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Hello . . . Are You Still There? An Empirical Analysis How Market Structure Affects Quality of Mobile Networks

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Hello ... Are You Still There?

An Empirical Analysis of How Market Structure Affects the Quality of Mobile Networks

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Abstract

For the ongoing and upcoming auctioning of 5G spectrum an important question is, what drives network quality in mobile markets? When comparing the provided mobile network quality between various EU countries considerable differences between these markets become apparent, which cannot be solely explained by financial and geographic factors. Recent findings in the literature suggest a negative effect of (price) competition on investments in mobile networks. To the best of our knowledge this is the first academic paper to provide a detailed analysis of how different characteristics of the market structure affect mobile network quality. In total, we consider 500 million measurements of the mobile network quality of 48 mobile network operators (MNO) from 14 European countries between 2011 and 2016. Our results indicate that a reduction in market players may actually increase mobile network quality, thus supporting the findings in the recent literature. Further, we observe a significantly higher mobile network quality for late entrants in the market, underlining how outcomes from spectrum auctions may alter competition in the mobile market.

JEL classification: L96, L40, L50, K21, K23, D22

keywords: mobile telecommunication, market structure, network quality, investment, competition policy, regulation, antitrust,

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1 Introduction

“Mobile telecom services are increasingly important in our daily lives. We use our mobile phones not only to get in touch with our family and friends but also to read the news, shop online or check the train schedule. [...]” (European Commission 2016b). This statement by the EU Competition Commissioner underlines not only the importance of mobile services for consumers, it also corresponds to applications in business: 96% of large enterprises in the EU provide employees with mobile devices and 44% of these are for dedicated business applications (Eurostat, 2017). All these examples rely on fast, reliable and affordable access to mobile networks.

According to a report by the European Commission 97,9% of EU-households are covered by 4G networks (European Commission, 2018). However, actual connectivity is much more heterogeneous in Europe and various areas exist where connectivity is slower or not available at all. For one, the demand for mobile services is not only restricted to households and it also includes traffic routes or commercial areas. For another, this includes rural areas where 4G coverage reaches only 89,9% of EU households (European Commission, 2018). Certainly, investments into mobile networks are costly and thus subject to a critical cost-benefit analysis by mobile network operators (MNO). But these discrepancies in costs cannot explain why significant differences in connectivity persist between different countries: It seems surprising that economies like Germany, France or the UK are outnumbered in LTE coverage by countries where geography makes running a mobile network costly (e.g., low population density in Scandinavian Countries or topography in Switzerland) or with fewer financial resources (e.g., Eastern European countries).¹

Recently, a discussion evolved in competition policy about how market structure affects the quality of mobile networks. To be more precise, how many MNOs are required in a market to sustain both low price levels and sufficient investments in the network infrastructure. This is an important question in merger analysis, as in most countries in Europe competition takes place between three or four MNOs. Coinciding with economic and political changes various M&A have been observed in recent years.² Economically, the maturing demand for mobile telecommunication services is a challenge for the industry as it limits the opportunities for additional growth and revenues. At the same time mobile communication has also shifted to over-the-top services (OTT services) like Facebook. As a consequence consumers have higher demands for mobile data services both quantitatively and qualitatively (see also Peitz and Valletti 2015). Politically, the European Union is pushing for more consolidation in the industry as part of its agenda for a joint digital market in the EU (European Commission, 2019). This includes, for example the regulation of roaming fees, which have been steadily

¹ Actually mobile coverage in Germany is so bad that the German Minister of Economic Affairs had to admit that he avoids mobile calls from foreign politicians as he is too embarrassed about the poor mobile network infrastructure in his country (Der Spiegel 2018).

² This includes for example the following mergers in Europe: H3G Italy /Vimpelcom 2016, TeliaSonera/Telenor 2015, H3G United Kingdom/Telefónica UK 2015, H3G Ireland/Telefónica IE 2014, Telefónica Germany/E-Plus 2014, H3G Austria/Orange AT 2012.

reduced to zero in the past, and also the harmonization of data protection laws into the General Data Protection Regulation (European Union 2016, European Commission 2016c).

In recent merger cases in the mobile telecommunication market a popular claim has been that more consolidation is required to meet the rising investment demands in mobile networks. For example, Telefónica Germany/E-Plus (2014) brought forward the argument in their merger that their complementary spectrum setup leads to a faster roll-out of 4G networks, better coverage, and higher maximum speeds for consumers (European Commission 2014). Similarly, Hutchison 3G Italy/Wind (2016) stated that neither firm by itself has sufficient resources to compete with the mobile network of the two leading operators in the market (European Commission 2016a). Currently, T-mobile/Sprint are wooing in the US for an approval of their merger by arguing that a joint network will also foster innovation and roll-out of 5G networks (T-Mobile US 2018). Given the various applications of mobile telecommunication services which may be even further extended with the introduction of 5G such as self-driving cars or telemedicine, the evaluation of these merger decisions has a strong impact for business and consumers.

While there exists a broad literature which explores the role of market structure on prices in mobile telecommunication markets, the effects on mobile network infrastructure are barely covered.³ To the best of our knowledge this paper is the first academic paper which provides a detailed analysis of how different characteristics of the market structure affect mobile network quality. For this purpose we consider 500 million observations on the network quality of 48 MNOs from 14 European countries between 2011Q1 and 2016Q1. In our empirical estimation we relate this to different parameters on market structure while controlling for various economic and regulatory influences. Our results indicate that a reduction in market players may improve various measures for mobile network quality. This adds to the recent literature which observes a negative relationship between competition and investments in mobile network infrastructure and thus a potential trade-off with lower price levels in competition policy (Jeanjean and Hounghonon 2017, Hounghonon and Jeanjean 2016, Genakos et al. 2018). However, our estimates indicate a lower magnitude of the effect on mobile network quality. Additionally, we note a considerably higher mobile network quality for late entrants. This is an interesting finding in the context of 5G spectrum auctions which are ongoing and upcoming in various countries, since these may allow the entry of a new player in the market. Thus, the results of our study have a high relevance not only for competition and regulation authorities, but also for decision-makers in the mobile industry.

The remainder of the paper is as follows: Section 2 gives an overview of related literature on the mobile telecommunication market. Section 3 describes the data used in the analysis. Section 4 presents the econometric setup and estimation results. Section 5 discusses our findings and policy implications. Section 6 concludes.

³For details see the literature in section 2.

2 Related Telecommunication Literature

There exists an extensive literature in industrial organization which explores the impact of market structure on prices and innovation.⁴ We focus on those papers which analyze the mobile telecommunication market, considering that it is subject to various technical and regulatory restrictions which make it distinct from others.

