same. Table 4 therefore presents results for the share of reviews that were submitted via a smartphone app out of all reviews as the dependent variable. The small size of the point estimates reflects that the measurement unit is now percentage points instead of number of reviews. Nevertheless, the coefficients in the first three columns are still surprisingly low. They remain statistically significant, however, even after including all controls and fixed effects.

The last three columns of table 4 show regressions for a reduced sample of restaurants in rural areas. As described above, I use a very fine-grained definition of rurality that is based on the 1-ha population density grid depicted in Figure 5. The restricted sample includes about 5,500 restaurants. Columns 4-6 show that in this rural sample, the association between visibility and the share of mobile reviews is actually stronger than in the full sample. One explanation for this stronger relationship could be the variation in the visibility variable, which is stronger in the countryside. The high density of antennas in urban areas reduces the probability that the 3G signal is blocked by obstacles. Even if the visibility dummy indicates that there is no clear line-of-sight, there might be

cases in which 3G is still available. In rural areas, however, hills and forests are much more likely to completely block the signal. The clear-line-of sight dummy might therefore be more reliable in the countryside. Another explanation could be that review platforms like Qype play a relatively more important role in rural areas. If information about restaurants can be more easily obtained in cities, potential customers may be more likely to find a restaurant without the assistance of their smartphone. Tourist guides, for example, often provide lists of restaurants and tourists could write a review of a restaurant after they return home, all without the need for 3G. It is also remarkable that the R-squared of the estimations is much higher in the rural sample. The share of mobile reviews can be better explained by visibility and the other observables for restaurants in rural areas.

To identify the causal effect of 3G coverage, I estimate a difference-in-difference model where I compare restaurants with and without a clear line of sight before and after mobile Internet became a mass phenomenon. The reasoning behind this strategy is that given the antenna density in an area and the distance to the next antenna, a clear line of sight was not important in the 2G world. Before 3G reception became important to consumers, the visibility of an antenna should not have had an impact on usage of local online services like Qype. With the growing popularity of 3G-enabled phones, mobile websites, and smartphone applications, 3G availability became important to smartphone users. Even though all 3G smartphones can be used on 2G networks, using mobile Internet without 3G means considerable waiting times when accessing online services. For example, loading pictures or maps without 3G can be a very time-consuming undertaking.

For many reasons, 2008 was the year in which 3G started to become a technology for the masses. Two corporate events fueled the popularity of 3G. Most importantly, in July 2008, Apple introduced its iPhone 3G, arguably the device that contributed the most to the mobile Internet revolution. In the same month, Apple opened its App Store, which allowed users to install third-party applications. Before Apple revolutionized the way online content is consumed on mobile phones, many in the industry believed a "new version" of the Internet was needed before a breakthrough in mobile Internet would be possible (West and Mace, 2010). After Apple's success, the competition followed suit and the first Android phone was introduced in October 2008. In the same month, Google opened a competing app store, the Android Market. It would be naive to assume that it was only the devices themselves that changed the paradigm of mobile Internet. In fact, it was the combination of modern devices like the iPhone, smartphone apps that deliver online content optimized for small touch screens, and the 3G broadband network that led to the popularity of mobile Internet.

Figure 6 shows the data volumes in the German mobile network. In line with the discussion above, the amount of data sent over the network was negligible before 2008. Between 2008 and 2010, however, the data volumes increased by almost a factor of six. For the difference-in-difference setting, I therefore use 2008 as the base year in which 3G started to become attractive for the average consumer. The year 2012 is used as the post-treatment period in which the infrastructure upgrade from 2G to 3G was available for most consumers.

I estimate a difference-in-difference model of the following form:

$$y_{it} = \beta_0 + \beta_1 \text{visibility}_i + \beta_2 2012_t + \beta_3 (\text{visibility}_i \times 2012_t) + \beta_4 X_i + \beta_5 R_i + \beta_6 \text{type}_i + \beta_7 \text{county}_i + \epsilon_i$$

where 2012_t is a dummy that is 0 in 2008 and 1 in 2012. $\text{visibility}_i \times 2012_t$ is the interaction term for visibility in 2012, meaning it becomes 1 for having a clear line-of-sight to a cellular antenna in the period when 3G is relevant. Note that for 2G coverage, visibility did not play a major role and we can assume that virtually all restaurants were covered by 2G in 2008.

Figure 7 shows how many reviews restaurants with and without a clear line of sight received between 2005 and 2012. Until 2007, there were very few reviews at all, but from 2008 onward, the number increased dramatically. This can be explained by the amount of value added to the service by the advent of smartphone apps. Before, Qype could be used only on a PC and thus was of limited use in finding restaurants on the go. What can also be seen in Figure 7, is that it is only from 2008 onward that the development between restaurants with and without visibility diverged. This indicates that the parallel trend assumption holds. While both types of restaurants had a steep increase in the number of reviews, the increase was steeper for those restaurants with a clear line of sight to the next cellular antenna.

Table 5 confirms the observations from figure 7 and shows the results of the difference-in-difference estimation described above. The interaction term in the first line shows that those restaurants with a clear line of sight received significantly more reviews than restaurants without a clear line of sight, even after controlling for a common underlying trend. Column 1 shows the baseline estimation, which is an analog to Column 1 in Table 3. The coefficient in the first row is similar to the visibility coefficient in Table 3. Columns 2-5 show that the coefficient remains quite stable when the same sets of controls from before are added. In Column 6 of Table 5, restaurant-fixed effects are added to the estimation. This eliminates any restaurant-specific characteristics that might have influenced the number of reviews a restaurant received. The interaction term in the first line remains statistically highly significant. Columns 7-8 show results for the rural-area sample. The smaller point estimates in rural areas reflect that restaurants in cities have a higher total number of reviews.

To better compare the magnitude of the coefficients in urban and rural areas, it is useful to return to a relative measure. Table 6 shows regressions for the share of mobile reviews as the dependent variable. In contrast to Table 5, the point estimates are now larger in rural areas. Although a 2 percentage point increase in the mobile review share does not seem very large, the mean share of mobile reviews is only 20 percent. The effect of the infrastructure upgrade on the mobile usage of Qype is therefore not negligible.

4 Conclusions

This paper provides evidence that upgrading the mobile Internet network from 2G to 3G influenced usage of a local online service. Specifically, data from the

review platform Qype show that restaurants in areas with 3G reception receive more reviews than restaurants in areas without 3G. By exploiting technical differences between 2G and 3G signals in regard to their absorption by different kinds of terrain, the effect of the infrastructure upgrade can be interpreted as causal. In addition to the total number of reviews, also the share of those reviews written on a mobile phone has increased in areas with 3G. For rural areas, the results are even stronger, indicating that infrastructure upgrades can influence usage of the infrastructure even if the initial demand for the upgrade is relatively low. Given a change in usage, economic effects are likely to follow. For example, Anderson and Magruder (2012) show the economic importance of review platforms for restaurants. The local online service analyzed in this paper is only one of many applications that are becoming increasingly important for local businesses. If an upgrade of the infrastructure impacts their usage, there could be important economic consequences.

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Table 1: Descriptive Statistics

	mean	sd	min	max	N
antennas 10km	422.18	485.68	2	1978	25340
distance closest	3.61	5.08	0	93	25340
population	372.79	307.70	35	1260	23359
area	0.70	0.56	0	3	23359
DSL share	90.97	8.70	0	99	23359
3G share	93.94	21.30	0	100	23359
claimed	0.23	0.42	0	1	25340
photo	0.66	0.47	0	1	25340
phone	0.95	0.22	0	1	25340
stars	3.85	0.83	0	5	25340
web	0.48	0.50	0	1	25340
rank	52.71	105.35	1	2448	25340
booking	0.05	0.23	0	1	25340
author experience	94.23	150.44	1	2782	25340
review first	2007.36	0.78	2005	2008	25340

Table 2: The number of reviews received by a restaurant and the visibility of a cellular antenna mast

	(1)	(2)	(3)	(4)	(5)
visibility	3.9050*** (0.2645)	1.2073*** (0.2388)	0.6810*** (0.2476)	0.5498*** (0.1978)	0.4848** (0.1978)
antennas 10km		0.0172*** (0.0004)	0.0167*** (0.0004)	0.0188*** (0.0009)	0.0185*** (0.0009)
distance closest			-0.1973*** (0.0135)	-0.1196*** (0.0115)	-0.0919*** (0.0113)
population				-0.0008 (0.0007)	-0.0007 (0.0007)
area				-0.3720** (0.1859)	-0.3753** (0.1877)
DSL share					0.0137 (0.0085)
3G share					0.0154*** (0.0019)
N	24051	24048	24048	23486	22716
R2	0.007	0.178	0.180	0.154	0.156

Dependent variable: number of reviews until 2012.