Traditionally, a major body in the literature on mobile telecommunication markets has focused on price effects in their analyses. This includes, for example, studies of specific mergers: Aguzzoni et al. (2018) investigate the price effects of two mergers, one in Austria in 2006 and in the Netherlands in 2007. They employ a Diff-in-Diff approach to compare price baskets of mobile telecommunication services before and after the merger with the development in other European countries. Their findings suggest a price increase in the Netherlands after the merger but no price effect in Austria where remedies were part of the merger. Andini and Cabral (2011) and Grzybowski and Pereira (2007) employ two different kinds of merger simulations to study the price effects of the proposed Optimus/TMN merger in 2006 in Portugal. Both approaches indicate a significant price increase related to the merger. Other papers use prices to assess competition between different providers (e.g., Karacuka et al. 2011, Grzybowski and Pereira 2011) or different technologies (e.g., Grzybowski and Verboven 2016).

A consensus in this literature of price effects is that lower levels of competition are associated with higher price levels in the market. This is also reflected in the investigation of mobile merger cases by the European Competition Commission. Typically these primary, focus on price effects, which is also underlined in accompanying statements of the EU Competition Commissioner, for example, in the H3G Italy/Vimpelcom merger in 2016: *'[...] We need to make sure that the proposed transaction will not lead to higher prices or less choice in mobile services for Italian consumers.'* as well as the H3G Austria/Orange AT merger in 2012: *"[...] The merger will reduce the number of network operators from 4 to 3 in Austria. Therefore, the Commission must make sure that this concentration does not lead to higher prices for end consumers"*. More generally, this focus on prices in competition analysis is not surprising: Often, prices are directly observed not only by the econometrician but also by consumers for which prices might be the most salient product characteristic. Analogue firms may more quickly adjust prices in competition rather than altering product characteristics. While the analysis of price effects is important and the availability of prices may also be beneficial for the assessment of competition, focusing strictly on prices may ignore relevant changes on other levels of competition.

More recently, various studies have emerged which focus on how competition affects investments in the mobile network infrastructure. For example, Genakos et al. (2018) conduct a study based on 33 OECD countries between 2002 and 2014. An interesting aspect of their

⁴See, for example, Aghion et al. (2005), Bresnahan (1989), Schmalensee (1989) or further papers mentioned in the literature review in Genakos et al. (2018).

work is that they investigate how both prices and investments are affected by variations in the market structure. Their findings suggest that competition authorities face a very particular trade-off when deciding in mergers. Accordingly, a hypothetical merger from 4 to 3 MNOs, increases prices for consumers by 16.3% but raises capital expenditures per operator by 19.3%. Interestingly, they do not observe that total investments change significantly in this case. But findings from the theoretical literature suggest that this should be the case when no efficiencies are present.⁵ So it remains ambiguous whether merger efficiencies are present and if these originate from costs savings or quality improvements. Another study which investigate the trade-off between competition and investments is conducted by Hounghonon and Jeanjean (2016). Accordingly, competition has a maximum effect on investments when the gross profit of the operator accounts for 37% or 40% of their revenues.⁶ Under this threshold a trade-off between competition and investments is observed. A similar analysis is conducted by Jeanjean and Hounghonon (2017) which is based on both theoretical and empirical elements. They observe a positive effect of competition on investments only in the short run. In the long run this effect turns negative with a magnitude which is three to four times larger than the short-run effect. Additionally, they observe a negative effect on investments in symmetric markets.

Generally, the aforementioned studies provide an important contribution as they highlight that competition affects not only price levels but also investment in the mobile network infrastructure. However, a remaining limitation is that it is unknown how these changes in investments will affect the quality of the mobile network infrastructure. On the one hand, what is the general effect of changing investments on the quality of mobile network infrastructure will be remains unknown. While it is likely that there is a positive correlation between both variables in question, a concurrent reduction of competition may *ceteris paribus* also lower the incentives to allocate funds efficiently. Consequently, the net effect on mobile network infrastructure is actually lower than the changes in investments. On the other hand, the aforementioned studies specify investments with capital expenditures, which is a fairly broad measure. As also noted in Genakos et al. (2018), these expenditures include all types of investments in physical assets, leaving it unknown in what respect the mobile network infrastructure has improved for consumers.

Faccio and Zingales (2019) study the political determinants of competition in the mobile telecommunication industry. As part of this study they consider a regulatory score of the ITU and evaluate how it affects different measures for network quality. The score includes questions like on the degree of competition (monopoly, partial competition, ...) or if the telecom regulator is independent. In the regression they conduct a cross-sectional analysis which is based on average data between 2010 - 2014 and includes up to 145 countries. They observe a significant and positive effect of the regulatory score and conclude that more pro-competition rules do not decrease coverage or quality in general. A limitation of this study is that it has a fairly broad focus. For one, the reported results average the effects for

⁵See, for example, Motta and Tarantino (2017) below.

⁶This depends on the normalization of capital expenditures. See also Hounghonon and Jeanjean (2016).

countries with huge differences in their economic development. As the analysis is based on cross-sectional data it is also not possible to control for country-specific differences which may significantly distort the analysis. For another, the regulatory score considers different variables but only to a limited degree. Other included control variables are rather generic and are not specifically related to the market structure like GDP per capita or inflation. Consequently, it remains unknown what drives the results, if the results are similar across all countries, and what the role of market structure is.

The topic of this work is also related to the literature on hedonic price indices as they also consider quality measures in their analysis. For example, Nicolle et al. (2018) estimate a hedonic price index for mobile services in France using data between May 2011 and December 2014.⁷ They specify quality in the regression by using tariff characteristics from mobile plans e.g., data allowances. Their findings suggest a significantly larger decline of the quality-adjusted price index compared to the non-adjusted price index. Moreover, they identify competition and investments in 4G networks as significant drivers for reductions of the quality-adjusted price index. However, the validity of the latter results may be questioned as these are based on a very small sample (n=44). Yun et al. (2018) estimate a hedonic price index for 12 metropolis in 10 countries. They use the tariff characteristics of mobile services in the regression as an indicator for quality but also consider measurements of download and upload speeds. They also note significant differences in the magnitude of the price index if this is adjusted for quality. This underlines the importance of taking into consideration for these effects on network quality in competition analysis.