Ordinary least squares (OLS) estimations with robust standard errors clustered at the municipality level in parentheses.

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 3: The number of reviews and restaurant specific characteristics

	(1)	(2)	(3)	(4)	(5)	(6)
visibility	3.9050*** (0.2645)	2.9528*** (0.2383)	2.1710*** (0.2128)	1.5526*** (0.2085)	0.5620*** (0.1689)	0.4181** (0.1715)
claimed		12.6164*** (0.4150)	10.1596*** (0.3867)	9.6763*** (0.3839)	5.8565*** (0.3182)	5.3438*** (0.3147)
photo		8.7226*** (0.1559)	7.7023*** (0.1453)	7.2642*** (0.1497)	5.1953*** (0.1159)	4.4350*** (0.1204)
booking		5.4460*** (0.8071)	4.8813*** (0.7815)	6.5506*** (0.7996)	2.1999*** (0.5955)	2.4764*** (0.5948)
web		3.8615*** (0.2369)	3.3699*** (0.2073)	3.5632*** (0.2123)	2.6030*** (0.1564)	2.4982*** (0.1566)
stars			-1.3735*** (0.1072)	-1.2807*** (0.1114)	-1.3713*** (0.0831)	-1.4178*** (0.0926)
rank			0.0073*** (0.0017)	0.0047*** (0.0017)	-0.0216*** (0.0015)	-0.0331*** (0.0030)
author experience			-0.0077*** (0.0005)	-0.0064*** (0.0004)	-0.0049*** (0.0003)	-0.0050*** (0.0004)
first review			5.5568*** (0.1738)	5.2434*** (0.1819)	3.2952*** (0.1279)	3.3344*** (0.1323)
phone			1.3425*** (0.3126)	1.4843*** (0.3252)	1.3888*** (0.2941)	1.5650*** (0.3001)
restaurant type dummies	No	No	No	Yes	Yes	Yes
regional characteristics	No	No	No	No	Yes	Yes
county-fixed	No	No	No	No	No	Yes
N	24051	24051	23228	23228	21940	21939
R2	0.007	0.208	0.266	0.303	0.341	0.381
chi2						

Dependent variable: number of reviews until 2012.

Ordinary least squares (OLS) estimations with robust standard errors clustered at the municipality level in parentheses.

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 4: Share of reviews written on a smartphone in the full sample and the restricted sample

	Full sample			Rural areas		
	(1)	(2)	(3)	(4)	(5)	(6)
visibility	0.0054** (0.0025)	0.0052** (0.0025)	0.0046* (0.0025)	0.0180*** (0.0047)	0.0160*** (0.0047)	0.0142*** (0.0051)
regional characteristics	Yes	Yes	Yes	Yes	Yes	Yes
restaurant characteristics	No	Yes	Yes	No	Yes	Yes
restaurant type dummies	No	No	Yes	No	No	Yes
county-fixed	No	No	Yes	No	No	Yes
N	22713	22030	21938	5557	5402	5401
R ²	0.009	0.033	0.060	0.019	0.074	0.190

Dependent variable: share of mobile reviews out of all reviews until 2012.

Ordinary least squares (OLS) estimations with robust standard errors clustered at the municipality level in parentheses.

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 5: Difference-in-difference estimation of the number of reviews on the visibility of an antenna mast

	Full sample						Rural areas	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
visibility*2012	3.2662*** (0.2690)	3.0364*** (0.2313)	3.0359*** (0.2276)	2.9745*** (0.2328)	2.9740*** (0.2316)	3.2689*** (0.2547)	1.2099*** (0.2739)	1.2135*** (0.2719)
2012	8.2419*** (0.2169)	7.8026*** (0.1855)	7.8028*** (0.1822)	8.1397*** (0.1869)	8.1407*** (0.1857)	8.2360*** (0.2206)	5.3998*** (0.1947)	5.3707*** (0.2088)
visibility	0.6387*** (0.0486)	-0.2632*** (0.0788)	-0.6083*** (0.0828)	-1.2089*** (0.0947)	-1.2341*** (0.0987)		-0.5845*** (0.1246)	
restaurant characteristics	No	Yes	Yes	Yes	Yes	No	Yes	No
restaurant type dummies	No	No	Yes	Yes	Yes	No	Yes	No
regional characteristics	No	No	No	Yes	Yes	No	Yes	No
county-fixed	No	No	No	No	Yes	No	Yes	No
restaurant-fixed	No	No	No	No	No	Yes	No	Yes
N	48240	46489	46489	43910	43908	48240	10808	12213
R2	0.127	0.279	0.299	0.339	0.350	0.285	0.363	0.256

Dependent variable: number of reviews until 2012.