Findings in the theoretical literature are indeed less conclusive on how competition affects investments on the mobile telecommunication market. Motta and Tarantino (2017) study a game in which firms simultaneously choose prices and cost-reducing investments. They find that, without efficiency gains, a merger leads to lower industry investments and consumer surplus. This finding is robust for different types of demand functions. Bourreau and Julien (2018) use a similar model and delineate a situation where a merger does indeed have a positive effect on investments. By increasing margins in the equilibrium, mergers may also raise incentives to invest in coverage which also increases total coverage and consumer surplus. Finally, different policy reports have covered the relationship between competition, investments, and the quality of mobile network infrastructures (HSBC 2015, Frontier Economics 2015, GSMA 2017, OECD 2014). While industry reports wooing for more consolidation, the OECD is opposed to these. The emergence of these reports highlights that this work's research question is also an important and controversial discussion topic in both industry and politics.

⁷For another study see also Karamti and Grzybowski (2010).

3 Data Description

For the analysis we focus on European countries, as these are bound to a similar economical, geographical, and technical background. In total we use 500 million measurements on network connectivity from 48 MNOs from 14 European countries.⁸ As part of the investigation these are aggregated on a quarterly basis by MNO and then matched with different economic indicators, which will be explained in detail henceforth.

Assessing the quality of mobile networks is a challenging task, as the observed connectivity is subject to various confounding influences. For example, if a call is initiated from a mobile phone it needs to be sent to the base station of the cellular network before being transported via the backbone of the MNO, where it is then routed via the telephony network and finally transmitted to the recipient. In here, the connectivity does not only depend on conditions which affect the transmission of the wireless signals, like weather, terrain or speed of movement. The connectivity may also be affected by congestions in the mobile cell, in the backbone of the MNO, as well as the connection to and the connectivity within the foreign telephony network itself.⁹ Though these variables may significantly affect connectivity, these are only partially under the control of the MNO or related to competition in the market.

Our analysis is based on a large-scale dataset which is collected during real-world mobile phone usage. This is done through a crowdsourcing app called *Device Analyzer* which is offered for free in the Google Playstore. It continuously logs all kinds of smartphone activities to provide users with statistics on their usage (Wagner et al. 2014). The data provides several benefits for the analysis. One advantage is that it is collected from real-world phone usage. Hence, the measurements are collected from all types of situations as typically experienced by the mobile phone user: e.g., urban and rural areas, different weather conditions or different driving speeds. Another advantage is that it is a general purpose app which provides all kinds of statistics on phone usage. This makes it unlikely that the usage depends on user connectivity which may create a selection bias in the estimation. In contrast, this is likely the case for data from dedicated speed test apps or websites: mobile users which face a particular low or high network connectivity may be more likely to participate, which may then lead to a downward or upward bias in the measured variable. Finally, it is a large-scale dataset which covers not only a fairly long time from the first quarter of 2011 till the first quarter of 2016, but also includes a large number of measurements.

In the analysis we focus on wireless coverage, i.e., the standard of mobile broadband connection and signal strength. Firstly, wireless coverage is a major determinant in mobile connectivity. Secondly, as it is displayed in real time to smartphones users, it is likely to be a major element for how network quality is perceived by consumers and thus influences

⁸Namely these countries are Austria, Croatia, Czech Republic, Germany, Hungary, Italy, Ireland, France, Netherlands, Romania, Slovakia, Spain, the United Kingdom, and Norway. Number of measurements rounded.

⁹For details on the functionality of mobile telecommunication networks see for example Gruber (2005) chapter 2.2.

competition between MNOs. Furthermore, we focus only on mobile connections based on the GSM standard, since this is the dominating standard in Europe. In order to fully exploit geographical coverage of our measurements we use a two-step aggregation procedure. Initially we use the collected information to calculate for each operator the average access speeds by mobile cell and quarter. We then calculate different measures for mobile network quality by operator and quarter as a centered rolling average. These are namely the share of mobile network connections with 3G and 4G, the share of connections which exceed 1Mbps, 2Mbps, 3Mbps as well as the maximum speed. Compared to a direct calculation of these measures across all observations, the two-step procedure has the advantage of ruling out that our measurements are driven by few but popular locations. Failing to account for this may significantly distort the aggregation if measurements in these popular locations deviate significantly from other observations. As part of the aforementioned procedure we also compute the mean of the number of wireless access points for each mobile cell and quarter. We use this information as a proxy to control for the degree of urban density in the estimation.

Market data such as the number of competitors in each country, subscriber numbers, the market entry position as well as subsidiaries in the European market are gathered from financial statements of MNOs, market reports of regulatory authorities, and also Gruber (2005). Information on GDP per capita and population size, which is used as a proxy variable for market size in the regression, is collected from Eurostat. Mobile termination rates are obtained from BEREC.¹⁰ Based on the total number of postpaid and prepaid subscribers we calculate the Herfindahl-Hirschman-Index (HHI) for each country and quarter.¹¹ Moreover, we calculate for each country the mean number of multimarket contacts of the operating MNOs via subsidiaries in other European countries. For the analysis we focus on those countries where the most signal measurements were taken and which could also be matched with market data. Unfortunately, this type of information is not consistently available over time, particularly for smaller MNOs and countries.

Figure 1 depicts the HHI by country at the beginning of the analysis in Q1 2011 and Figure 2 the HHI at the end of the analysis in Q1 2016. It becomes apparent that market concentration is overall high, as the number of MNOs varies only between 3 or 4 players. For example according to the European guidelines for the assessment of horizontal mergers a merger is part of a closer analysis as soon as the HHI is larger than 2,000 and changes by more than 150 due to the merger. During the time period of analysis a moderate decrease in overall concentration can be observed. This is particularly evident for Spain and also for France where the entry of Free mobile in 2012 increased competition. An exception of the overall trend is Germany where concentration significantly increased due to the merger of Telefónica DE/E-Plus in 2014. Further mergers in the period of analysis occurred in Austria (H3G Austria/Orange AT 2012), Ireland (H3G Ireland/Telefónica IE 2014), and in Norway (Tele2/Telia Sonera 2014) but only with moderate changes in concentration. In the former

¹⁰Body of European Regulators for Electronic Communications (BEREC)

¹¹The HHI is commonly defined as: $HHI = \sum_{i=1}^n (Market\ Share_i)^2 \times 10000$.

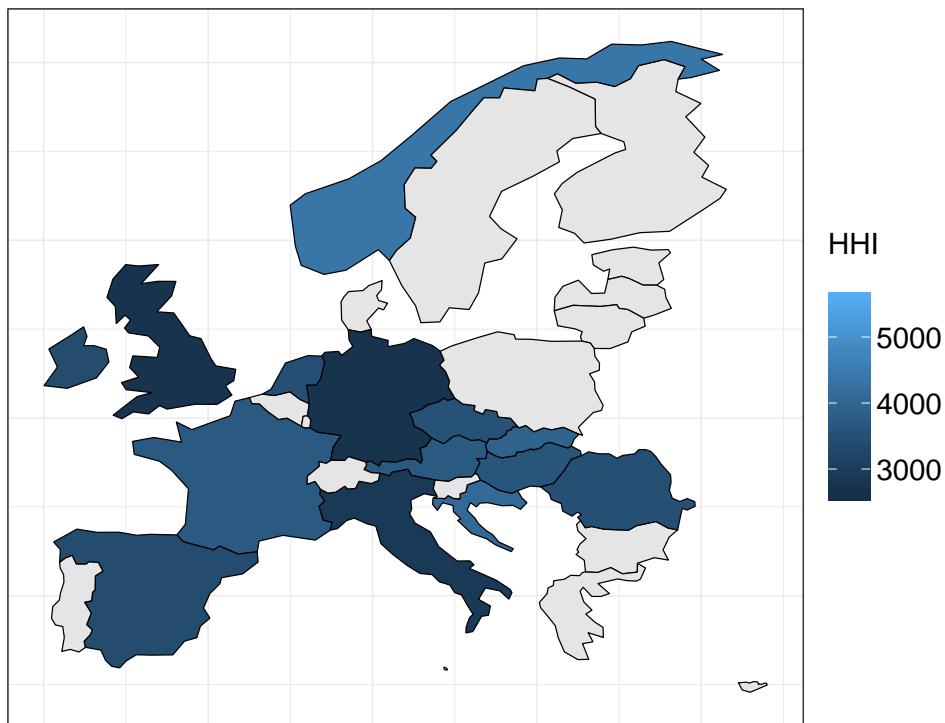


Figure 1: HHI by country in Q1 2011 for those considered in the analysis, own calculations based on prepaid and postpaid subscribers. Own computation and illustration, data source: company statements and market reports of regulation authorities.

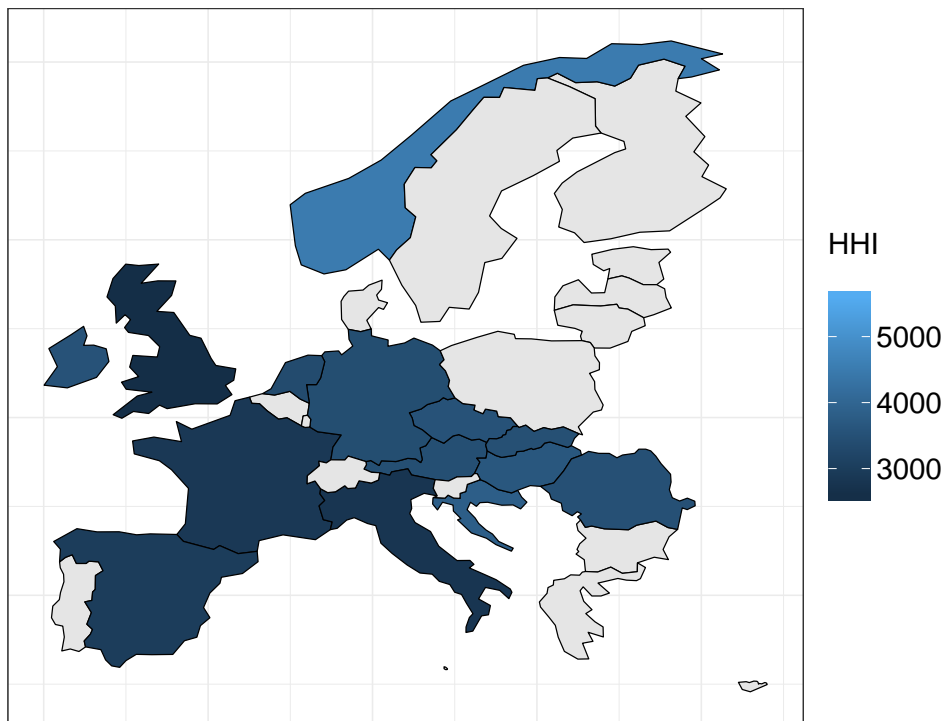


Figure 2: HHI by country in Q1 2016 for those considered in the analysis, own calculations based on prepaid and postpaid subscribers. Own computation and illustration, data source: company statements and market reports of regulation authorities.

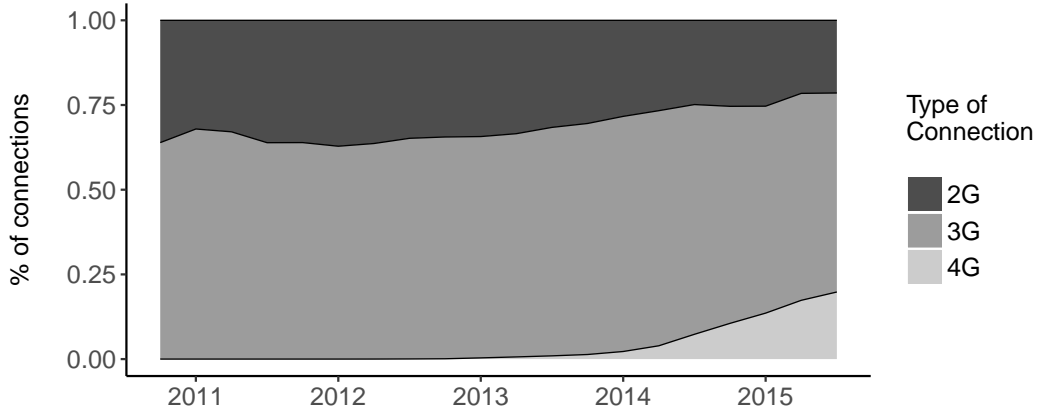


Figure 3: Share of connections in the dataset for different technology types between Q1 2011 and Q1 2016. Own calculation and illustration, data: Device Analyzer.

two markets the mergers coincide with a downward sloping trend in market concentration, in Norway the merger involved remedies which allowed the entry of a new player in the market.

Figure 3 displays the share of connections in the dataset by connection type between Q1 2011 and Q1 2016. It can be observed that most of the connections are based on 3G which also persists during the period of analysis. In contrast, the importance of 2G connections is constantly decreasing over time. From the end of 2014 onwards a significant rise of 4G connections is observed, which is the current standard for mobile broadband connections.

4 Empirical Framework and Results

Our analysis is based on the empirical framework by Genakos et al. (2018). We adapt this for our analysis by considering different measures for network quality instead of operator investments as a dependent variable. This includes the share of mobile cells with 3G or 4G connections, the share of mobile cells which exceed different definitions of minimum speeds as well as the maximum mobile broadband speed.