Ordinary least squares (OLS) estimations with robust standard errors clustered at the restaurant level in parentheses.

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 6: Difference-in-difference estimation with the share of reviews written on a smartphone as the dependent variable

	Full sample			Rural areas				
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
visibility*2012	0.0080*** (0.0024)	0.0077*** (0.0024)	0.0066*** (0.0024)	0.0080*** (0.0023)	0.0211*** (0.0044)	0.0210*** (0.0044)	0.0217*** (0.0045)	0.0211*** (0.0044)
2012	0.1273*** (0.0021)	0.1280*** (0.0021)	0.1289*** (0.0021)	0.1273*** (0.0020)	0.1176*** (0.0033)	0.1187*** (0.0033)	0.1196*** (0.0034)	0.1176*** (0.0034)
visibility	0.0000*** (0.0000)	-0.0008** (0.0003)	-0.0015** (0.0006)		0.0000 (0.0000)	-0.0027*** (0.0008)	-0.0039*** (0.0015)	
restaurant characteristics	No	Yes	Yes	No	No	Yes	Yes	No
restaurant type dummies	No	Yes	Yes	No	No	Yes	Yes	No
regional characteristics	No	No	Yes	No	No	No	Yes	No
county-fixed	No	No	Yes	No	No	No	Yes	No
restaurant-fixed	No	No	No	Yes	No	No	No	Yes
N	48235	46486	43906	48235	12210	11836	10807	12210
R2	0.275	0.292	0.314	0.431	0.234	0.264	0.311	0.377

Dependent variable: share of mobile reviews out of all reviews until 2012.

Ordinary least squares (OLS) estimations with robust standard errors clustered at the restaurant level in parentheses.