To be more precise we assume that the network quality of MNO i in country c at time t is specified by the following functions:

$$netQuality_{cit} = \beta_1 N_{ct} + \beta_2 entry_{ci} + \beta_3 X_{cit} + \beta_4 \lambda_c + \beta_5 T_t + \varepsilon_{cit}$$

where N_{ct} denotes the number of MNOs, $entry_{ci}$ their entry position in the market and X_{cit} denotes a vector of further control variables which market characteristics and regulatory variables, λ_c and T_t include, respectively, country and time-specific effects and ε_{cit} denotes the idiosyncratic error term.

One of our main variables of interest is the number of MNOs in each country. Following traditional theory in industrial organization we would expect that a higher number of MNOs raises competitive pressure and thus yields a higher network quality. Though if recent findings in the literature on competition and investments are true (Jeanjean and Houngebnon 2017, Houngebnon and Jeanjean 2016, Genakos et al. 2018) a negative effect on network quality is expected.¹² In an alternative specification we also consider the HHI instead of the number of MNOs as it captures additional differences in the asymmetry of market shares. The other variable of main interest is the position in market entry which may exhibit two opposing effects on network quality. On the one hand, market incumbents may benefit from first-mover advantages (Jakopin and Klein 2012). Accordingly, incumbents may not only benefit from synergies with their fixed networks, their historically grown customer base may also give rise to economies of scale. On the other hand, Whalley and Curwen (2012) also note that incumbents were more hesitant to upgrade their networks to 3G and instead relied on the advantage of a large customer base to compete. While this may be a profitable strategy it would also provide an explanation for why the network quality of incumbents may be inferior compared to later market entrants. In the regression we account for this market entry effect by specifying dummies for the first, second, third, and fourth or later entrant.

Additional control variables can be divided into further market characteristics and regulatory variables. Market characteristics comprise the GDP per capita which accounts for the income of subscribers and which might be associated with a higher willingness to pay for mobile services. We also include the market size in a specification to account for economies of scale in the provision of the mobile network infrastructure. Furthermore, we include measures for the urbanization to control for varying demands between urban and rural areas. More precisely, we proxy for urbanization with the number of wifi access points across mobile cells. Today, wifi networks are common not only in most households and enterprises but also in other areas of urban life such as bars, cafés or even on public transport. So we expect the number of wifi access points to increase not only near these locations but also with the number of floors of surrounding houses which typically indicate a higher urban density. We account for this in the regression by considering the mean as a proxy for the degree of urbanization.

MNOs in the EU are subject to different regulations, which may also have an important influence on investments and thus on mobile network quality. These interconnection fees have to be paid by an MNO if a call from their mobile network terminates in another mobile network. As these fees give rise to the exploitation of market power they are regulated in the EU. Albeit termination rates have been reduced in the past, significant differences between countries and operators remain. Studies suggest that reductions in termination rates can significantly affect price levels, either by lowering prices (e.g., Hawthorne 2018, Grzybowski 2008) or under certain circumstances also by increasing prices, which is known as

¹²For details see the literature review in chapter 2.

the waterbed effect (Genakos and Valletti 2011). Against this background it will be interesting to investigate if and how mobile termination rates affect mobile network quality. On the European level the regulation of mobile telecommunication services includes price caps for roaming fees. As for termination rates, a reduction of price caps for roaming fees implies that MNOs receive lower reimbursements for their services although they are bound to the same costs as before. Since these were constantly reduced during the period of analysis, we evaluate whether this has had an effect on the mobile network quality. Finally, we include time fixed effects to account for the rapid technological development in mobile network infrastructure as well as country fixed effects control for consumer-specific preferences, geographic differences in the topology and general differences in the mobile network infrastructure.

Mobile virtual network operators (MVNO) do not own any spectrum themselves, but their wholesale access to spectrum may be affected by competition between MNOs in the upstream market. Moreover, wholesale access for MVNOs has also been used as a remedy in past merger cases in the EU.¹³ Against this background it will be interesting to see whether systematic differences in the network quality between MVNOs and MNOs are present. In the specification we account for these differences by adding a dummy variable in the regression and considering data from MVNOs additionally.

As our estimation includes variables which are determined in market equilibrium we need to discuss the exogeneity of our specification. Generally, the number of operators is often regarded as endogenously determined in the market. However, in the context of the mobile telecommunication market this is subject to debate (Genakos et al. 2018, Jeanjean and Hounghonon 2017): In order to provide mobile services an MNO requires access to spectrum. This depends on the institutional endowment by countries, the availability of spectrum, and license terms. Considering that spectrum is often only auctioned once or twice in a decade, this limits the market entry of new MNOs. Exits are restricted by merger control in the EU while cases in the mobile telecommunication are typically under the close scrutiny of competition authorities due to the high concentration in the market. Consequently, the number of operators may be considered as exogenous in the analysis. In order to ensure the validity of our results this paper considers either case in the specifications, one with and one without instrumental variables. However, this issue is not subject to debate for the HHI. Since the HHI is calculated based on market shares that reflect choices of consumers in market equilibrium, it is likely to be endogenous.

To account for the possible endogeneity of the number of competitors as well as the HHI we employ instrumental variables. The European mobile telecommunication market consists of many players which compete at the national level, but in many cases they belong to large multinationals. In other words, the market actually consists of fewer players which repeatedly meet again. Seminal papers by Bernheim and Whinston (1990) and Parker and Roeller

¹³This includes, for example, the H3G Austria/Orange AT merger in 2012 as well as the Telefónica Germany/E-Plus merger in 2014.

(1997) find that these multimarket contacts may lead to collusive behavior which may significantly impede competition. We exploit these multimarket contacts as an instrument for the analysis as this is likely to be correlated with competition and thus affects market shares. But, we argue that it is independent from network quality in the market and only affects this indirectly by altering market concentration. Considering further evidence (Baum and Korn 1999) we account for a possible U-shaped relationship between both variables by including a quadratic term of the instrument in the estimation. As an additional instrument we include, following Jeanjean and Hounghonon (2017), the asymmetry of mobile termination rates. These are typically determined in favor of smaller operators and may thus foster competition. However, as the regulation is influenced by persistent size differences between mobile operators, for example, in the case of late entrants, this is likely to be exogenous.

Table 1 presents the estimation results with different types of control variables. All specifications have been estimated with country and year fixed effects. The reported standard errors are robust to heteroscedasticity and clustered on the operator-country level. Generally, it can be observed that all estimates remain nearly identical for all specifications both in sign as well as magnitude. In more detail, it can be observed in specification 1) that raising the number of MNOs by 1 MNO lowers the share of mobile cells with 3G or 4G connection by -5.1 percentage points. A similar effect is indicated by the HHI, an alternative measure for competition, which also accounts for changes in the asymmetry of market shares. Accordingly, a lower market concentration by $\Delta HHI = -150$ lowers the share of 3G or 4G connection as well by -4.5 percentage points. Interestingly, the regression results indicate that late entrants provide a significantly higher share of 3G or 4G connection compared to the market incumbent. This share is 3 percentage points higher for the 2nd entrant, 4.4 percentage points for the 3rd entrant and with 10 percentage points it is highest for the 4th or later market entrants. That indicates that usage of the legacy technology 2G is still very present for market incumbents.

Lower mobile termination rates seem to exhibit a positive effect on the dependent variable by 0.5 percentage points for a reduction of 1 cent. But given the regulation of termination rates has reached very low price levels in many countries (mean = 2.27 cents), the leeway for further improvements of mobile network quality is limited. Nonetheless it is interesting that these termination rates influence not only prices but also mobile network quality. Further higher income of consumers positively affects the share of provided 3G or 4G connections while the differences between urban and rural areas are less present in the dataset. For the latter the difference between the 1st and 3rd quartile of urban density results in a 1.6 percentage points higher share of 3G or 4G connections. No statistical effect is found for the control variables market size, different roaming caps or MVNOs. Consequently, no differences can be observed for the share of 3G or 4G connections between MVNOs and MNOs. The results in Table 2 confirm our previous findings in Table 1 for different specifications of mobile network quality. These are precisely the share of areas where minimum speeds of 1Mbps, 2Mbps, 3Mbps are exceeded as well as the maximum speed. The only

<i>Dependent variable:</i>					
Share of 3G or 4G connections					
	(1)	(2)	(3)	(4)	(5)
No. of Competitors	-0.051*** (0.017)		-0.051*** (0.017)	-0.051*** (0.017)	-0.067*** (0.016)
HHI		0.0003** (0.0001)			
2nd Entrant	0.030*** (0.010)	0.028*** (0.010)	0.030*** (0.010)	0.030*** (0.010)	
3rd Entrant	0.044*** (0.012)	0.045*** (0.013)	0.044*** (0.012)	0.044*** (0.012)	
4th Entrant+	0.100*** (0.013)	0.098*** (0.014)	0.100*** (0.013)	0.100*** (0.013)	
Mobile Termination Rates	-0.008* (0.004)	-0.006 (0.004)	-0.008* (0.004)	-0.007* (0.004)	
Mean Urban Density	0.004** (0.002)	0.006*** (0.002)	0.004** (0.002)	0.004** (0.002)	0.005*** (0.002)
log(GDP per capita)	0.199*** (0.072)	0.169** (0.081)	0.202*** (0.074)	0.190** (0.075)	0.190*** (0.069)
log(MarketSize)		-1.967 (1.512)			
Data Roaming Cap			0.0001 (0.001)		
Voice Call Roaming Cap				-0.001 (0.002)	
MVNO					0.013 (0.014)
Country Fixed Effects	Yes	Yes	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes
F-Statistic	35.71***	30.60***	34.47***	34.42***	35.50***
Observations	715	715	715	715	822
Adjusted R ²	0.398	0.318	0.398	0.398	0.343

Note:

*p<0.1; **p<0.05; ***p<0.01
Heteroskedasticity and Cluster Robust Standard Errors

Table 1: Main regression results with different control variables.

divergence in results is found for maximum speeds which are significantly lower for late entrants. Furthermore it is noteworthy that the effect of mobile termination rates on mobile network quality is more significant with a higher magnitude, especially on maximum speeds. This underlines that regulations on a national level clearly have an effect on mobile network quality.

	<i>Dependent variable:</i>			
	Share > 1MBps (1)	Share > 2MBps (2)	Share > 3MBps (3)	Max speed (4)
HHI	0.0004*** (0.0002)	0.0005*** (0.0002)	0.0004*** (0.0001)	0.0004 (0.0004)
2nd Entrant	0.005 (0.015)	-0.004 (0.014)	-0.015 (0.012)	-0.064 (0.041)
3rd Entrant	0.070*** (0.016)	0.052*** (0.015)	0.021 (0.014)	-0.187*** (0.053)
4th Entrant+	0.078*** (0.018)	0.063*** (0.017)	0.042*** (0.015)	-0.122*** (0.044)
Mobile Termination Rates	-0.019*** (0.006)	-0.019*** (0.005)	-0.017*** (0.004)	-0.061*** (0.014)
Mean Urban Density	0.002 (0.003)	0.004 (0.003)	0.005* (0.003)	0.018** (0.008)
log(GDP per capita)	0.237** (0.105)	0.212** (0.099)	0.152* (0.088)	2.135*** (0.287)
Country Fixed Effects	Yes	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes	Yes
F-Statistic	25.69***	28.74***	38.36***	168.20***
Observations	715	715	715	715
Adjusted R ²	0.313	0.338	0.430	0.756

Note: *p<0.1; **p<0.05; ***p<0.01
Heteroskedasticity and Cluster Robust Standard Errors

Table 2: Alternative regression results for different measures of mobile network quality.

To ensure the robustness of our estimation results various steps have been taken. First, in the analysis we control for various confounding influences: this includes country fixed effects which may account for geographic differences, consumer preferences as well as other country-specific market characteristics which are constant over time. Moreover, yearly dummies consider for general trends e.g., technological improvements in the mobile telecommunication market as well as different market-specific control variables are considered, but without any change in the regressions results. This does not alter when considering different types of time dummies such as additional quarterly dummies, a linear or quadratic time

trend. Second, we rule out an estimation bias due to weak instruments (see Bound et al. 1995). First-stage regression results indicate a strong power as both types of instruments are very significant at the 1% level. This is complemented by the F-statistic of the excluded instruments which is substantially larger than 10. Further, we obtain very similar regression results both in sign and magnitude, which are found with and without instrumentation of the number of competitors as well as for different sets of instrumental variables for the HHI. This is statistically confirmed by the Durbin–Wu–Hausman test ($p=0.625$) as well as the results of the Sargan-test ($p\text{-value} = 0.9575$). Third, as noted before, the results of our estimation are also reaffirmed when considering different measurements for mobile network quality. These are namely the share of mobile cells where the average speed exceeds 1Mbps, 2Mbps, 3Mbps. The only notable change is the maximum measured speed, which seems to be unaffected by market concentration and lower effects for late entrants. Fourth, as the data is gathered by crowdsourcing it might be subject to a selection bias. However, as already mentioned in the data description, the app collects data for various purposes and does not exclusively focus on network data. Therefore, it is rather unlikely that the data is subject to a selection bias.