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Figure 1: Screenshots

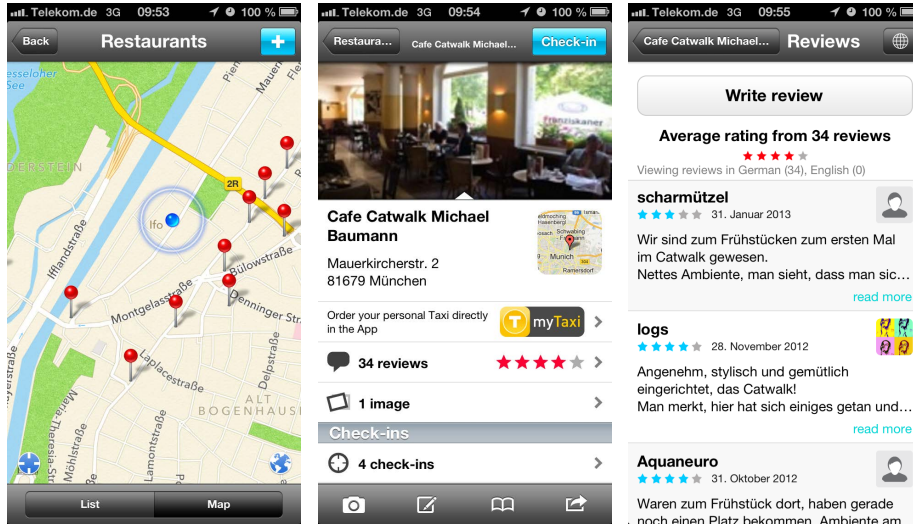


Figure 2: Restaurants

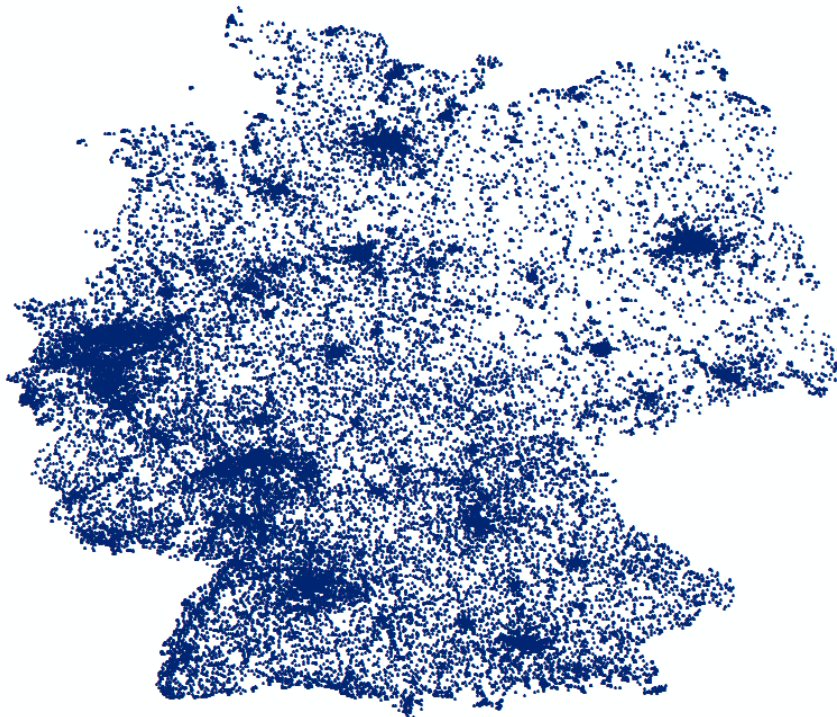


Figure 3: Antennas

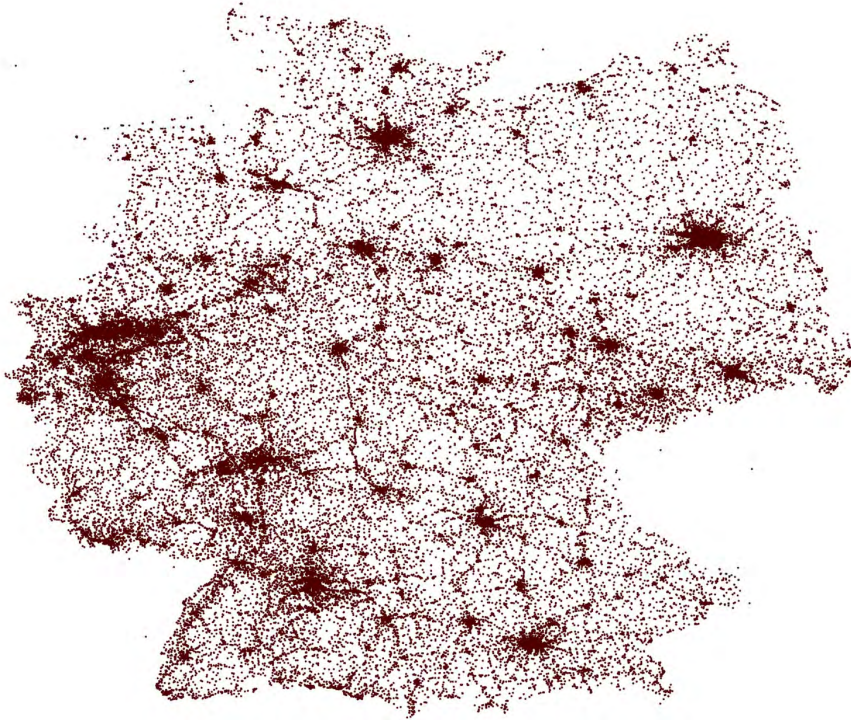


Figure 4: Digital Surface Model (DSM) and antenna locations