5 Discussion

In this section we discuss the results of our work and potential implications for competition and regulation policy.

First, we find evidence that a lower number of players has a positive effect on various measures for mobile network quality. So, our results confirm the finding in the literature (Jeanjean and Hounghonon 2017, Hounghonon and Jeanjean 2016, Genakos et al. 2018) that more competition may yield lower price levels but this is traded-off with lower investments in the mobile network infrastructure. Though it seems that the magnitude of the effect is lower than found in previous studies. For example, we find for the share of 3G and 4G connections a 7.3% increase compared to a rise in investments of 19.3% as reported by Genakos et al. (2018). To some extent this might be driven by differences between the considered mergers in the dataset. But it may also indicate that the observed increase in investments does not completely transmit into a higher mobile network quality, for example due to lower allocative efficiency. This work has focused on data between 2011Q1 and 2016Q1 in 14 European countries and includes several important mobile merger decisions. Nonetheless, more work is required to get a better understanding of the underlying mechanisms and what market conditions are required such that a reduction of MNOs may actually improve mobile network quality. In any case, a simple reduction of MNOs will not be a panacea to improve mobile network quality. Instead, it needs to be embedded into a careful analysis of competition in the market and existing regulations while merging parties may need to carefully outline why their merger may actually lead to an improvement of mobile network quality. For both industry and competition authorities this may imply that an in-

investigation of efficiencies with respect to potential improvements of mobile network quality will become more prominent in future merger cases.

Second, we observe that late entrants in particular exhibit provide a higher share of areas with 3G or 4G connection as well as a higher share of areas which exceed different minimum speeds. This might be surprising, given that new entrants may lack not only a customer base but also the mobile network infrastructure and the knowledge to build it. Otherwise, this may, under certain circumstances, also turn into an advantage for consumers: First, if late entrants enter the market, they have an incentive to compete aggressively. As observed by the European competition commission in previous mergers (Hutchison 3G Austria / Orange AT 2012, T-Mobile Austria/Tele.ring 2006), particular late entrants face competitive pressure to attract new customers as they face high upfront investments and cannot rely on their customer base to recoup their costs.¹⁴ New customers can be attracted by lower prices, more advertisement, but also a higher mobile network quality. Second, late entrants are able to leapfrog legacy technology for mobile networks and can directly start with the roll-out of state-of-the-art mobile networks. This has been, for example, observed for Hutchison 3 which directly used 3G technology in various European countries and explicitly marketed this competitive advantage in its company name. Another example is Tele2 which marketed itself, after its entry into the Dutch market, as a '4G-only' operator. Late entrants may not only profit from strong cost reductions due to the rapid development of ICT technology, they may also not face any costs for the integration of new technology in the existing mobile network and potential compatibility issues. Third, late entrants are not necessarily start-ups with limited knowledge or restricted access to resources. This includes, for example, the entry of Hutchison 3 in Ireland and Austria, the entry of the joint venture 'Everything Everywhere' in the United Kingdom, which was run by Orange and Deutsche Telekom, or the entry of Tele2 in the Netherlands. All these provide examples where late entrants are run by large multinationals which operate in various other markets. Finally, the results do not imply that late entrants strictly dominate market incumbents, as the observed maximum speeds are significantly higher for market incumbents. This indicates that incumbents upgrade their mobile networks with recent technology but they balance the costs of upgrade with cost savings from using legacy 2G technology. For regulation authorities this underlines that the auctioning of spectrum is an important instrument in the regulation toolbox to adjust competition in the market. Herein authorities face the challenging task of balancing political demands or requirements e.g., coverage of rural areas, without daunting new entrants which are willing to invest in mobile networks.

Although the findings of this work indicate that a reduction of market players may have a positive effect on mobile network quality, this does not provide any support for the creation of "European Champions". Recently, a debate evolved in politics about whether competition policy needs to be altered and whether large European companies are required to compete better with their rivals in China and America. (The Economist, 2018). This topic

¹⁴For details see also COMP/M.3916, paragraph 74ff. as well as COMP/M.6497, paragraph 76ff.

is also discussed for the mobile telecommunication market. However, given the universal usage of mobile telecommunication services, any limitations of competition in this market will affect most European consumers and industries. Thus, for all industries other than the mobile industry, this implies a competitive disadvantage in global competition. Consequently this underlines the need for vital competition in the mobile market and the need for competition and regulation authorities which monitor and enforce this.

6 Conclusion

In this paper we analyze how market structure affects different measures of quality in mobile networks. For this purpose we make use of 500 million observations of 48 MNOs from 14 European countries which were gathered by a crowdsourcing app between 2011Q1 and 2016Q1. During this time period of analysis several important mergers were observed in the European mobile telecommunication market. For the analysis we construct different measures for mobile network quality and conduct a fixed effects estimation with instrumental variables. In the estimation we relate these different parameters for network quality to different characteristics of the market structure while controlling for confounding influences of economic and regulatory variables. To the best of our knowledge this is the first academic paper which provides this kind of detailed analysis for mobile telecommunications.

We find evidence that a lower number of operators may improve different measures of mobile network quality. Thus, we can confirm findings from the recent literature which suggests a trade-off between price competition and investments in mobile networks. Though the observed investments in this literature are higher than the observed improvements in mobile network quality. This might be explained by a lower allocative efficiency. More generally, our results imply that the investigation of merger efficiencies in terms of mobile network quality may gain a higher importance in future mobile merger cases. Moreover, we observe a particular higher mobile network quality for late entrants. We argue that this is explained by a higher competitive pressure at market entry, cost advantages due to the leapfrogging of technology and backing from large multinational firms. Our findings underline how outcomes from spectrum auctions may alter competition in the market. Furthermore, we consider influences from the regulation of roaming price caps, termination rates and test how MVNOs are affected by competition in the upstream market, though, we only note a limited but positive effect from the reduction of mobile termination rates. In order to ensure the robustness of our results, we conduct various checks. We can confirm our results with different measures for competition and mobile network quality, a varying set of control variables, as well as different sets of instrumental variables.