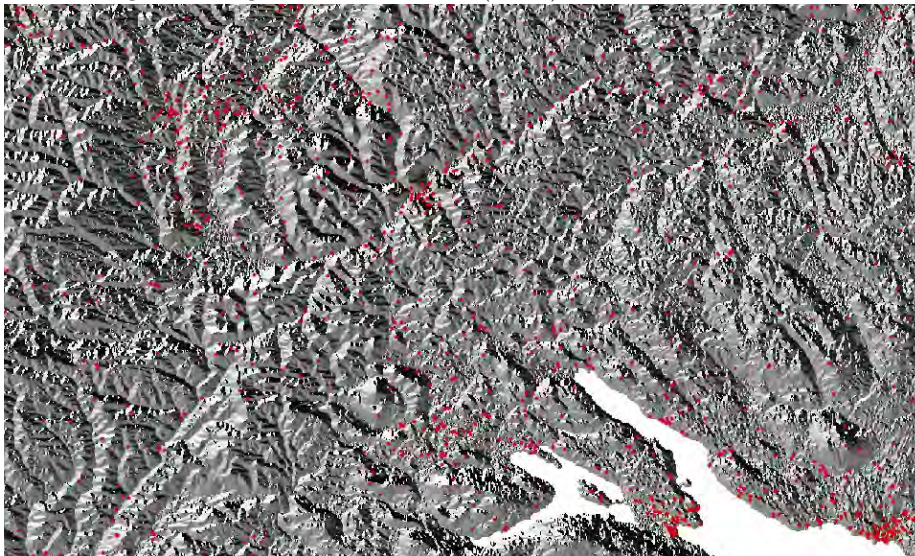


Figure 5: Disaggregated population density in the area around Munich

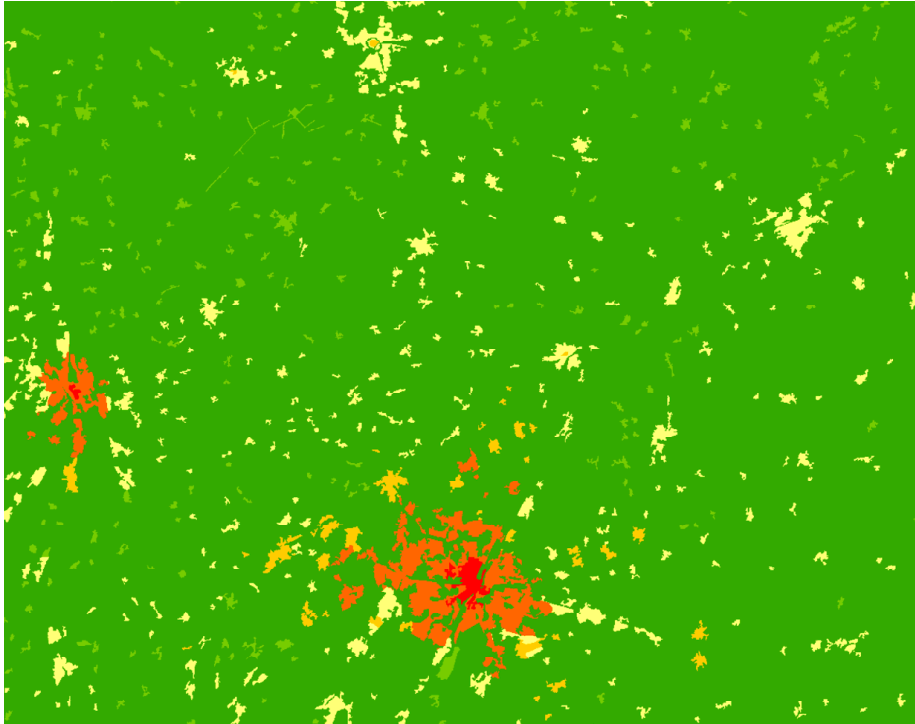
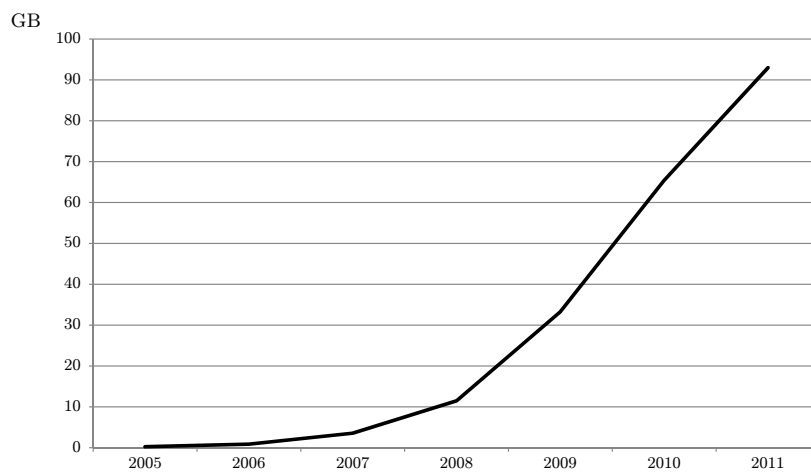


Figure 6: Data volumes in the German mobile network



Source: Bundesnetzagentur

Figure 7: Number of reviews by visibility