On the one hand further research should include further criteria for mobile network quality in the estimation. This may include ping speeds, call drops, and also loading times for different kinds of websites and services. On the other hand further research will be particularly interesting for non-EU markets. The high market fragmentation, the importance of MVNOs

and low investment levels make the EU distinct from other mobile telecommunication markets in several aspects (see also Bruegel 2015). Finally, it will be interesting to investigate whether a similar trade-off as discussed for the mobile telecommunication market is found for other markets, too, where investments play a similar important role. However, an essential requirement for this might be that quality can be objectively quantified, which is not always the case.

7 Appendix

	<i>Dependent variable:</i>			
	Share of 3G or 4G connection			
	(1)	(2)	(3)	(4)
No. of Competitors	-0.051*** (0.017)	-0.065** (0.027)		
HHI			0.0004*** (0.0001)	0.0003** (0.0001)
2nd Entrant	0.030*** (0.010)	0.030*** (0.010)	0.029** (0.011)	0.029*** (0.010)
3rd Entrant	0.044*** (0.012)	0.045*** (0.012)	0.048*** (0.014)	0.046*** (0.013)
4th Entrant+	0.100*** (0.013)	0.100*** (0.013)	0.098*** (0.014)	0.099*** (0.014)
Mobile Termination Rates	-0.008* (0.004)	-0.008** (0.004)	-0.009* (0.004)	-0.008* (0.004)
Mean Urban Density	0.004** (0.002)	0.004** (0.002)	0.005** (0.002)	0.005** (0.002)
log(GDP per capita)	0.199*** (0.072)	0.190*** (0.074)	0.163** (0.081)	0.188** (0.076)
Country Fixed Effects	Yes	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes	Yes
Instrument Variables	-	MMC	Diff MTR	MMC
F-Statistic	35.71***	35.26***	29.70***	32.50***
Observations	715	715	715	715
Adjusted R ²	0.398	0.398	0.268	0.333

Note: *p<0.1; **p<0.05; ***p<0.01
Heteroskedasticity and Cluster Robust Standard Errors

Table 3: Regression results with different instrumental variables.

	<i>Dependent variable:</i>		
	No. of Competitors	HHI	
	(1)	(2)	(3)
2nd Entrant	−0.001 (0.015)	−0.806 (15.099)	3.934 (15.129)
3rd Entrant	0.013 (0.017)	−12.308 (14.329)	−11.667 (13.905)
4th Entrant+	−0.002 (0.018)	0.502 (15.418)	4.753 (16.795)
Mobile Termination Rates	−0.013** (0.006)	5.259 (4.611)	12.829*** (4.251)
Mean Urban Density	−0.0001 (0.002)	−2.405 (1.916)	−4.056** (1.960)
log(GDP per capita)	−0.262*** (0.082)	215.886*** (74.732)	43.543 (74.534)
Multimarket Contact	1.567*** (0.052)	−294.241*** (41.846)	
Multimarket Contact2	−0.338*** (0.017)	97.562*** (13.327)	
Diff Mobile Termination Rates			−29.455*** (5.612)
Country Fixed Effects	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes
F-Statistic of Excluded Instruments	465.51***	31.03***	27.55***
Observations	715	715	715
Adjusted R ²	0.899	0.888	0.884

Note:

*p<0.1; **p<0.05; ***p<0.01

Heteroskedasticity and Cluster Robust Standard Errors

Table 4: First-Stage Regression Results

Statistic	N	Mean	St. Dev.	Min	Max
Share of Areas with G3 or G4 connection	823	0.69	0.14	0.002	1.00
Share of Areas with Mobile Broadbandspeed > 1MBps	823	0.47	0.19	0.001	0.96
Share of Areas with Mobile Broadbandspeed > 2MBps	823	0.41	0.18	0.00	0.88
Share of Areas with Mobile Broadbandspeed > 3MBps	823	0.34	0.17	0.00	0.80
Maximum Speed in MBps	823	39.25	26.63	1.16	72.43
Number of Competitors	823	3.61	0.49	3	4
Herfindahl Hirschman Index - HHI	823	3201.99	464.21	2584	5043
MVNO	823	0.13	0.34	0	1
Position at Market Entry	716	2.24	1.10	1	4
Mobile Termination Rate in Euro Cents	716	2.27	1.53	0.56	13.88
Mean of Urban Density	823	6.46	3.60	0.64	33.70
GDP per capita in 10000 Euro	823	7.26	3.42	1.30	17.60
Market Size	823	38569281.00	28964244.00	4195240	82122000
Wholesale Roaming Data Cap in Euro Cents	823	21.54	16.74	5	80
Roaming Outgoing Voice Call Cap in Euro Cents	823	25.89	5.94	19	39

Table 5: Urban density and market size are proxy variables which are specified with the mean number of wifi access per mobile cell in each quarter by MNO as well as the population size in each country and quarter respectively.

Country	MNO	N
Austria	A1 Telekom Austria	261575
Austria	Deutsche Telekom	3122798
Austria	Orange	81525
Austria	Hutchison 3	268278
Croatia	Tele2	24316658
Croatia	Deutsche Telekom	2876253
Czechrepublic	Telefonica	8466874
Czechrepublic	Deutsche Telekom	4325546
Czechrepublic	Vodafone Group	3818711
France	Bouygues Telecom	5625535
France	Orange	11247811
France	SFR	2710134
France	Free Mobile	4953947
Germany	Deutsche Telekom	17583402
Germany	Kpn	1732691
Germany	Telefonica	7274964
Germany	Vodafone Group	10982857
Hungary	Telenor	2459600
Hungary	Vodafone Group	3393252
Hungary	Deutsche Telekom	973499
Ireland	Vodafone Group	1739736
Ireland	Meteor	420759
Ireland	Telefonica	2318388
Ireland	Hutchison 3	266613
Italy	Vodafone Group	14508268
Italy	Wind	7363387
Italy	Hutchison 3	11744940
Italy	Telecom Italia	18468062
Netherlands	Kpn	30283484
Netherlands	Deutsche Telekom	11378971
Netherlands	Vodafone Group	19396684
Norway	Telenor	80796941
Norway	Telia Company	15867734
Norway	Tele2	222590
Romania	Orange	2535989
Romania	Vodafone Group	20988160
Romania	Deutsche Telekom	14787
Slovakia	Orange	2846459
Slovakia	Telefonica	1734217
Slovakia	Deutsche Telekom	1214029
Spain	Telia Company	1720112
Spain	Telefonica	7531097
Spain	Vodafone Group	5036085
Spain	Orange	3221934
Unitedkingdom	EE	49449867
Unitedkingdom	Hutchison 3	18885791
Unitedkingdom	Telefonica	48179895
Unitedkingdom	Vodafone Group	18633426

Table 6: Number of measurements considered in the analysis by country and group.

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